DMA Webinar Series

INFLO Bundle

Cory Krause and Govind Vadakpat
FHWA Office of Operations Research and Development

February 24th , 2015

TODAY'S AGENDA

- Cory Krause

  Pathways Civil Engineer, FHWA Office of Operations Research & Development
  - DMA Program Overview
  - Project Status of INFLO Prototype Impact Assessment

- Govind Vadakpat

  Research Transportation Specialist, FHWA Office of Operations Research & Development
  - INFLO Bundle Overview
  - INFLO Prototype Description and Project Status

- Stakeholder Q&A
  - We can only answer questions related to the DMA program.
  - We cannot answer any questions related to the CV Pilots.

DMA Program Overview

Cory Krause
Pathways Civil Engineer
FHWA Office of Operations Research and Development

Dynamic Mobility Applications Program

- **Vision**
  - Expedite development, testing, commercialization, and deployment of innovative mobility application
    - maximize system productivity
    - enhance mobility of individuals within the system
- **Objectives**
  - Create applications using frequently collected and rapidly disseminated multi-source data from connected travelers, vehicles (automobiles, transit, freight) and infrastructure
  - Develop and assess applications showing potential to improve nature, accuracy, precision and/or speed of dynamic decision
  - Demonstrate promising applications predicted to significantly improve capability of transportation system
  - Determine required infrastructure for transformative applications implementation, along with associated costs and benefits
- **Project Partners**
  - Strong internal and external participation
    - ITS JPO, FTA, FHWA R&D, FHWA Office of Operations, FMCSA, NHTSA, FHWA Office of Safety

DMA Program Approach To Overcoming Two Key Challenges To Application Deployment

- **Challenge 1 (Technical Soundness)**
  Are the DMA bundles technically sound and deployment-ready?
  - Create a “trail” of systems engineering documents (e.g., ConOps, SyRs)
  - Share code from open source bundle prototype development (OSADP website: http://www.itsforge.net/)
  - Demonstrate bundle prototypes (in isolation)

- **Challenge 2 (Transformative Impact)**
  Are DMA bundle-related benefits big enough to warrant deployment?
  - Engage stakeholders to set transformative impact measures and goals
  - Assess whether prototype show impact when demonstrated
  - Estimate benefits associated with broader deployment
  - Utilize analytic testbeds to identify synergistic bundle combinations

DMA Bundles and Applications

FRATIS: Freight Advanced Traveler Information Systems

Apps: Freight-Specific Dynamic Travel Planning and Performance, Drayage Optimization (DR-OPT)

IDTO: Integrated Dynamic Transit Operations

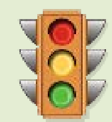
Apps: Connection Protection (T-CONNECT), Dynamic Transit Operations (T-DISP)
Dynamic Ridesharing (D-RIDE)

R.E.S.C.U.M.E.: Response, Emergency Staging and Communications, Uniform Management, and Evacuation

Apps: Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)
Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)
Emergency Communications and Evacuation (EVAC)

MMITSS: Multimodal Intelligent Traffic Signal System

Apps: Intelligent Traffic Signal System (I-SIG), Transit and Freight Signal Priority (TSP and FSP)
Mobile Accessible Pedestrian Signal System (PED-SIG), Emergency Vehicle Preemption (PREEMPT)



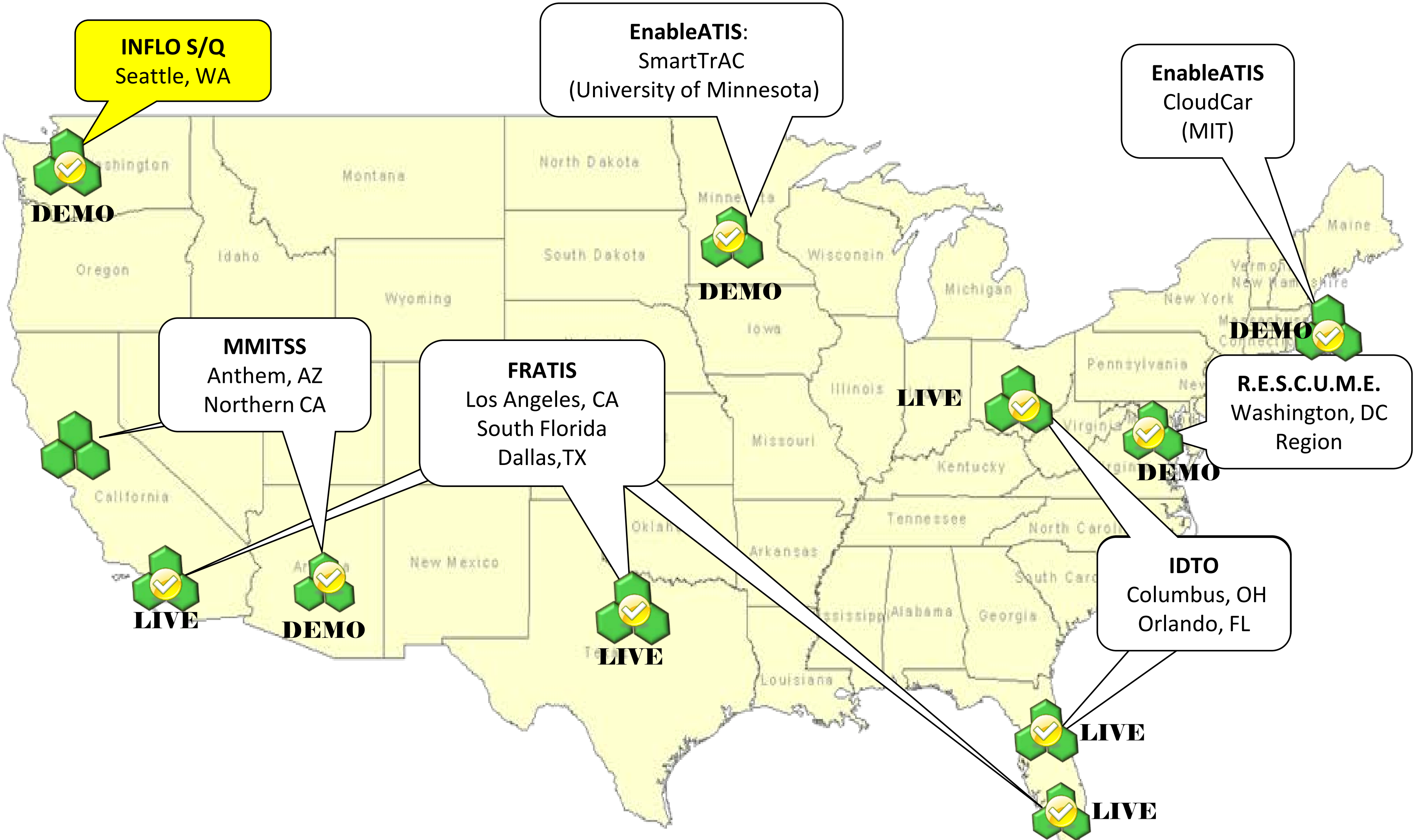
INFLO: Intelligent Network Flow Optimization

Apps: Dynamic Speed Harmonization (SPD-HARM), Queue Warning (Q-WARN)
Cooperative Adaptive Cruise Control (CACC)

Enable ATIS: Enable Advanced Traveler Information Systems

Apps: EnableATIS (Advanced Traveler Information System 2.0)

DMA Prototype Development Activity



INFLO Bundle Overview

Govind Vadakpat, PhD, P.E.
Research Transportation Specialist
FHWA Office of Operations Research and Development

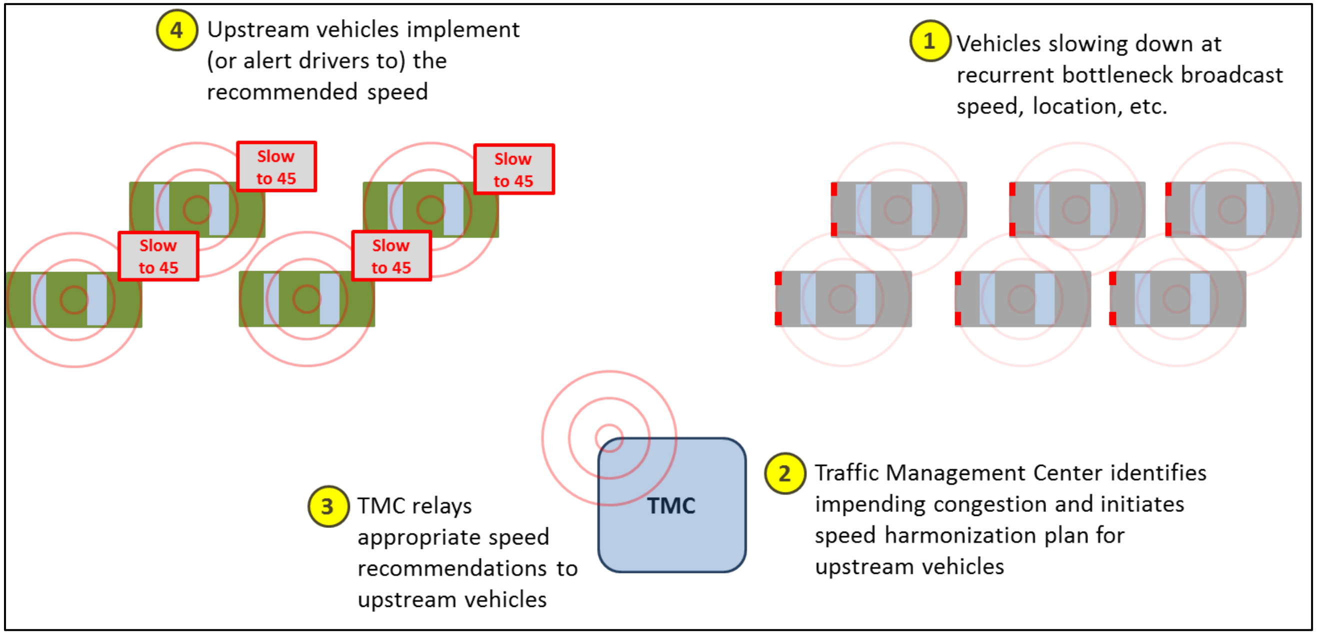
INFLO Application Descriptions

- Intelligent Network Flow Optimization (INFLO) bundle is a collection of transformative applications capable of collecting and rapidly disseminating multi-source data drawn from connected vehicles, infrastructure, and travelers to:
  - Increase roadway throughput
  - Reduce primary and secondary crashes
  - Reduce emissions and fuel consumption

- Bundle of applications include:
  - Dynamic Speed Harmonization (SPD-HARM)
  - Queue Warning (Q-WARN)
  - Cooperative Adaptive Cruise Control (CACC)

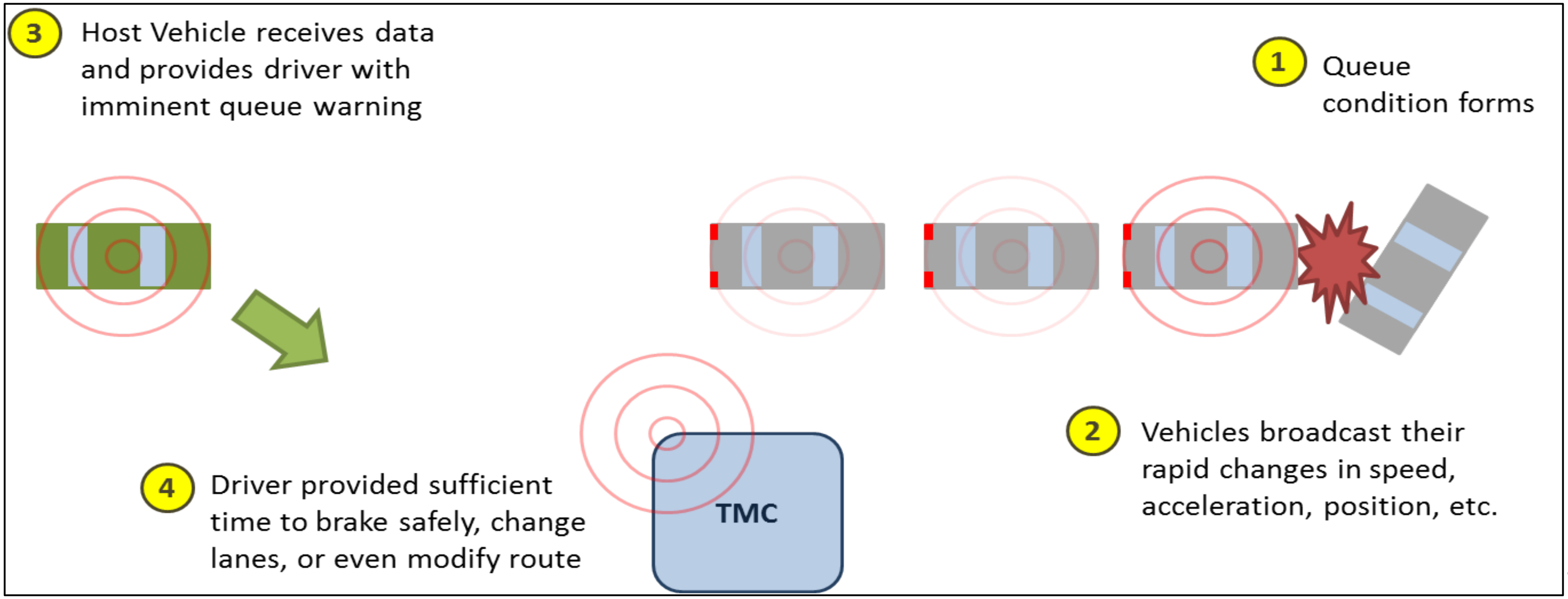
Dynamic Speed Harmonization (SPD-HARM)

- Aims to harmonize speeds in response to congestion, incidents, and road weather conditions
  - Reduces speed variability among vehicles to improve traffic flow and minimizes or delays flow breakdown formation
  - Utilizes V2V and V2I communication to coordinate vehicle speeds
  - Provides recommendations directly to drivers in-vehicle
  - Applicable to freeways, arterials, and rural roads



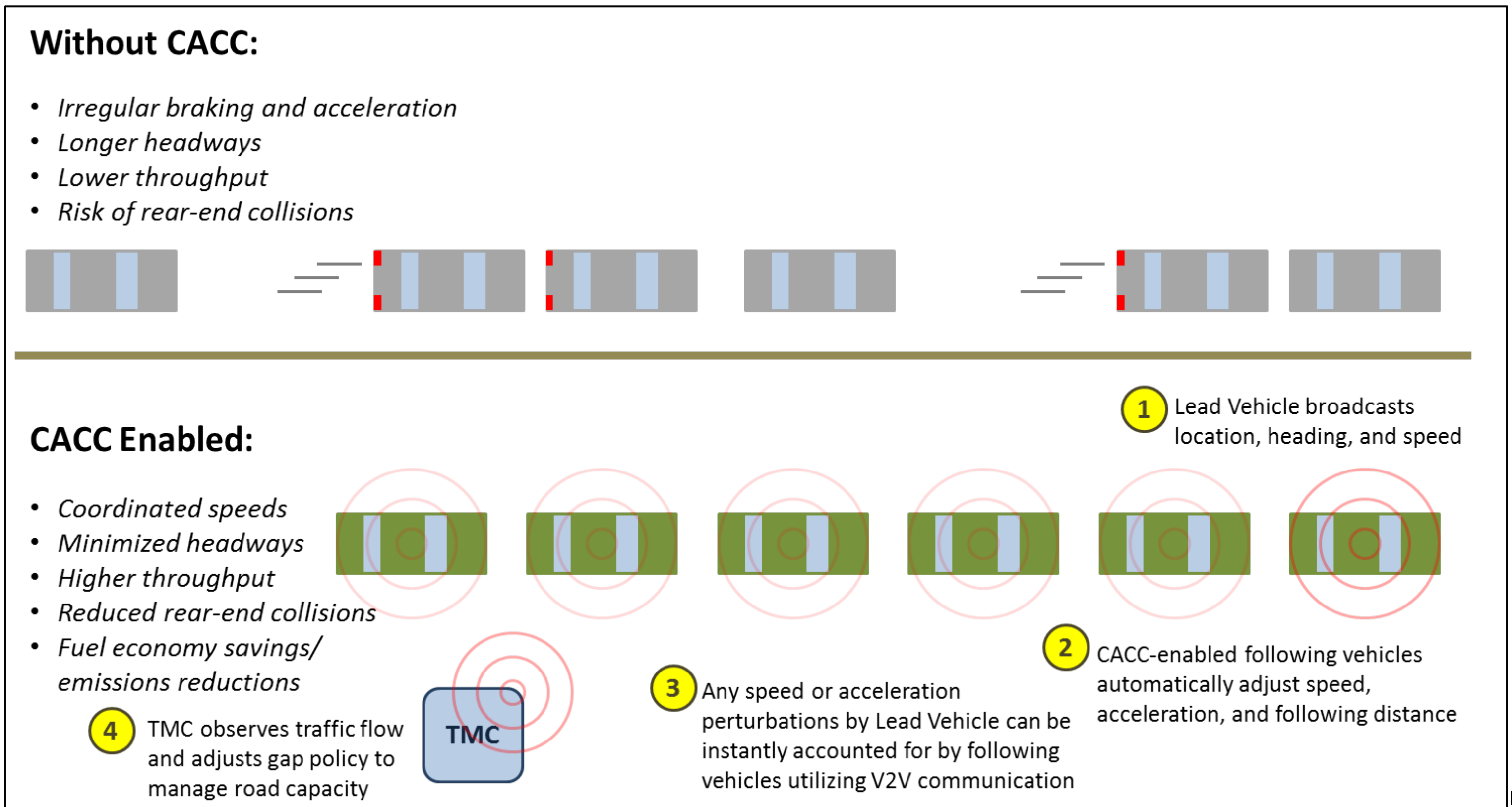
QUEUE WARNING (Q-WARN)

- Aims to provide drivers timely warnings and alerts of impending queue backup
  - Reduces shockwaves and prevents collisions and other secondary crashes
  - Predicts location, duration and length of queue propagation
  - Utilizes V2V and I2V communication for rapid dissemination and sharing of vehicle information
    - E.g., position, velocity, heading, and acceleration of vehicles in the vicinity
  - Allows drivers to take alternate routes or change lanes
  - Applicable to freeways, arterials, and rural roads



Cooperative Adaptive Cruise Control (CACC)

- Aims to dynamically adjust and coordinate cruise control speeds among platooning vehicles to improve traffic flow stability and increase throughput
  - Closely linked with SPD-HARM to reduce stop-and-go waves
  - Utilizes V2V and/or V2I communication to coordinate vehicle speeds and implement gap policy



INFLO Prototype

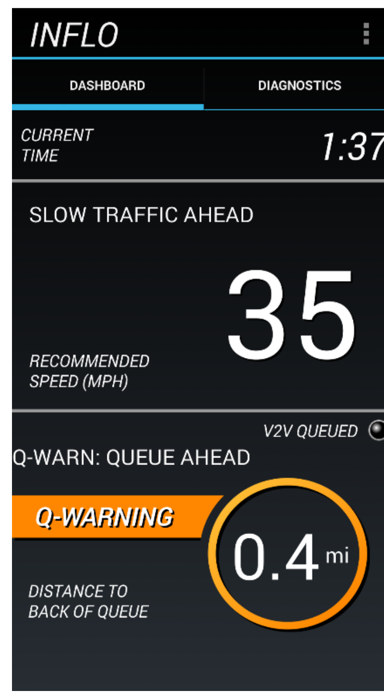
INFLO Prototype Objectives and Team

- **Prototype Objectives**
  - Design and develop prototype INFLO Applications
    - Dynamic Speed Harmonization (SPD-HARM)
    - Queue Warning (Q-WARN)
  - Conduct a small-scale demonstration of the prototype
  - Collect data to support
    - Assessment of the impacts of the prototype
    - Regional deployment of the two applications

- **Project Team**
  - Battelle
  - Texas A&M Transportation Institute
  - Demonstration supported by:
    - Washington State Department of Transportation

INFLO Prototype Applications

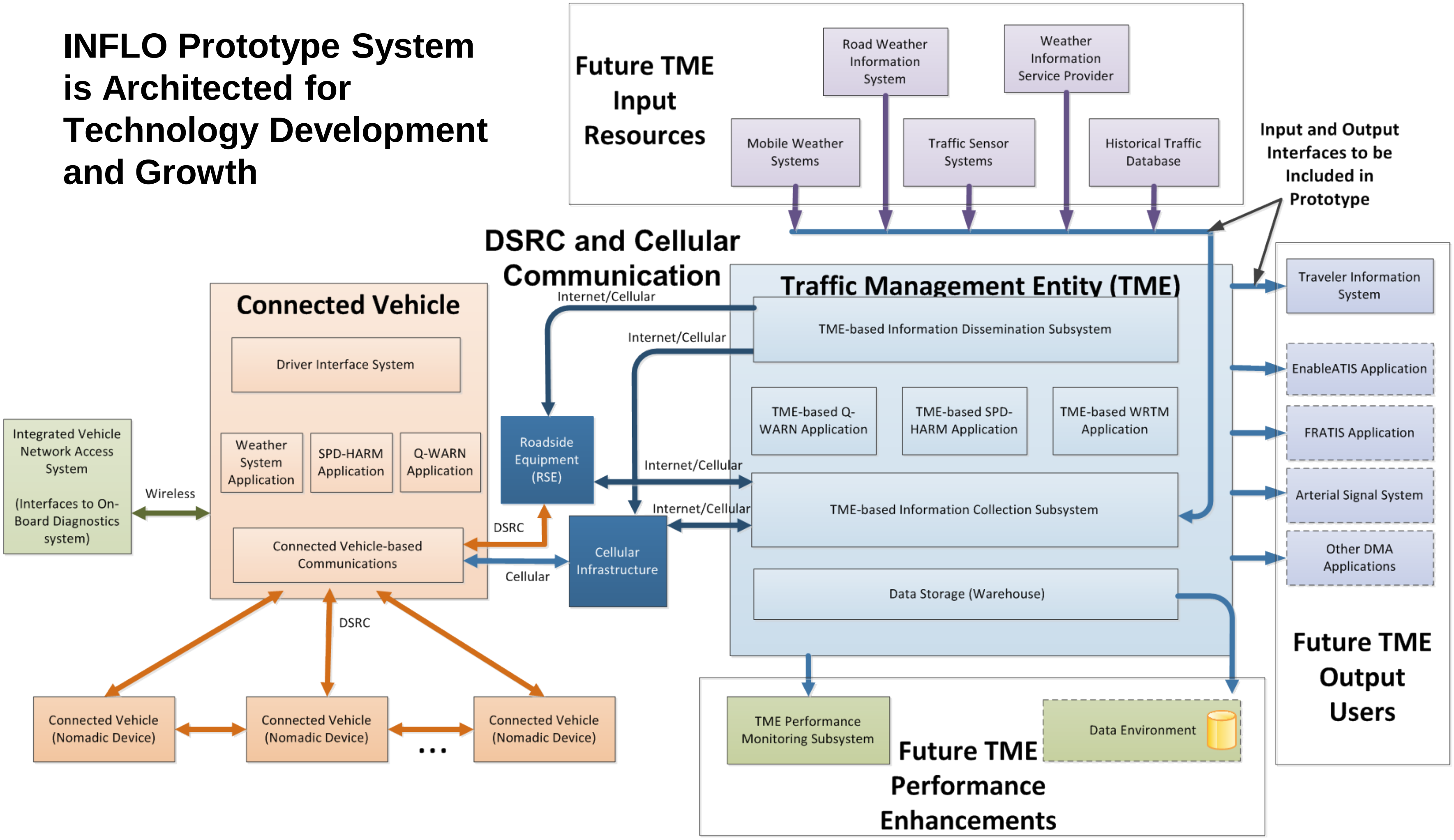
- **TME-Based Q-Warning Application**
  - TME uses V2I data to determine the back of queue and issues Queue Ahead messages
- **TME-Based Speed Harmonization Application**
  - TME uses V2I data to recommend speeds to minimize traffic turbulence, maximize traffic throughput and reduce crashes
- **Cloud-Based Queue Warning Application**
  - Vehicles use V2V to determine if they are in a queued state
  - Cloud processor captures and shares queued vehicle locations
- **V2V Queue Warning Application**
  - Vehicles use V2V to determine if they are in a queued state
  - Q-WARN (TIM) messages are relayed to approaching vehicles using V2V comm.



Queue Ahead and Speed Harmonization Recommended Speed Message

INFLO Prototype System Design Architecture

INFLO Prototype System is Architected for Technology Development and Growth

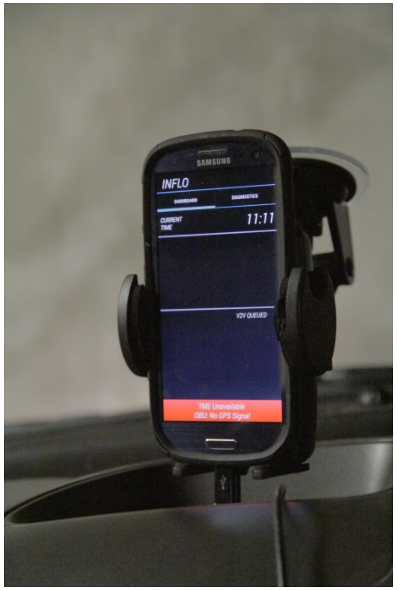


INFLO Prototype Field Demonstration-Seattle I-5 Corridor

- **Objectives**
  - Demonstrate and capture data in an operational traffic environment on:
    - INFLO system functionality
    - INFLO system performance
    - INFLO algorithm performance
    - Measured driver behaviors
    - Driver feedback
- **Rationale for Site Selection**
  - Recurring congestion
  - Existing infrastructure-based queue detection
  - Existing Variable Speed Limit (VSL) signage on the northbound side
  - Highly supportive leader in Intelligent Transportation Systems (ITS) research, WSDOT

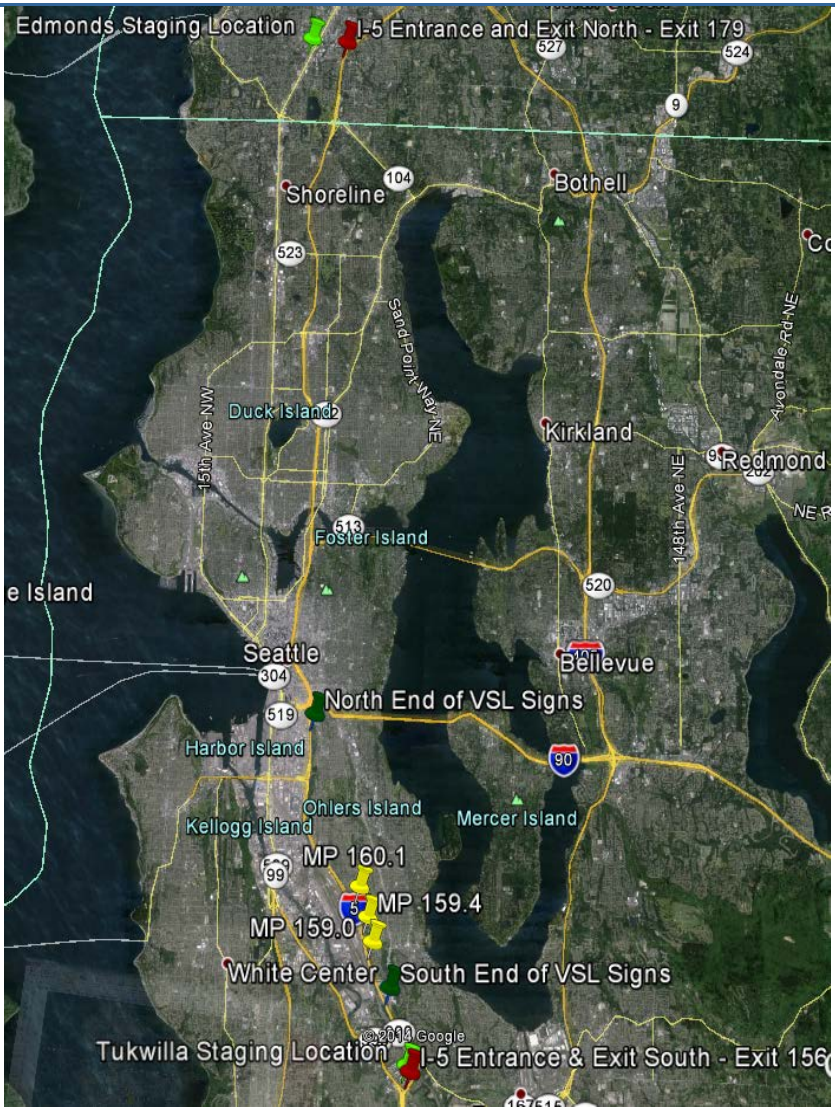
INFLO Prototype Field Demonstration – Vehicle Deployment

- Battelle and TTI worked with WSDOT to deploy connected vehicle systems in over 20 vehicles with naïve drivers
- Drivers were deployed in a scripted driving scenario circuiting the I-5 corridor, northbound and southbound, during morning rush hour on five sequential days.



INFLO Prototype Field Demonstration – Data Capture and Processing

- Battelle and TTI
  - Collected vehicle speed data from both the WSDOT infrastructure-based speed detectors and the connected vehicles.
  - Connected vehicle data collected through both DSRC Roadside Units and cellular backhaul communications.
  - Processed the data in real time and delivered Q-WARN and SPD-HARM messages to drivers.
  - Captured system performance data and driver behavior and feedback to demonstrate the INFLO system and examine potential benefits of connected vehicle technology.



INFLO Prototype Field Demonstration – Example Hypotheses

- System Functionality and Performance
  - INFLO system delivers Q-WARN and SPD-HARM messages to the drivers at least 1 mile in advance of congestion.
  - INFLO system delivers messages to drivers within 5 seconds of detection of congestion.
- Algorithm Performance
  - With adequate market penetration, connected vehicle-based speed data by itself can provide estimates of the location of the back of the queue and the length of the queue that are comparable to that provided by infrastructure-based speed sensors only.
- Measured Driver Behavior
  - On average, there are fewer panic stops as indicated by longitudinal deceleration.
- Driver Feedback
  - On average, drivers report that they find Q-WARN and SPD-HARM messages useful, valuable and appropriate for traffic conditions.
  - On average, drivers report that they believe Q-WARN and SPD-HARM messages will improve safety by notifying them of slowed and congested traffic ahead.

INFLO Prototype Development Challenges and Solutions

- **Challenge: Requirement for Nomadic DSRC Device**
  - Solution: Development and fielding of a versatile portable DSRC system which
    - Can be installed in vehicles or be carried by a pedestrian
    - Can communicate with the TME via DSRC when available or cellular when not
- **Challenge: Demonstrate Queue Warnings without infrastructure**
  - Solution: Development and demonstration of vehicle-to-vehicle Queue Warning (TIM) Message Relay
- **Challenge: Integration of Infrastructure and Connected Vehicle Data**
  - Solution: Development of link/sublink methodology for infrastructure/CV data integration and fielding in a cloud-based data system
- **Challenge: Detection of Congestion**
  - Solution: Development and testing of advanced Q-WARN data analysis algorithms and iterative refinement to determine effective criteria for locating the back of the queue.
- **Challenge: Recommend Speeds based upon Traffic and Road Weather Conditions**
  - Solution: Development and fielding of advanced SPD-HARM data algorithm which recommend speeds to smooth speed reduction ahead of congestion based upon traffic and road surface conditions.

INFLO Prototype Description Documentation and Data Available

- Following items are currently being prepared for publication by the U.S. DOT:
  - INFLO Prototype Seattle Small-Scale Demonstration Report (March 2015)
  - Final Project Technical Report on Prototype of Dynamic Speed Harmonization with Queue Warning (April 2015)
- Applications being prepared for posting on the Open Source Application Development Portal (OSADP) (February 2015) :
  - TME-Based Components of Queue Warning (Q-WARN)
    - Includes Cloud-Based Queue Warning
  - TME-Based Components of Speed Harmonization (SPD-HARM) with Weather Responsive Traffic Management (WRTM)
  - Arada DSRC Radio components of Q-WARN and SPD-HARM Application
    - Includes V2V Q-WARN
  - Android components of Q-WARN and SPD-HARM Application
- Data being prepared for posting on the Research Data Exchange (RDE; www.its-rde.net) (February 2015)
  - Seattle Demonstration Database

INFLO Impact Assessment

Cory Krause

Pathways Civil Engineer

FHWA Office of Operations Research and Development

IMPACT ASSESSMENT OBJECTIVES & TEAM

- **Project Objectives**
  - Assess the impacts of the prototype of Dynamic Speed harmonization (SPD-HARM) with Queue Warning (Q-WARN)
  - Assess the impacts of the prototype at various levels of future market acceptance on the facility where the prototype demonstration is conducted

- **Project Team**
  - Kittelson & Associates
    - Brandon Nevers
    - Rick Dowling
    - Anxi Jia
    - Jorge Barrios

KITTELSON & ASSOCIATES, INC.
TRANSPORTATION ENGINEERING/PLANNING

KEY RESEARCH QUESTIONS

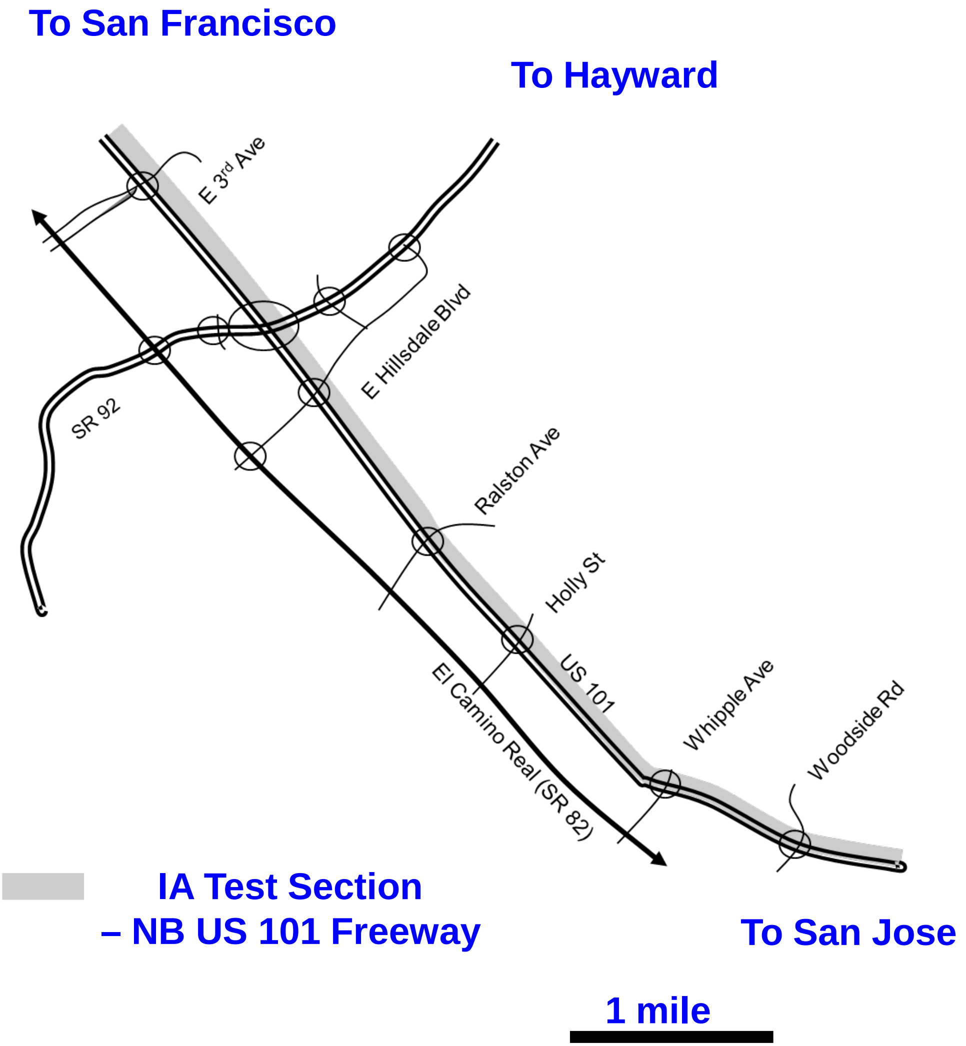
- Synergistic Benefits
  - Are the applications more beneficial when implemented in conjunction or in isolation?
- Operational Conditions with Most Benefit
  - Under what operational conditions are the applications the most beneficial?
  - Under what conditions is one application superior to the other?
- Communication Methods, Latency, and Loss
  - Which communication method is the best and when? When is DSRC needed and when will cellular suffice?
  - Will a nomadic device that is capable of communicating via both DSRC as well as cellular meet the needs of the two applications?
  - What are the effects of communication loss and latency?
- Deployment Readiness
  - At what levels of market penetration of connected vehicle technology do the applications become effective?
  - What are the impacts of future operational deployments of the applications in the near, mid, and long term?

IMPACT ASSESSMENT APPROACH

- Two-pronged approach used to accommodate scale and timing of demo:
  - Analyze data from small-scale demo conducted on I-5 Corridor in Seattle
  - Supplement small-scale demo results with results from a simulation testbed (US 101 NB in San Mateo County, CA) that will model the prototype applications
- Identified Performance Measures
  - Shockwaves, queues, throughput, speed variance, average travel time, reliability, emissions, safety
  - Identified proxy measures for safety: speed variance and shockwaves
- Developed Experimental Plan to answer key research questions
  - Developed testable hypotheses associated with each research question
  - Identified realistic operational conditions observed for US 101 NB in a year
  - Developed simulation experiments for each hypothesis
  - Examined only SPD-HARM in US 101 NB:
    - Q-WARN not modeled since inadequate information on how drivers respond to advanced information of queues
- Conducted simulation model runs, processed results
  - Preliminary results available from simulation analysis
  - Will supplement results with small scale demo results, when available

Impacts Assessment Approach – Simulation Testbed

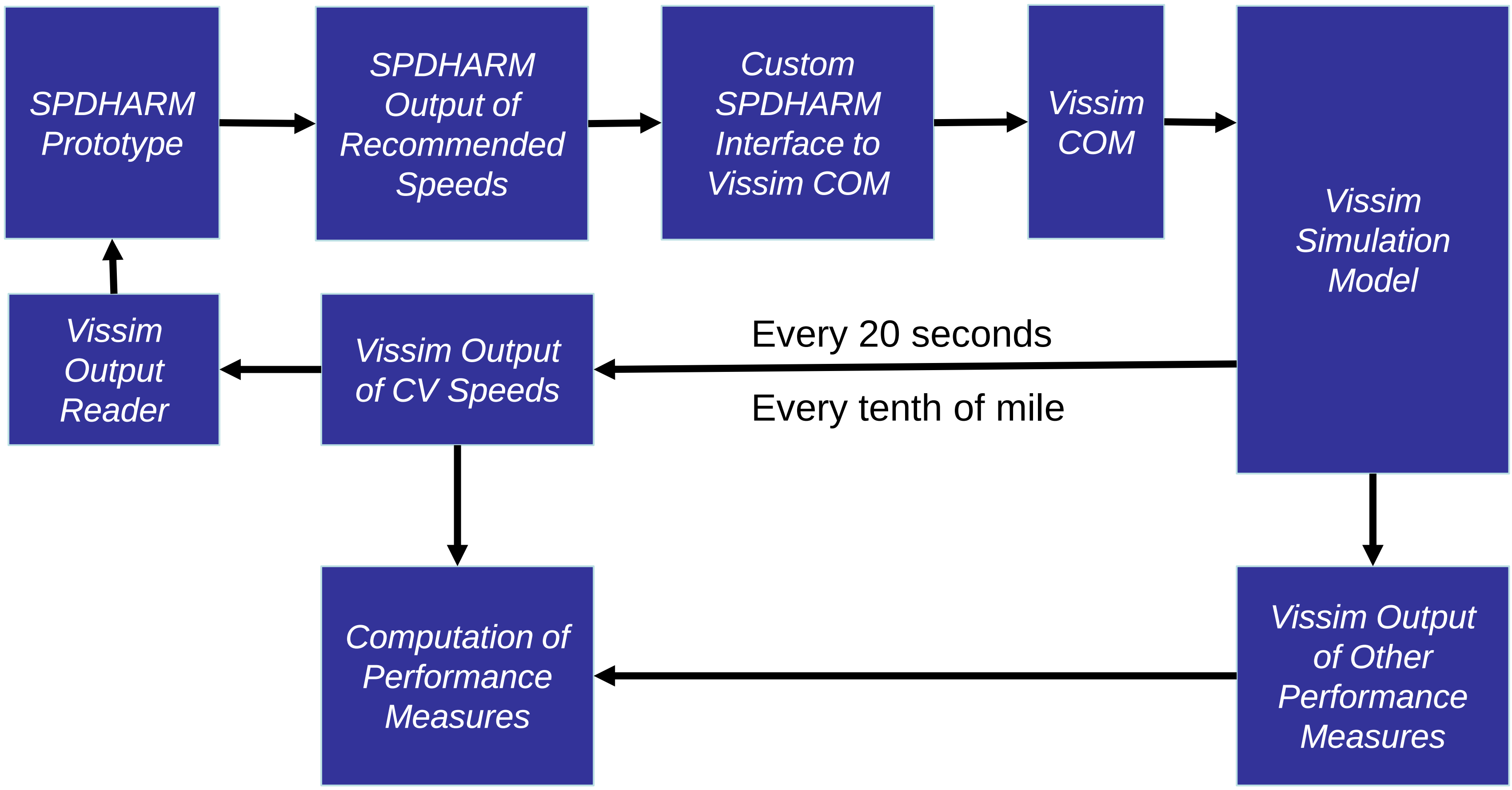
- Selected US 101 NB in San Mateo County, CA due to significant recurring congestion and availability of calibrated simulation model and continuous monitoring data on historic speeds, volumes, and incidents for freeway
  - 8.5 miles long stretch of the US101 freeway
  - Located approximately 10 miles south of the San Francisco International Airport (SFO)
  - Implemented Prototype Algorithms in VISSIM



IMPACTS ASSESSMENT APPROACH – IDENTIFICATION OF OPERATIONAL CONDITIONS

- **Objective:**
  - Identify realistic operational conditions that span the likely range of congestion, incidents, and weather that would be seen in a typical one year period at the site
- **Approach:**
  - Examined one year (2012) of travel time, incident, and weather logs for US 101
    - Determined that southbound congestion is infrequent, so ruled out SB
    - Ruled out incident types that have negligible effects on congestion (e.g. shoulder stalls, etc.)
    - Ruled out incident, weather combinations that occurred < 1% of days in 2012
    - Ruled out uncongested time periods and days (weekends, holidays, off-peak)
    - Selected 4 hour PM peak NB as regularly producing recurring congestion
  - Identified six operational conditions using remaining 251 days:
    - 1. Dry Weather, No recorded incidents likely to block one or more lanes (79%)
    - 2. Dry Weather, Incident blocking one lane for 30 minutes (7%)
    - 3. Dry Weather, Incident blocking one lane for 60 minutes (4%)
    - 4. Rain, no recorded incidents likely to block one or more lanes (8%)
    - 5. Rain, Incident blocking one lane for 30 minutes (1%)
    - 6. Rain, Incident blocking one lane for 60 minutes (1%)

IMPACTS ASSESSMENT APPROACH – INTEGRATION OF PROTOTYPE WITH VISSIM



Impacts Assessment Approach – Modeling Communications and Compliance

- **Assumptions:**
  - SPD-HARM prototype has built in 15 second latency between updates to human, because of “human-in-the-loop” latency needs
  - Driver compliance rates with SPD-HARM speeds are unknown
  - Real world observer and microsimulation model cannot tell the difference between a driver who got the message but ignores it, and a driver who did not get the message because they did not have the device or there was communication loss
  - Defined new term, “net response rate” which is the percentage of drivers complying precisely with SPD-HARM speeds
    - Net Response Rate = Market Penetration x Compliance Rate x (1-Communication Loss)

- **Approach:**
  - Varied net response rates: 0%, 10%, 25%, 50%
  - Extrapolated simulation results to different combinations of market penetration, communication loss, and compliance yielding the same overall net response rate

PRELIMINARY RESULTS FROM SIMULATION ANALYSIS

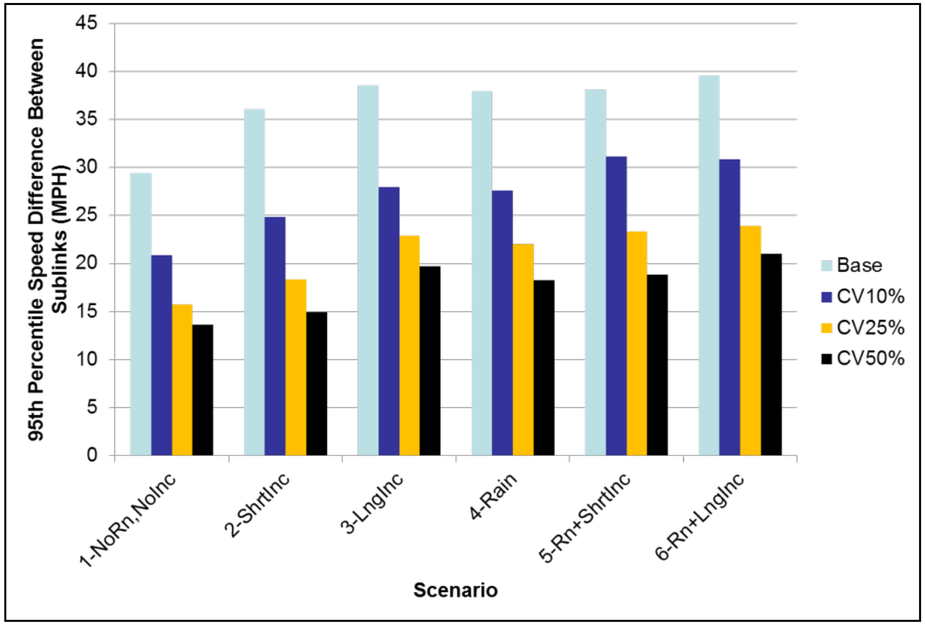
SPD-HARM can potentially increase safety benefits,
but impacts on mobility statistically insignificant

CV Level	Scenario	Probability	Interlink Shock (mph)	Intralink Shock (mph)	VMT Served (1,000s)	VHT (veh-hr)	Speed (mph)	VSQ (secs/veh)	95th % TTI	Lane Change/veh	Stops/veh
0% CV	1. Dry, No Incident	79%	29	18	275	6,453	43	52	1.66	449	71
	2. Short Incident	7%	36	20	275	6,755	41	55	1.63	446	83
	3. Long Incident	4%	39	26	274	7,587	36	117	1.99	455	255
	4. Rain, No Incident	8%	38	27	262	9,765	27	290	3.85	489	850
	5. Rain + Shrt Inc.	1%	38	28	258	10,614	24	304	4.11	493	914
	6. Rain + Lng Inc.	1%	40	30	250	11,509	22	363	4.56	486	1,167
10% CV	1. Dry, No Incident	79%	21	16	275	6,571	42	46	1.70	428	60
	2. Short Incident	7%	25	18	275	6,939	40	62	1.81	430	99
	3. Long Incident	4%	28	19	273	7,994	34	133	2.22	429	313
	4. Rain, No Incident	8%	28	21	263	10,028	26	271	3.91	468	795
	5. Rain + Shrt Inc.	1%	31	22	257	10,836	24	314	4.18	466	983
	6. Rain + Lng Inc.	1%	31	24	250	11,727	21	356	4.58	461	1,168
25% CV	1. Dry, No Incident	79%	16	13	275	6,955	40	52	1.78	456	73
	2. Short Incident	7%	18	15	275	7,170	38	61	1.90	463	96
	3. Long Incident	4%	23	18	273	8,248	33	134	2.27	470	312
	4. Rain, No Incident	8%	22	19	260	10,445	25	291	4.26	498	879
	5. Rain + Shrt Inc.	1%	23	19	257	11,216	23	309	4.08	491	960
	6. Rain + Lng Inc.	1%	24	17	248	12,276	20	356	4.59	482	1,194
50% CV	1. Dry, No Incident	79%	14	13	275	7,169	38	53	1.95	488	74
	2. Short Incident	7%	15	14	275	7,295	38	63	2.00	485	102
	3. Long Incident	4%	20	14	274	8,405	33	123	2.30	492	287
	4. Rain, No Incident	8%	18	17	262	10,637	25	273	4.04	513	826
	5. Rain + Shrt Inc.	1%	19	18	257	11,165	23	297	4.11	505	946
	6. Rain + Lng Inc.	1%	21	16	249	12,104	21	350	4.57	502	1,165

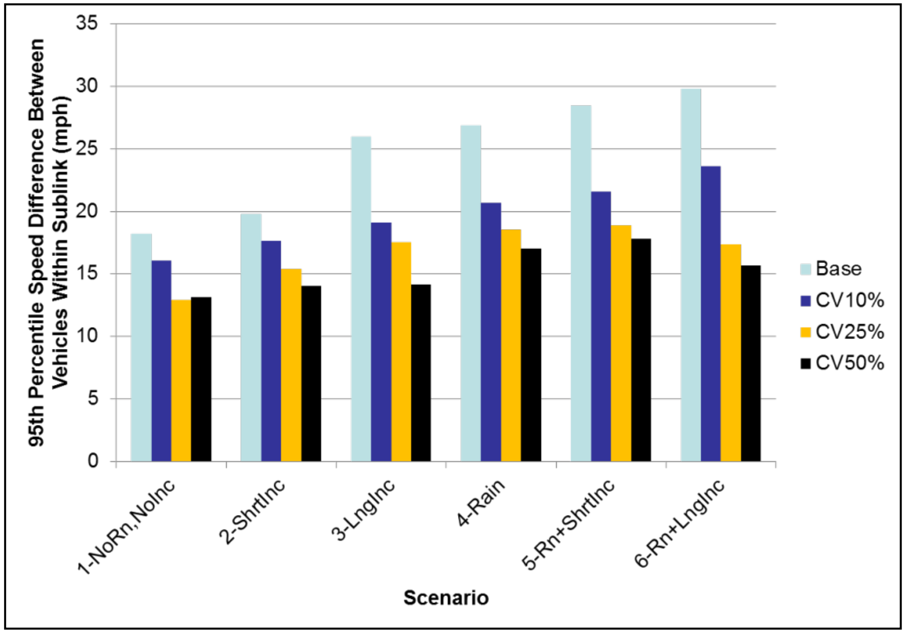
PRELIMINARY FINDINGS FROM SIMULATION ANALYSIS: SYNERGISTIC BENEFITS AND OPERATIONAL CONDITIONS

- No conflicts observed between the functions of Q-WARN and SPDHARM; quantitative impacts are still being analyzed
- SPD-HARM potentially results in increased safety benefits
  - Speed variations between freeway segments reduced by 18-58%
  - Speed variations within freeway segments reduced by 10-47%
- SPD-HARM was effective in reducing shockwaves and speed variations under all six conditions

SPD-HARM REDUCES SHOCKWAVES



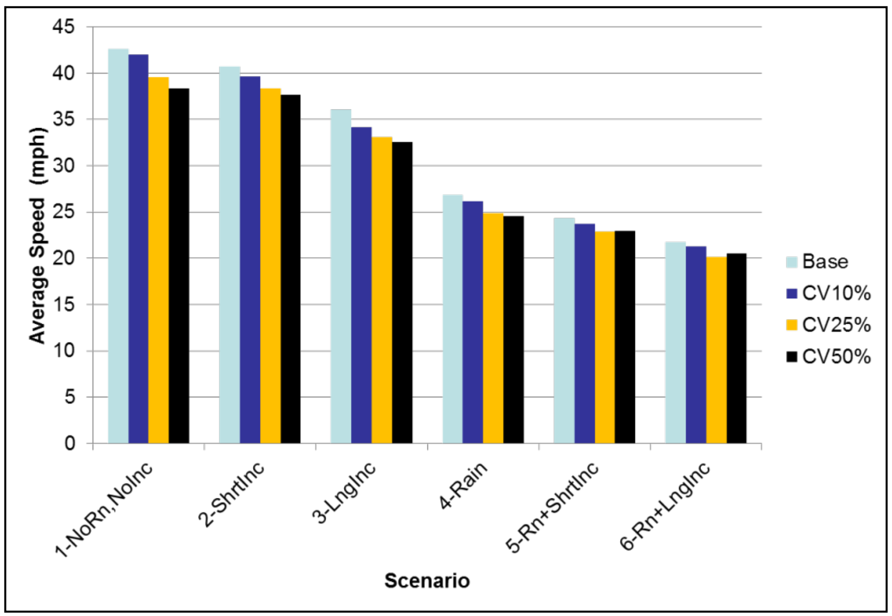
SPD-HARM REDUCES SPEED VARIATION



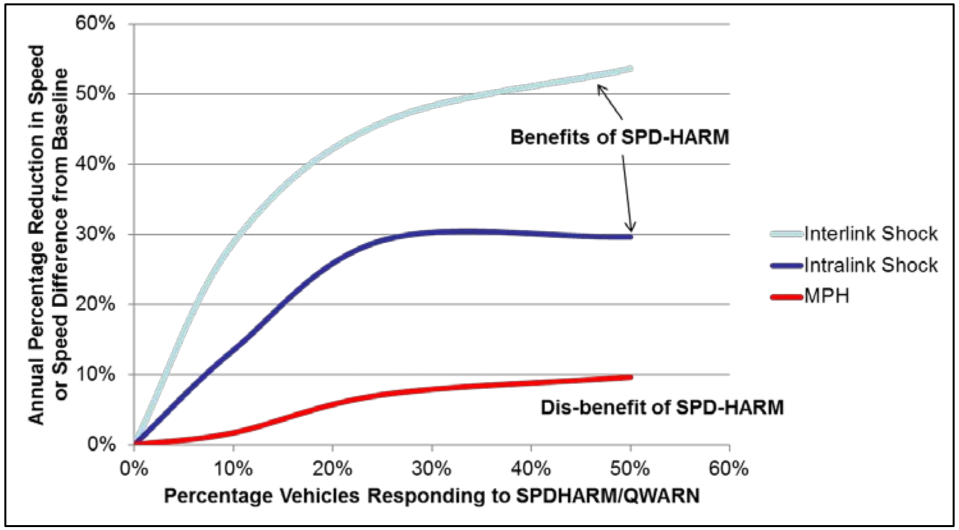
Preliminary Findings from Simulation Analysis: Deployment Readiness

- Significant benefits even in the near term as significant advantages accrue at even the 10% net response rate
  - Dis-benefit is slightly lower average speeds (reduction of 2.8% to 7.4%)
- Longer term, as market penetrations and compliance increase, there should be continuing benefits, but the benefits will increase at a slower rate
  - Highest marginal benefits for the first 20% net response rate

SPD-HARM Reduces Average Speeds



Biggest Payoff Seen for First 20% of Net Response Rate



NEXT STEPS

- Analyze small-scale demonstration data
- Update DRAFT Impacts Assessment Report (March 2015)
- Develop Final Impacts Assessment Report (April 2015)
- Post Final Report and Code on OSADP (http://www.itsforge.net/) (April 2015)

Stakeholder Q&A

CONTACTS

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Webinar Speakers

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DMA Website

http://www.its.dot.gov/dma/