Project ID# eems031
Pillar(s): CAV

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

CAV Task 7A.1.2. Traffic Micro-Simulation of Energy Impacts of Connected and Automated Vehicles (CAV) Concepts at Various Market Penetrations

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Project Team: Dr. Hao Liu
2019 Vehicle Technologies Office Annual Merit Review
June 12, 2019

Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
BERKELEY LAB
OAK RIDGE National Laboratory
NREL NATIONAL RENEWABLE ENERGY LABORATORY

OVERVIEW

- **Timeline**
  - **Project start date: Jan 1 2017**
  - **Project end date: Sept 30 2019**
  - **Percent complete: 90%**
- **Budget**
  - **Total project funding: $681K**
    - **100% DOE/VTO**
  - **Funding for FY 2017: $181K**
  - **Funding for FY 2018: $250K**
  - **Funding for FY 2019: $250K**
- **Barriers**
  - **Energy consumption evaluation in freeway and arterial corridor traffic level with different CAV market penetrations**
  - **Traffic improvement in the case of low CAV market penetrations**
- **Collaboration**
  - **Berkeley Lab (project lead)**
  - **UC Berkeley**
  - **Output: used by EEMS075: Micro to Meso**

RELEVANCE AND OBJECTIVES

- **Relevance**
  - **Vehicle energy savings in real world traffic mainly affected by factors at three levels:**
    - **meso/macroscopic traffic patterns;**
    - **local vehicle following behavior; and**
    - **vehicle level: control & powertrain/drivetrain characteristics**
  - **Progressive market penetration of CAVs and Active Traffic Management (ATM) changes the traffic pattern significantly**
  - **Field test of CACC impact on energy savings in traffic level is not feasible**
- **Objectives**
  - **Simulating energy saving benefit for CACC operation on a freeway pipeline section and a 20-km freeway corridor**
  - **Simulating effect of CACC management strategies**

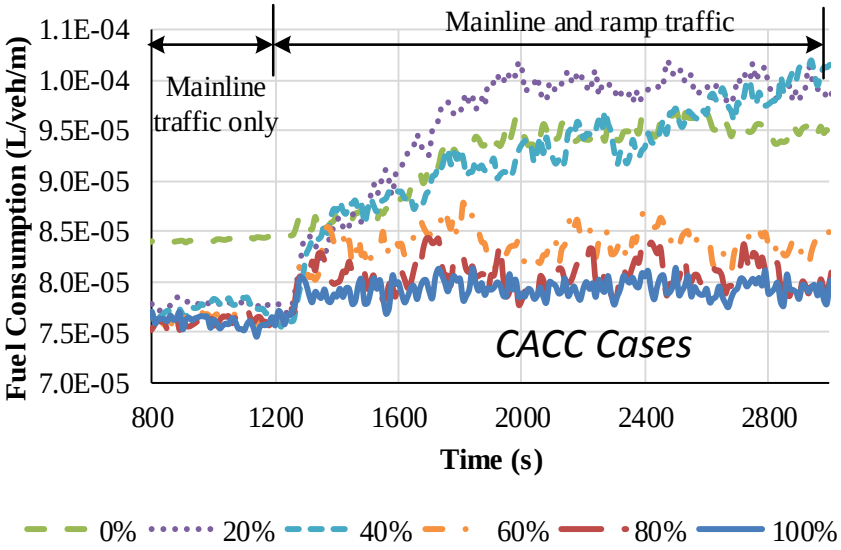
MILESTONES

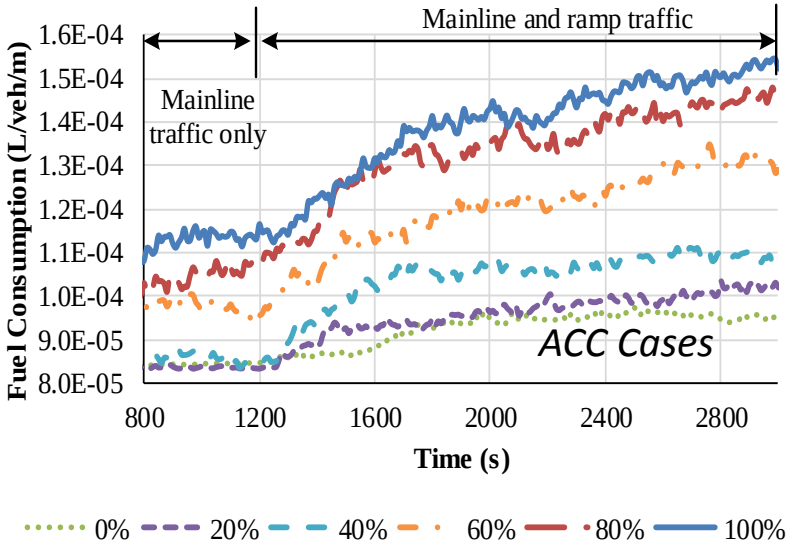
Milestone	Milestone or Deliverable Description	Milestone Type / Go/No-Go Criteria
Q1	Initial network model with freeway and arterial	Operation level micro-traffic simulation model in Aimsun
Q2	Calibrated network traffic with CACC model	Operation level micro-traffic simulation model in Aimsun
Q3	Implemented ATM for both freeway and arterial with optimal coordination	Operation level micro-traffic simulation model in Aimsun
Q4	Data from extensive simulation with analysis results	Report on energy saving benefit for CACC operation over network traffic with ATM and coordination strategies
Go/No-go		

APPROACH

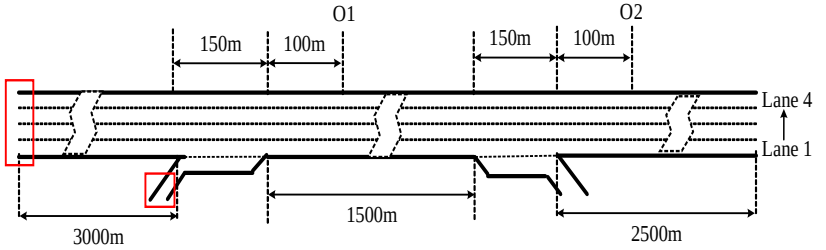
- **Model traffic network in Aimsun and implement CC/ACC/CACC modeling in MicroSDK**
- **Simple freeway pipeline area and freeway corridor traffic with CACC on SR-99 NB**
  - **Adopt more ATM strategies we have field-tested including**
    - **Coordinated Ramp Metering (CRM)**
    - **Variable Speed Advisory (VSA)**
    - **CACC managed lane strategy (ML)**
    - **Equipping manually driven vehicles with Vehicle Awareness Device (VAD)**
- **Analyzing fuel saving impact with variety of CACC penetration levels**

ACCOMPLISHMENTS: Freeway Pipeline Section

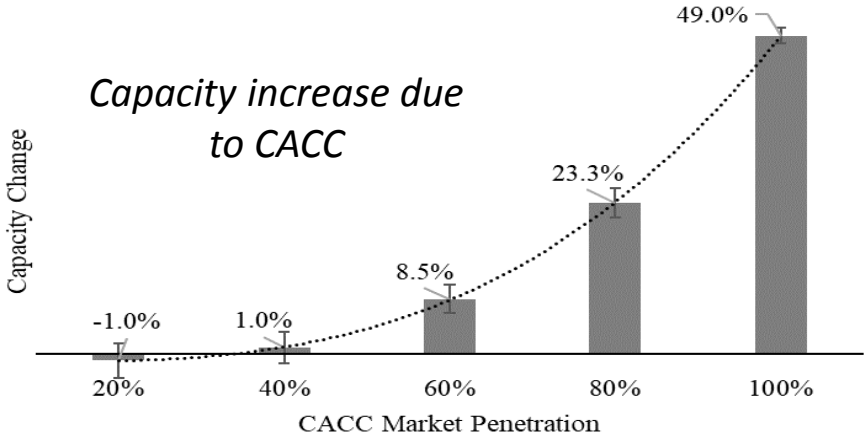


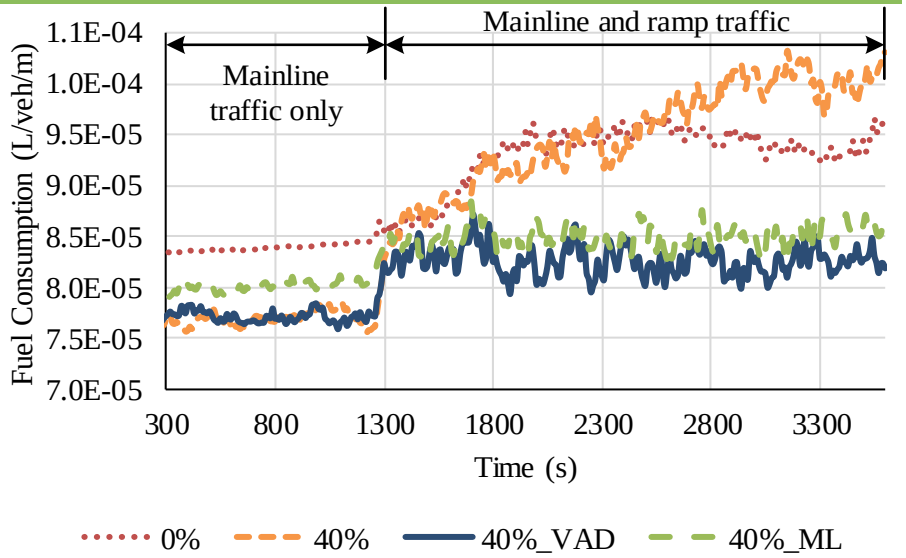


- **Impact on Energy Saving**
  - **ACC makes energy efficiency worse because it brings instability to traffic flow**
  - **ACC is not as good as experienced driver in vehicle control performance.**
  - **It demonstrate the significant impact of vehicle connectivity on CAV operations.**



ACCOMPLISHMENTS: Freeway Pipeline Section

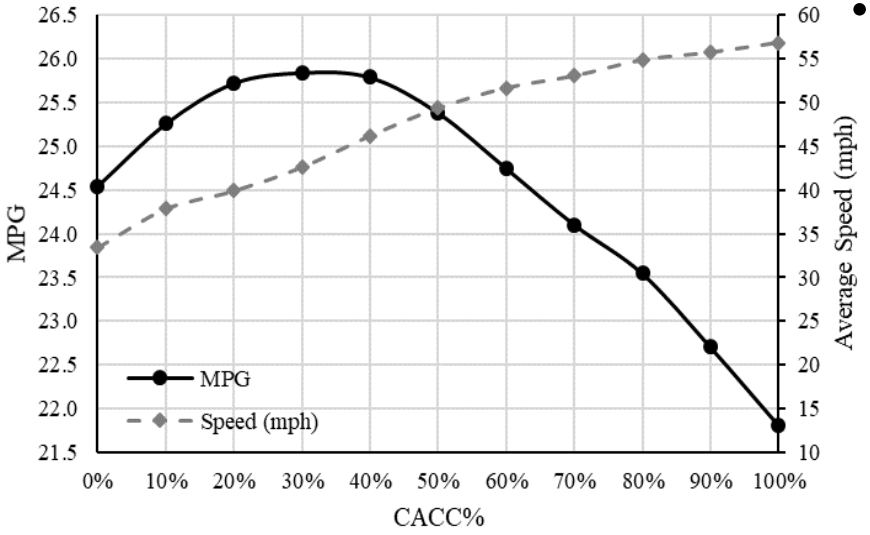




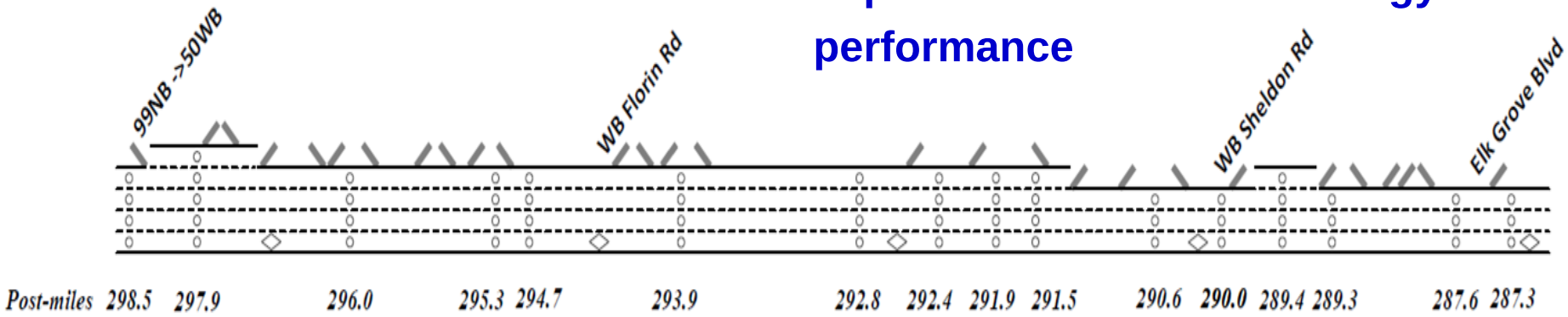
Impacts of VAD and ML Strategies

- **Impact on Energy Saving**
  - **The CACC string operation can improve the freeway capacity by 50% while maintaining a constant vehicle fuel economy.**
  - **The VAD and ML strategies substantially enhance the freeway performance under medium and low CACC market penetration cases.**

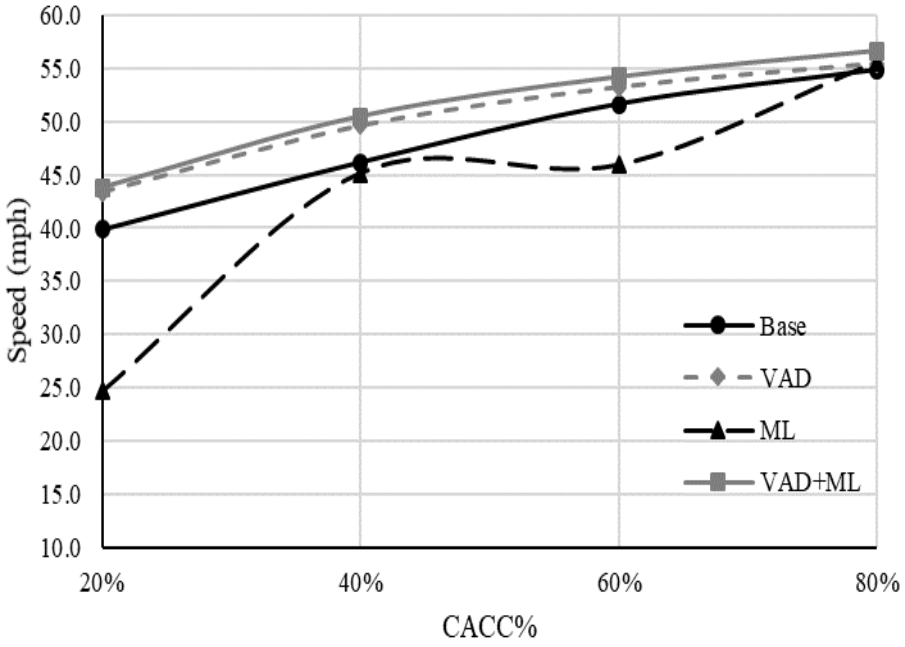
ACCOMPLISHMENTS: SR-99 Corridor

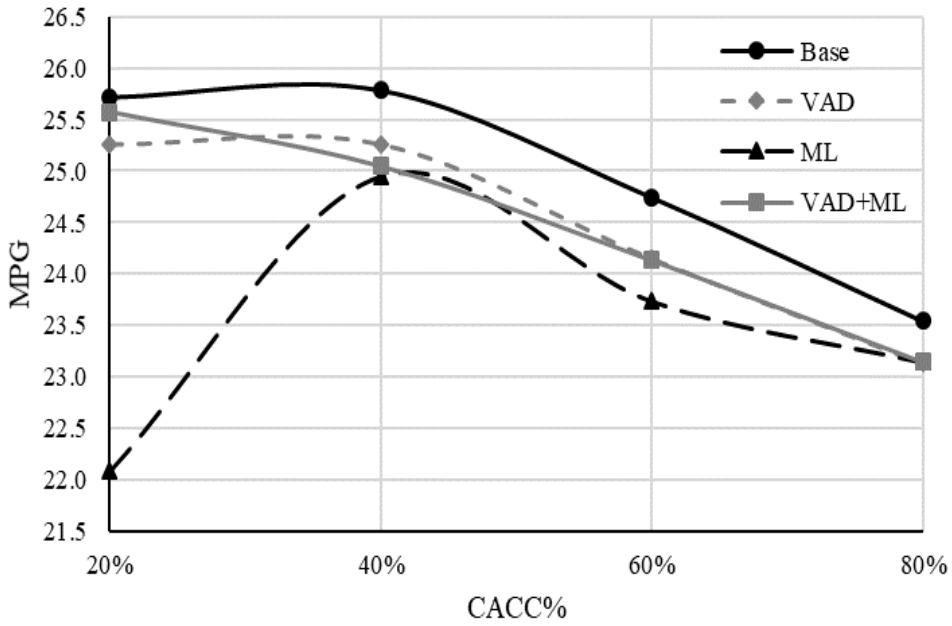


- **Impact on Energy Saving**
  - **Speed increases linearly with CACC market penetration**
  - **MPG first increases and then decreases with CACC market penetration**
  - **CACC controller design needs improvement for better energy performance**



ACCOMPLISHMENTS: SR-99 Corridor

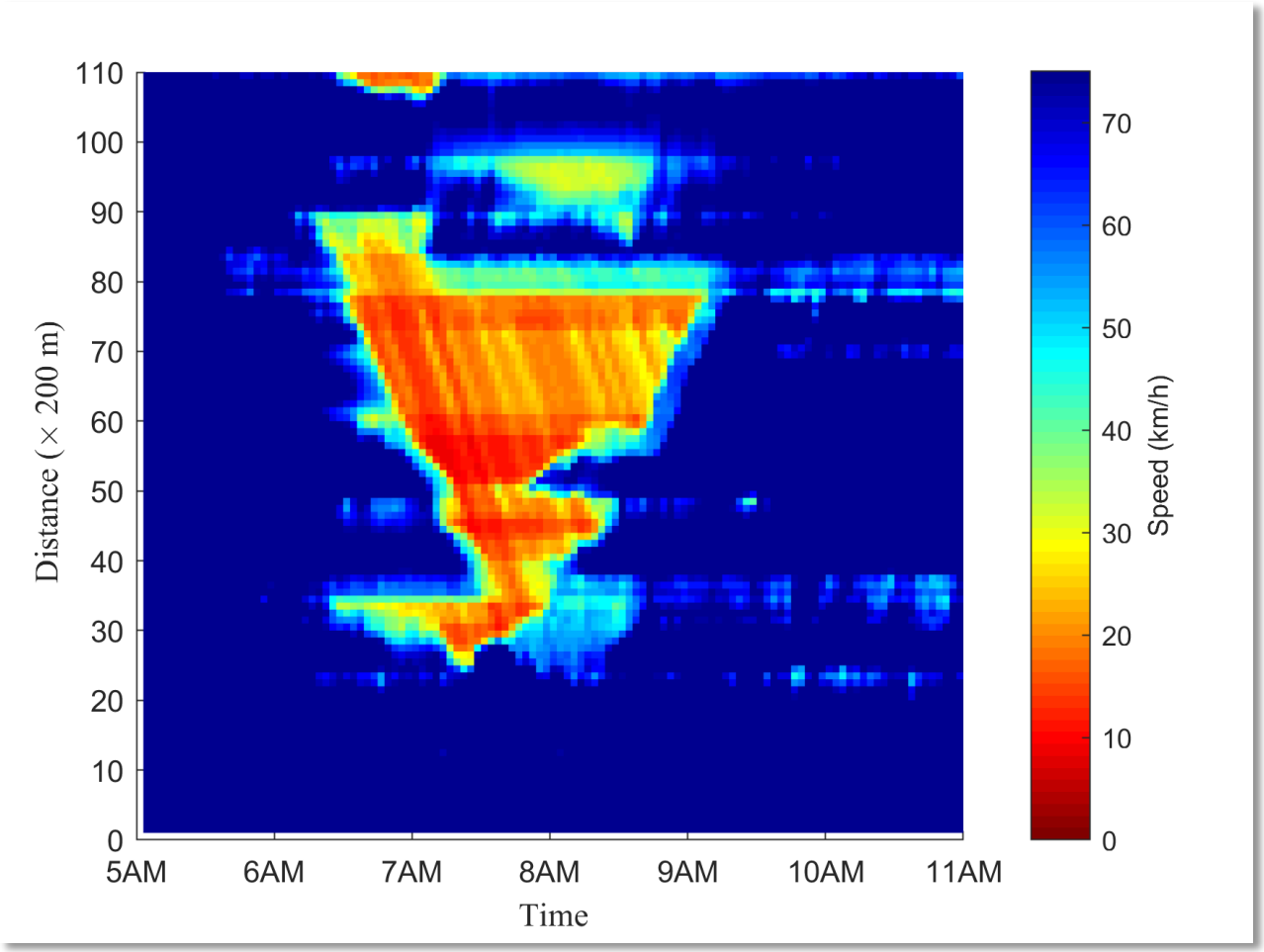




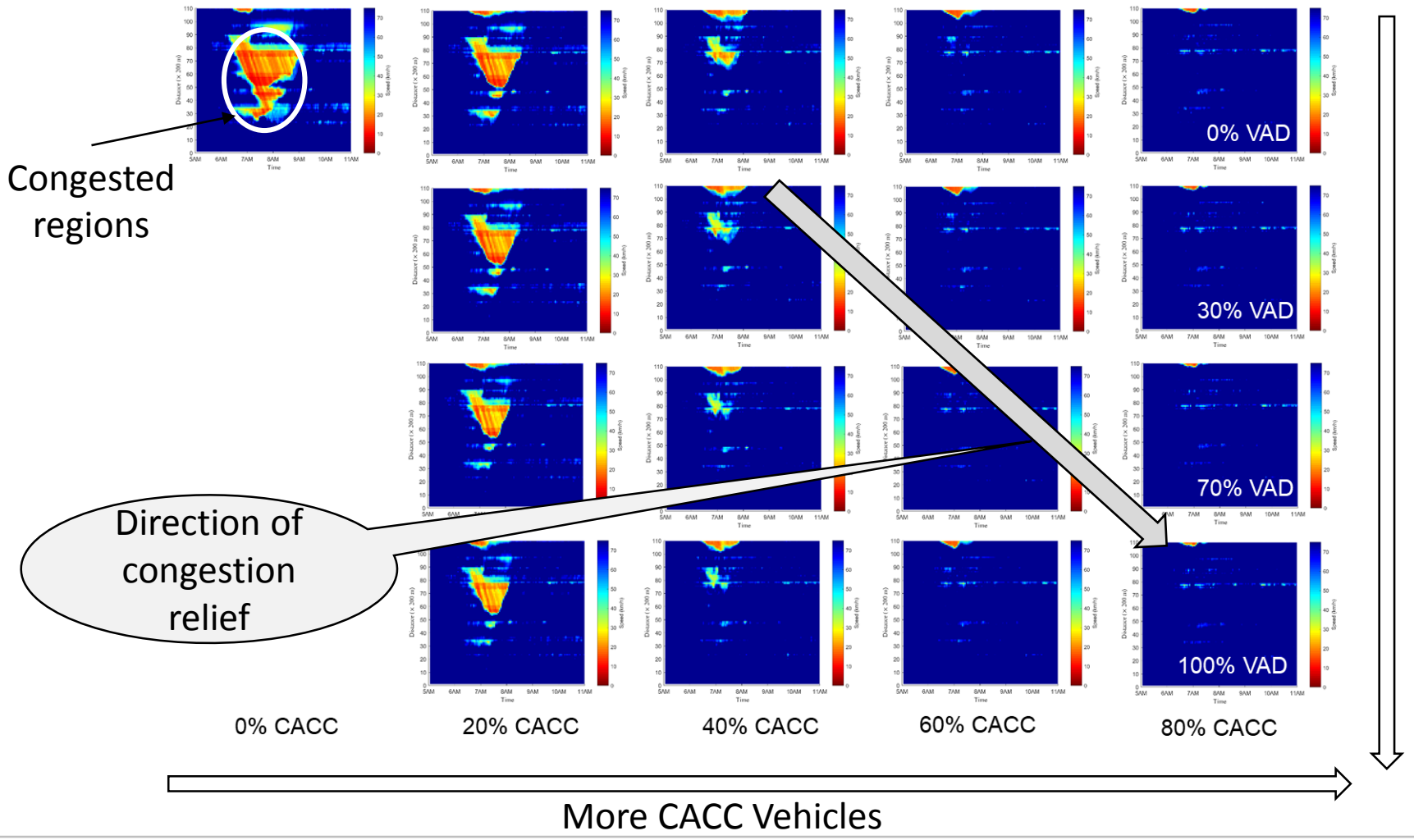
- **Impact on Energy Saving**
  - **The VAD strategy benefits mobility but reduces energy efficiency.**
  - **The Managed Lane (ML) strategy has negative impacts on both mobility and fuel consumption**

ACCOMPLISHMENTS: SR-99 Corridor

- **Time space diagram for depicting the detailed CACC impact**



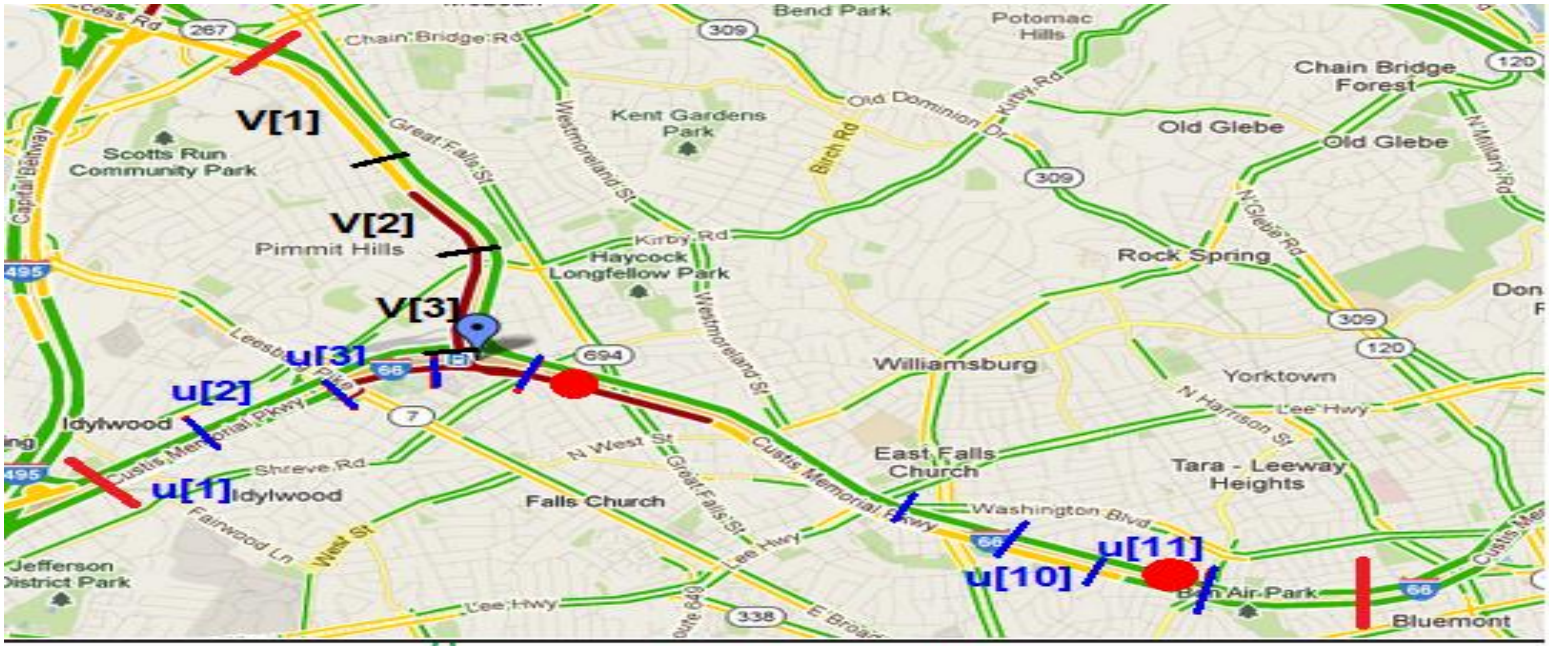
ACCOMPLISHMENTS: SR-99 Corridor

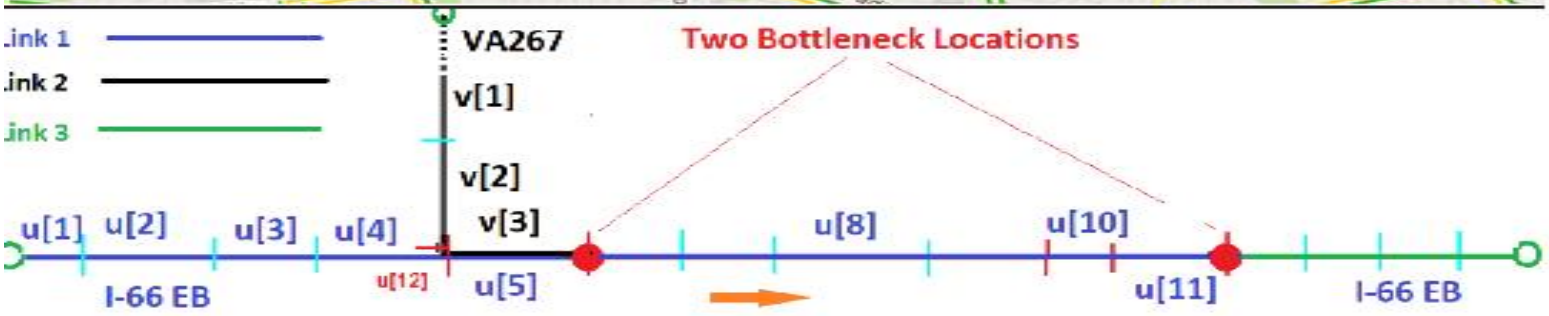


ACCOMPLISHMENTS

- At low CAV penetration levels vehicle likely to be in ACC mode which increase congestion
- Using Vehicle-to-Infrastructure (V2I) Variable Speed Limit (VSL) to resolve low CAV market penetration problem for traffic performance improvement
- Model Predictive Control applied for VSL determination
- ACC vehicle use the VSL as the set speed for traffic regulation
- No V2V connection assumed
- Simulated for I-66 inside the Belt Way in Washington D. C.
- Traffic performance parameters:
  - TTT: Total Travel Time
  - TTD: Total Travel Distance
  - TD: Total delay
  - Average Speed Variation
  - TNOS: Total Number of Stops
  - Flow at recurrent bottlenecks

ACCOMPLISHMENTS – I-66 Corridor Inside the Beltway





U.S. Department of Transportation Federal Highway Administration

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BERKELEY LAB

CALIFORNIA PATH

ACCOMPLISHMENTS – I-66 Corridor Inside the Beltway

- **Simulation results:**
  - **Time step is 30 [s]**
  - **2 predictive time-steps**
  - **Market penetration of (I2V type) CAV vehicle: 0% (baseline), 10%, 30% and 50%**
  - **Density is measured in simulation instead of estimated with the traffic dynamics**

market penetr.	TTT [%]	TTD [%]	TD [%]	Spd Var [%]	Ave # of Stops [%]	Flow @Syc. [%]	Flow @ Merge [%]
10%	-6.0	0.84	-9.41	-8.41	-3.48	1.80	-0.19
30%	-6.95	1.25	-11.0	-8.3	-4.21	2.37	0.07
50%	-8.94	1.4	-13.72	-9.28	-4.90	2.24	-0.06
Mean	-7.30	1.16	-11.38	-8.66	-4.20	2.14	-0.06

REMAINING CHALLENGES AND BARRIERS

- **It is necessary to quantify energy saving benefit of the Cooperative Adaptive Cruise Control (CACC) string operation under various market penetrations via simulation analyses.**
- **Implement Variable Speed Limit/Advisory in microscopic simulation of mixed traffic along a freeway corridor.**
- **It is necessary to quantify energy saving benefits for Active Traffic Management strategies: Coordinated Ramp Metering and Variable Speed Limit.**
- **To generate microscopic mixed traffic simulation data with more demand levels (5% ~ 35% over baseline) for modeling Fundamental Diagram with respect to different market penetration of CAVs required in the MORTAR projects**

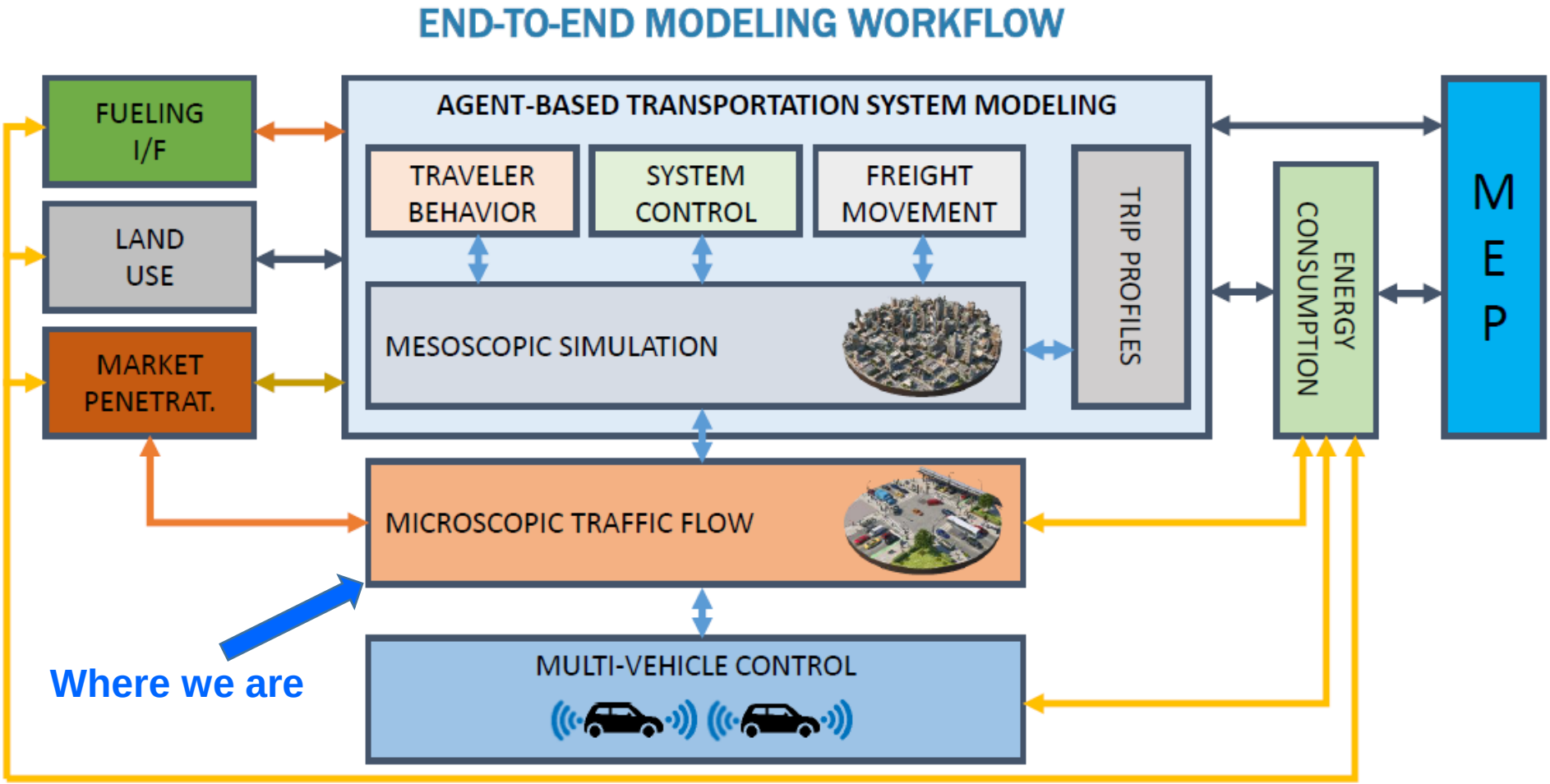
RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

- **How this project is different from the other efforts? CACC vehicle model and human driver model validation need justification.**
  - **This project adopt a bottom-up approach in the sense that:**
    - **(a) field test data of CACC vehicles (passenger cars and trucks) used for develop microscopic vehicle-following model;**
    - **(b) Next Generation Simulation Data (NGSIM) used to develop manually driven vehicle-following model;**
    - **(c) baseline traffic model calibrated with field data for freeway corridor;**
    - **(d) the switching criteria between CACC and manually driving mode used CAMP developed ACC and CACC driver behavior model; (e) performance evaluation conducted for variety market penetration levels of CAVs.**
- **If time delay/lag in the powertrain was considered in the equations?**
  - **The microscopic model for CACC passenger cars and trucks were based on vehicle behavior data (distance following, speed and acceleration). Therefore, all the delays (sensor, feedback control and actuation) have been incorporated. This is necessary and sufficient for microscopic traffic simulation.**

RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

- **If the desired CACC truck T-gap of 1.2 or 1.5 seconds is safe and what would happen if the lead passenger car braked hard?**
  - **Driver attention will always be necessary. Driver behavior test on freeway indicated that most drivers preferred time gap of 0. 9 & 1.2 [s]. The CACC trucks have Coordinated Emergency Braking capability developed based on V2V for safety improvement.**
- **Should Autonomie instead of MOVES-based model be used for energy consumption evaluation in simulation?**
  - **Autonomie has detailed vehicle dynamics model. Therefore, it could be applied to a small number of vehicles but not hundreds even thousands of vehicles in microscopic traffic simulation along a freeway corridor due to overhead of machine time. MOVES only needs aggregated data. Both needs calibration and revision based on our data analysis.**

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS - Where it Fits in Workflow



COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

- **Berkeley Lab (project lead)**
- **UC Berkeley: Researchers and Post-docs**
- **Output: generating mixed traffic simulation data for modeling Parameterized Fundamental Diagram (EEMS075 – Micro to Meso)**
- **Partner Projects in WorkFlow**
  - **EEMS075 – Micro to Meso simulation (Xiao-Yun Lu, LBNL)**
  - **EEMS078 - POLARIS MDS (Joshua Auld, ANL)**
  - **EEMS058 - ANL Workflow (Aymeric Rousseau, ANL)**
  - **EEMS011 - BEAM (Colin Sherpard, LBNL)**
  - **EEMS076 - RoadRunner to Micro (Dominik Karbowski, ANL)**
  - **EEMS078 - POLARIS MDS (Joshua Auld, ANL)**

SUMMARY

- CACC performs better at isolated bottlenecks or in pipeline than in complex corridors.
- Higher market penetration of ACC will worsen traffic and energy consumption.
- The ML induces frequent lane change worsening traffic. Using dedicated on-ramp may help improve ML performance.
- CAV improves traffic and energy savings when market penetration is above 40%
- VAD has the best impact on traffic under low or medium CACC market penetration cases.
- VSL can be used by V2I-based ACC vehicles (or, low market penetration CAVs < 40%) for traffic performance improvement. Those vehicles use VSL as the set speed for control, which has the effect of regulating traffic.

PROPOSED FUTURE RESEARCH

- Simulate fuel saving benefit for CACC vehicle operation along a freeway corridor with ATM including Variable Speed Limit/Advisory (VSL/VSA), Coordinated Ramp Metering, and Coordinated Merge
- Build a more accurate fuel consumption estimation model for arterial intersection operations in microscopic simulation
- Simulate fuel saving benefit for CACC vehicle operation along an arterial corridor with Active Traffic Signal Control (ATSC)
- Simulate fuel saving benefit for CACC vehicle operation in a traffic network with freeway corridor with ATM and arterial corridors with ATSC; and coordination of the two traffic control systems
- Future research will be subjected to the availability of funding

QUESTIONS?