U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Definition of Connected and Automated Vehicle (CAV) Concepts for Evaluation

STEVEN E. SHLADOVER

2017 AMR

JUNE 8, 2017

Argonne NATIONAL LABORATORY

INL Idaho National Laboratory

BERKELEY LAB

OAK RIDGE National Laboratory

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THIS PRESENTATION DOES NOT CONTAIN ANY PROPRIETARY, CONFIDENTIAL, OR OTHERWISE RESTRICTED INFORMATION

PROJECT OVERVIEW

Timeline

- Oct. 2016 – Sept. 2017
- 35% complete

Barriers Addressed

- Understanding CAV system capabilities
- Estimating energy impacts of CAVs over time

Budget

- $50 K, FY 17 only

Partners

- LBNL lead
- Contributions from other DOE SMART Mobility Labs: ANL, ORNL, NREL, INL

RELEVANCE/ OBJECTIVES

- To have common definitions so people working throughout DOE SMART Mobility can understand each other (talking about the same thing)
  - Avoid vague and misleading terminology
  - Avoid confusion and misunderstanding

- So analyses conducted by researchers in different Pillars and different labs can be compared “apples to apples”
  - Comparable assumptions about system functionalities
  - Comparable assumptions about deployment timing

- Define representative use cases to facilitate comparisons
  - Avoiding unnecessary duplications or overlaps

APPROACH

- Define dimensions of the CAV space
  - Connected vehicles (CV) without automation
  - Driving Automation System dimensions:
    - Connected vs. Unconnected (autonomous)
    - SAE Levels of Automation (driver vs. system roles)
    - Operational Design Domain (ODD)
  - Other attributes:
    - Vehicle class
    - Powertrain technology
    - Business models to govern operations
- Define example concept packages for study
- Estimate timing of market introduction and growth

TECHNICAL PROGRESS AS OF APRIL

- CAV Concept Dimensions defined and reviewed and updated with CAV Pillar partner lab inputs

- Example concept packages (use cases) defined and reviewed and updated with CAV Pillar partner lab inputs

CONNECTED VEHICLE (CV) SYSTEMS WITHOUT AUTOMATION

- Independent features, with limited coupling between them – can be analyzed individually:
  - V2V cooperative collision warnings
  - V2I/I2V cooperative intersection collision warnings
  - I2V speed advisories
  - V2V cooperative driving information
  - V2I/I2V route planning, parking information and reservations (eco-routing)
  - I2V local traffic signal phase and timing information (eco-signal control, signal priority requests)

DRIVING AUTOMATION SYSTEMS – KEY DIMENSIONS (CLOSELY COUPLED FOR IMPACT ESTIMATION)

- Connected or Unconnected (Cooperative vs. Autonomous)
- SAE Levels of Automation (http://standards.sae.org/j3016_201609/)
  - L0: No sustained automation, no change in driver role
  - L1: Driver Assistance (lateral OR longitudinal control)
  - L2: Partial Automation (lateral AND longitudinal control under continuous driver supervision)
  - L3: Conditional Automation (lateral AND longitudinal control plus object and event detection and response, driver fallback)
  - L4: High Automation (automation of all dynamic driving task functions, but limited to within an Operational Design Domain (ODD))
- Operational Design Domain

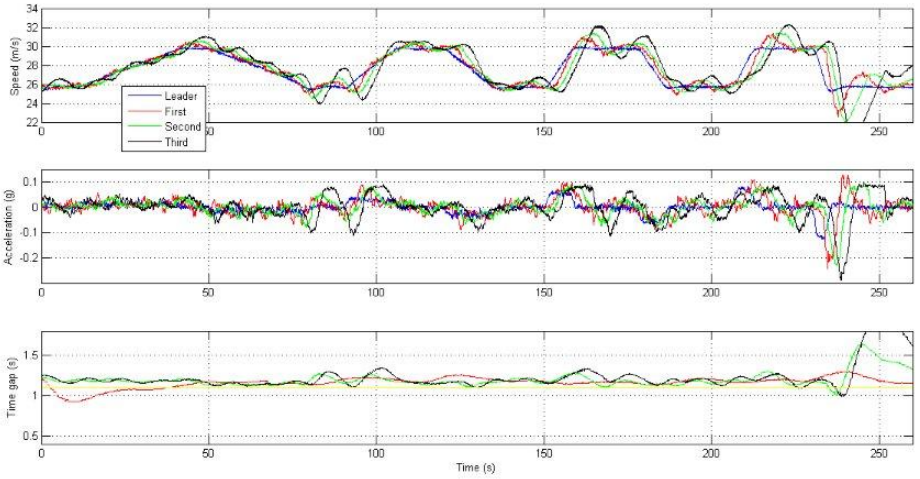
OPERATIONAL DESIGN DOMAIN (ODD)

The specific conditions under which a given driving automation system or feature thereof is designed to function, including:

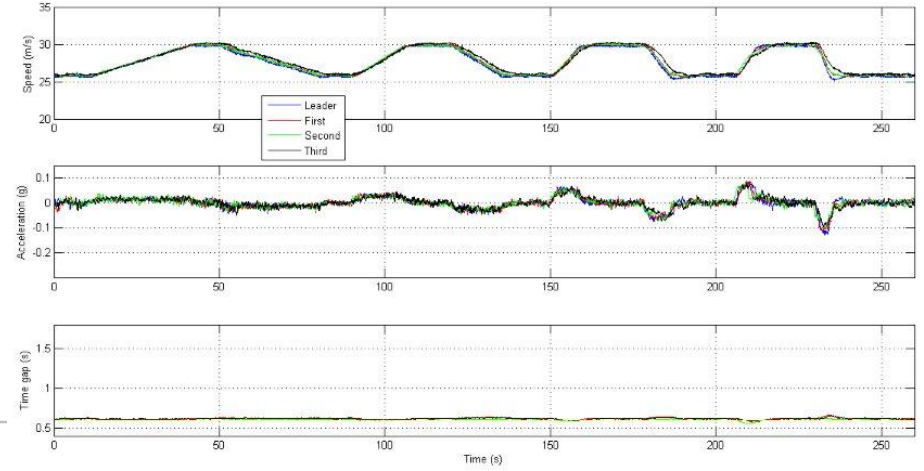
- Roadway type
- Traffic conditions and speed range
- Geographic location (within boundaries of digital map)
- Weather and lighting conditions
- Availability of necessary supporting infrastructure features
- Condition of pavement markings and signage
- Ability to cope with anomalies or foreign objects
- (and potentially more…)

EXAMPLE OF IMPORTANCE OF CONNECTIVITY TO PERFORMANCE

- Production autonomous ACC response (4 vehicles):



- Cooperative ACC (CACC) response to same disturbance:



VEHICLE CLASSES

- Passenger
  - –Ultralight (1-2 passengers)
  - –Light Duty (3-9 passenger capacity)
  - –Medium Duty (10-20 passengers)
  - –Heavy Duty (full-size buses)

- Freight
  - –Ultralight (few kilogram capacity)
  - –Light Duty (Class 1-3 trucks)
  - –Medium Duty (Class 4-6 trucks)
  - –Heavy Duty (Class 7-8 trucks)

POWERTRAIN TECHNOLOGIES

- Largely decoupled from the other dimensions for analysis:
  - –Gasoline
  - –Diesel
  - –Natural gas
  - –Hydrogen fuel cell
  - –Hybrid gasoline or diesel
  - –Plug-in hybrid
  - –Battery electric
  - –Externally-supplied electricity (catenary or inductive)

BUSINESS MODELS

- Private ownership and use
- Short-term rental / car-share (Zipcar, Getaround, Car2Go, etc.)
- Transportation network company (TNC = Uber, Lyft, conventional taxi, etc.)
- Public transit-like (fixed or semi-fixed route & timetable, possibly with first/last-mile capability)
- Private goods delivery
- Common carrier goods delivery

EXAMPLE CONCEPTS RECOMMENDED FOR STUDY (1/2)

- I2V cooperative eco-driving support (L0)
- Laterally guided bus on busway (L1)
- Highly automated bus on busway (L4)
- Semi-fixed route automated shuttle (L4)
- First-generation low-speed automated urban taxi (L4)
- Advanced automated taxi (L4)
- Basic truck platooning (L1)
- Advanced truck platooning (L1 leader, L3/L4 followers)

EXAMPLE CONCEPTS RECOMMENDED FOR STUDY (2/2)

- Low-speed urban goods distribution robot (L4)
- Cooperative ACC or platooning for passenger cars (L1)
- Urban eco-signal control with I2V signal information (L1)
- Urban freeway automated driving (L4)
- Intercity freeway automated driving (L4)
- Automated highway system (L4 in dedicated, segregated lanes)

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

- LBNL initially defines draft document on each topic
- Circulate draft among CAV Pillar lab representatives for comments and discuss in conference call
  - ANL (lead), ORNL, NREL, INL
- Update draft based on inputs received
- Circulate to other DOE SMART Mobility Pillar representatives for their review and use
  - Mobility Decision Science (LBNL lead)
  - Urban Science (NREL lead)
  - Multi-modal (ORNL lead)
  - Vehicles and Infrastructure (INL lead)

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

- New start – no previous year comments

REMAINING WORK: ESTIMATING TIMING OF AVAILABILITY

- Impacts depend on a sequence of actions, with significant time lags at each step:
  - Initial availability based on technical feasibility, safety
  - Rate of growth among new vehicle market
  - Potential for retrofits into existing vehicles
  - Turnover of full vehicle fleet
  - Actual utilization by drivers/travelers using equipped vehicles
- Historical data from prior vehicle technology changes provide initial guidance on lag times

NEXT STEPS (BALANCE OF FY17)

- Definition of estimates of timing for availability of **each** example concept, considering large uncertainties:
  - Study years 2030, 2040, 2050
  - Low, medium and high market penetration assumptions in each year for sensitivity studies
- Outreach to researchers in other pillars for their use in DOE SMART Mobility studies

SUMMARY

- Basic dimensions for characterizing connected and automated vehicle (CAV) systems have been defined
- Example use cases (or concepts) have been defined as a basis for evaluation studies
- Estimates of fast, medium and slow deployment profiles for each example concept are in process
- Outreach beyond CAV Pillar to other DOE SMART Mobility Pillars will follow, to seek consistency across studies

QUESTIONS?