Summary of Key Findings and Lessons Learned

• Data from existing field tests may not fulfill the need for traffic flow modelers
• Estimating impacts of AVs requires more accurate model of human drivers
• It is not likely that industry will use the AV algorithms developed by traffic modelers, but the insights of CAV on traffic flow may provide lessons for industry as they develop AVs
• Achieving traffic flow benefits at low market penetration rate is challenging but rewarding
Breakout Session # 14

**Recommended Action Items**

- Partnerships with government offer data collection opportunities
- Get involved in the design phase of field experiments and provide inputs from traffic flow modeling perspective
- Encourage funding allocation for common databases (data is expensive)
- Educate public on benefits of AV as traffic control actuators
- Improve the validity of baseline driver models
Welcome to Breakout #14

Enhancing the Validity of Traffic Flow Models with Emerging Data

Chair: Meng Wang, Xiaopeng (Shaw) Li, Samer Hamdar

Note-taker: Michael Levin

Contributors: Soyoung Ahn, Mark Brackstone, Danjue Chen, Steven Mattingly, Haizhong Wang, Alexander Skabardonis
TRB AHB45(3): Traffic Flow Modeling of Connected and Automated Vehicles

- Sub-committee of TRB standing committee AHB45
- Mission: to understand and predict the interactions between traffic flow characteristics and the future CAV control and sensing algorithms
- Interface with the vehicle/technology developers and industry partners
- 3 TRB workshops, 2 TRB CFP, 3 book chapters/AVS sessions, 3 sessions in Traffic and Granular Flow conference 2017
- Website: http://tftcav.seas.gwu.edu
- Chair: Samer Hamdar, George Washington University
About this session

• Goal

  • Better understand the fundamental characteristics of traffic flow with varying levels of automation and connectivity
  
  • Identify the research needs for developing models to assess real-world mobility (and environmental sustainability) implications of CAV

• Focus

  • Innovative traffic flow modelling techniques and simulation tools to quantify the mobility and environment impacts of CAV
  
  • Behavioural (lane change and car-following) differences and validation of existing and new CAV traffic flow models against empirical data.

• Output

  • Session presentations, research needs statements, discussion group notes, and a chapter of the symposium proceedings.
Agenda

• 1:30 PM – 1:45 PM: Welcome and Introduction
  • Meng Wang, Delft University of Technology, the Netherlands

• 1:45 PM – 3:50 PM: Panel Presentations
  • Rita Excell, Australia and New Zealand Driverless Vehicle Initiative, Australia
  • Dan Work, University of Illinois at Urbana Champaign (UIUC), US
  • Zhigang (David) Xu, Chang’an University, China
  • Steven Shladover, PATH Program, UC Berkeley, US
  • Jiaqi Ma, Leidos, Inc., US

• 3:50 PM – 4:00 PM Break

• 4:00 PM – 5:00 PM Panel discussion

• 5:00 PM – 5:30 PM Reporting and concluding
Introduction:
Relevance and Challenges

Meng Wang
Assistant Professor
Department of Transport & Planning
Delft University of Technology
Assessing traffic impact of CAV

- Media often overoptimistic about the benefits of AV
- Discrepancy in research findings
- Stakeholders need credible prediction
  - Policy makers: financial support, standardisation, regulation
  - Road operators: changes in traffic management
  - System developers: insights at traffic level
  - Users: personal interests (at microscopic level)

Tools for prediction: driver/driving/traffic flow models
Michon's driver model: used in classification of level of automation (SAE 2016)
From individual change to collective impact

- The magnitude of the impact depends on:
  - Functionalities of the system (e.g. level of automation)
  - User acceptance of the system
  - Parameter setting: desired speed, time gap, feedback gains

<table>
<thead>
<tr>
<th>Driving task level</th>
<th>Example individual behaviour</th>
<th>Possible traffic impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategic</td>
<td>Mode, route, departure time choices</td>
<td>Traffic distribution in network, congestion distribution</td>
</tr>
<tr>
<td>Manoeuvring</td>
<td>Lane, speed and gap choice, trajectory planning</td>
<td>Roadway capacity, emerge and evolution of congestion</td>
</tr>
<tr>
<td>Control</td>
<td>Steering, accelerating and braking</td>
<td>Dynamic characteristics: traffic stability, capacity drop, etc.</td>
</tr>
</tbody>
</table>
Automation v.s. Human

- faster reaction
- accurate control
- reliable performance over time
- understanding complex environment
- prediction of other participants
- limited line of sight (blocked by other vehicles), only react to direct neighbouring vehicles

- understanding of complex environment
- intention prediction of other participants
- observe and react to multiple vehicles
- delayed reaction
- inaccurate control
- behavioural adaptation, fatigue

We need models that can differentiate these features!
Intriguing questions for traffic flow modellers

• Are our models good enough in describing hierarchical manual driving behaviour?

• Are our models able to describe essential technological features of sensors and communication, and realistic vehicle dynamics?

• Are our models able to differentiate decision-making process between human, AV and CAV?
  
  • Lateral (lane choice, lane change decision and execution)
  
  • Longitudinal (car-following gap, reaction time, acceleration distribution)

• Do we understand the differences in the first place?
Data as the key

- Huge data needs from traffic modellers
- Increasing data due to worldwide effort in field tests of CAV
- Are the data available?
- Are the data usable?
- Can we design the data collection system and field tests with expertise of traffic flow involved?
Agenda

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• 5:00 PM – 5:30 PM Reporting and concluding
Recent Findings from Micro-Simulation of Traffic Impacts of Cooperative Longitudinal Control Systems

Steven E. Shladover, Sc.D., Xiao-Yun Lu, Ph.D., Hao Liu, Ph.D., Hani Ramezani, Ph.D., Dali Wei, Ph.D., David Kan, Fang-Chieh Chou
California PATH Program
University of California, Berkeley
July 11, 2017
Overview

- Traffic micro-simulation modeling
  - Manual driving behavior models
  - CACC and ACC vehicle following models based on full-scale vehicle test results
  - Simplified network for performance assessment
- CACC performance based on simulation results
  - Simplified corridor for trade-off studies
  - Complex real-world corridor case studies
Using CACC to Form High-Performance Vehicle Streams (FHWA EARP Project)

- Detailed micro-simulations to represent interactions with manually driven vehicles, including lane changing
- Baseline manual driving models – NGSIM Oversaturated Flow model (Berkeley) and MOTUS (TU Delft)
  - Extensive enhancements to both models to represent detailed vehicle-vehicle interactions accurately
  - NGSIM implementation in Aimsun, with SDK modules added
- ACC and CACC car following models derived from PATH-Nissan experiments on full-scale test vehicles
- Additional higher-level CACC maneuvering models
- Assessments of management strategies
Manual Driving Model (expanded from NGSIM oversaturated flow model as starting point)

- At each update interval, the driving mode is determined for each vehicle, and the speed, position and travel lane are updated based on the mode:
  - **CF**: Regular car following mode
  - **LC**: Lane change mode
  - **ACF**: After lane changing car following mode
  - **BCF**: Before lane changing car following mode
  - **RCF**: Receiving car following mode
  - **YCF**: Yielding (cooperative) car following mode
Manual Driving Model Structure

Start

Need LC? No

Accept gap? Yes

Need YCF? No

Need RCF? Yes

RCF

No

Yes

Need ACF? Yes

ACF

YCF

BCF

LC

Yes

No
Manual Driving Model Calibration on CA SR-99 Corridor (Sacramento)

- Length: 13 miles
- Morning peak: 6-9 AM
- 16 on-ramps
- 11 off-ramps
- Recurrent delay is mainly caused by high on-ramp demand
- On-ramps are metered

The 5-minute interval vehicle count and speed data observed at reliable detectors are used as the benchmark data.
Manual Driving Model Calibration on CA SR-99 Corridor (Sacramento)

Geometry change: 3 lanes → 4 lanes

Major bottleneck with a busy on-ramp and a weaving area

Weaving bottleneck: more than half vehicles take the interchange to Highway 50, while there is heavy merging traffic from the upstream on-ramp

HOV lane and ramp metering activated during the morning peak

Major upstream bottleneck: two close busy on-ramps for a 3-lane freeway segment

Modeling the complicated network in Aimsun
Manual Driving Model Calibration on CA SR-99 Corridor (Sacramento)

To get good GEH result, we must accurately model:

- Intensity and duration of the traffic congestion
- Congestion due to merging, diverging and weaving traffic
- Peak and non-peak traffic

\[
GEH(k) = \sqrt{\frac{2[M(k) - C(k)]^2}{M(k) + C(k)}},
\]

- \(k\): ID of the 5-min time interval
- \(M\): simulated flow
- \(C\): observed flow

### Freeway: 5-min flows of SR-99 Northbound

<table>
<thead>
<tr>
<th>Detector Location (post-mile)</th>
<th>Target</th>
<th>Cases</th>
<th>Cases Met</th>
<th>% Met</th>
<th>Target Met?</th>
</tr>
</thead>
<tbody>
<tr>
<td>287.3</td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
<td>930</td>
<td>930</td>
<td>100.0%</td>
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<tr>
<td>287.6</td>
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<td>289.3</td>
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<td>917</td>
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<td>930</td>
<td>917</td>
<td>98.6%</td>
<td>Yes</td>
</tr>
<tr>
<td>290.7</td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
<td>930</td>
<td>908</td>
<td>97.6%</td>
<td>Yes</td>
</tr>
<tr>
<td>291.5</td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
<td>930</td>
<td>877</td>
<td>94.3%</td>
<td>Yes</td>
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<td>291.9</td>
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<td>930</td>
<td>854</td>
<td>91.8%</td>
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<td>873</td>
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<tr>
<td>292.8</td>
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<td>873</td>
<td>93.9%</td>
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</tr>
<tr>
<td>294.0</td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
<td>930</td>
<td>871</td>
<td>93.7%</td>
<td>Yes</td>
</tr>
<tr>
<td>294.7</td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
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<td>890</td>
<td>95.7%</td>
<td>Yes</td>
</tr>
<tr>
<td>295.3</td>
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<td>891</td>
<td>95.8%</td>
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</tr>
<tr>
<td>296.0</td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
<td>930</td>
<td>834</td>
<td>89.7%</td>
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<tr>
<td><strong>Overall</strong></td>
<td>GEH &lt; 5 for &gt; 85% of (k)</td>
<td>13020</td>
<td>12461</td>
<td>95.7%</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Manual Driving Model Calibration on CA SR-99 Corridor (Sacramento)
Manual Driving Model Calibration on CA SR-99 Corridor (Sacramento)

• Comparison of fundamental diagrams of simulated and field observed flow-density relationships

• Two sample replications at Station 292.8
Animation of Base Case (Manual Driving)

8400 vehicles/hour on mainline approach + 1200 vehicles/hour from onramp (Example for oversaturated condition)
CACC and ACC Car-Following Models

- Data collected using programmed speed change profiles on first car, with three followers tracking it
- Simple models representing car following dynamics derived from test data using Matlab System Identification toolbox
- Model predictions of responses compared with test data to verify accuracy
Adaptive Cruise Control with and without V2V Cooperation (AACC and CACC)

Autonomous (no communication) at minimum gap of 1.1 s

Cooperative (V2V communication) at minimum gap of 0.6 s
Comparison of Performance

Autonomous (no communication)

Cooperative (V2V communication)
ACC Model

- **Time gap distribution** (from field test)
  - 1.1 sec 50%
  - 1.6 sec 20%
  - 2.2 sec 30%

- **Speed regulation**
  \[ a_k = 0.4(v_{k-1} - v_k) \]

- **Gap regulation**
  \[ a_k = 0.23(g_k - t_h v_k) + 0.07(v_{k-1} - v_k) \]
CACC Model Overview

- Desired time gap (DTG, sec)
- Number of vehicles in the preceding string (Np)
- Time gap (TG, sec)
- Desired speed (DSPD)
- Speed (SPD)

*The speed is always upper bounded by driver desired speed no matter what state vehicle is in.*
CACC Model – Form and Parameter Values

• Speed regulation
  \[ a_k = 0.4(v_{k-1} - v_k) \]

• Gap regulation
  \[ v_{cmd} = v_t + 0.45e_t + 0.0125\dot{e}_t \]
  \[ e_t = g_t - t_h v_t \]

  \( g_t \): preceding gap (m)
  \( t_h \): driver desired time gap (sec)
  \( v_t \): subject vehicle speed (m/s)
  \( v_{cmd} \): subject vehicle speed command (m/s^2)

Time gap distribution from field test

- 0.6 sec  50%
- 0.7 sec  25%
- 0.9 sec  10%
- 1.1 sec  15%
AACC Model Predictions and Test Results

**Speeds**
(Test above, model below)

**Accelerations**
(Test above, model below)
CACC Model Predictions and Test Results

**Speeds**
(Test above, model below)

**Accelerations**
(Test above, model below)
Additional Collision Avoidance Logic

• **CAMP forward collision warning algorithm**

  1. Compute $d_{REQ}$
  2. $d_{REQ} > 0$?
     - Yes: No warning, continue CACC mode
     - No:
       - Assuming the subject vehicle adopts $d_{REQ}$ and the preceding vehicle keeps the current acceleration, compute the minimum clearance-gap required for the subject vehicle to avoid the rear-end collision.
  3. Current gap < minimum gap?
     - Yes: Trigger alarm, switch to manual driven mode
     - No:

$d_{REQ}$: acceleration required for the subject driver to avoid the rear-end collision
Simple Highway Network Layout for Assessing Key Performance Trends and Trade-Offs

- Four-lane mainline highway, traffic generated further upstream
- One-lane on-ramp, volume ranging from 300 to 1200 veh/hr
- One-lane off-ramp, volume ranging from 5% to 20% of mainline
- On-ramp and off-ramp are 1.5 km apart
- Simulate far enough upstream and downstream to stabilize results
Aspects of Performance Tested in Simulation

• Maximum downstream throughput achievable under various conditions
• Travel times and delays traversing the test section
• Effects of variations in:
  – ACC, CACC market penetration
  – On-ramp and off-ramp traffic volumes
  – Maximum allowable CACC string length
  – Minimum gap between CACC strings
  – Priority use of left-side managed lane
  – Availability of automated merge/lane change coordination
Simulation Results with CACC Operations

- Freeway capacity increases because of CACC string operation
  - Small probability of forming CACC strings under low CACC market penetration
  - CACC strings are often interrupted by lane change maneuvers in the traffic stream and interactions with heterogeneous traffic
- Traffic management strategies are needed to help create CACC strings and maintain their operation
Simulation Results – Traffic Management

- Traffic management strategies considered:
  - Discretionary lane change (DLC) restriction for CACC vehicles when they are in the CACC string—reducing disturbances from lane changes
  - CACC managed lanes (ML)—reducing interactions of CACC vehicles and manually driven vehicles and increasing concentration of CACC vehicles together
  - Equipping manually driven vehicles with Vehicle Awareness Devices (VAD)—creating more CACC strings under low CACC market penetration
Lane Capacity Increases for Different CACC Strategies

- Quadratic increase of capacity as the CACC market penetration increases
- The ML strategy works best under the following conditions:
  - 40% CACC with 1 ML,
  - 60% CACC with 2 MLs,
  - 80% CACC with 3 MLs
- Different strategies are best under different CACC market penetrations
Throughput Limitations as On-Ramp Volume Grows

- Downstream throughput reduces as on-ramp traffic increases.
- It maintains quadratic trend with CACC market penetration.

**Throughput of the merging area**

The throughput is measured downstream from the merging area and averaged by lane.

**Ramp traffic in veh/hr/lane**
Mainline traffic volume equals the base case pipeline capacity shown in the previous slide.
Effects of Management Strategies on Throughput at Merging Section

Throughput of the merging section with 40% CACC

- ML and VAD strategies can increase the throughput of the on-ramp merging area
  - ML redistributes traffic load across lanes—creating more gaps in the general purpose lane
  - VAD increases the queue discharging flow by enabling more CACC usage
- DLC restriction strategy has little effect because it does not change lane change behaviors of the merging traffic

Mainline upstream input: 9600 veh/h
Higher Exiting Traffic Impacts on Throughput

- The exit area can become a major bottleneck at high CACC% cases when the off-ramp volume is high.
- The percentage of exiting traffic volume is high.
- The percentage of exiting traffic can serve without breakdown decreases with the CACC market penetration.
- 100% CACC: <10% exiting traffic; 80% CACC: <20% exiting traffic; 60% CACC or less: <25% exiting traffic.
Adverse Effects of Autonomous ACC (without V2V cooperation)

For various on-ramp volumes

For various off-ramp volumes
Simulation Animations

40% CACC

40% CACC with ML

In both cases: mainline input—9600 veh/h, on-ramp input—1200 veh/h
CACC Simulation Results for SR-99 Corridor

- No significant change of VMT—same demand inputs and OD matrix for all scenarios.
- Significant improvement of VTT and space mean speed—traffic flow condition greatly improved with CACC market penetration.
- Critical CACC market penetration between 20% and 40% — significant improvement occurs at the critical market penetration.
CACC Simulation Results for SR-99 Corridor

- Data points were collected at 5 minute intervals
- The most significant improvement of VTT and space mean speed happens during the peak hours
Speed contour plots show the same improvement pattern.

At 40% CACC, the most severe bottleneck near post-mile 292 is completely removed.

It starts as a local bottleneck around 6:00am and is intensified by the shockwave from downstream bottlenecks.

As CACC improves individual bottlenecks, it also has systematic influence along the corridor.
Modeling a Congested Freeway Corridor with Heavy Truck CACC Traffic (I-710)

- 16 miles of I-710 NB, coded in Aimsun plus additional features in SDK
- 21 off ramps & 20 on ramps
- Truck vehicle following models derived from truck experiment results
Truck Corridor Performance as a Function of CACC Market Penetration

**VMT**

<table>
<thead>
<tr>
<th>Penetration rate</th>
<th>Trucks</th>
<th>Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>2.3%</td>
<td>0.24%</td>
</tr>
<tr>
<td>20%</td>
<td>8.0%</td>
<td>0.09%</td>
</tr>
<tr>
<td>40%</td>
<td>11.7%</td>
<td>0.04%</td>
</tr>
<tr>
<td>60%</td>
<td>15.4%</td>
<td>0.19%</td>
</tr>
<tr>
<td>80%</td>
<td>20.4%</td>
<td>0.44%</td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Avg speed (VMT/VTT) mph**

<table>
<thead>
<tr>
<th>Penetration rate</th>
<th>Trucks</th>
<th>Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>4.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td>20%</td>
<td>7.3%</td>
<td>0.8%</td>
</tr>
<tr>
<td>40%</td>
<td>10.9%</td>
<td>1.6%</td>
</tr>
<tr>
<td>60%</td>
<td>16.3%</td>
<td>2.3%</td>
</tr>
<tr>
<td>80%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Avg Truck Travel Time**

<table>
<thead>
<tr>
<th>Penetration rate</th>
<th>Trucks</th>
</tr>
</thead>
<tbody>
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<td>0%</td>
<td>2.3%</td>
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<tr>
<td>20%</td>
<td>4.0%</td>
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<td>40%</td>
<td>6.3%</td>
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<tr>
<td>80%</td>
<td>14.0%</td>
</tr>
<tr>
<td>100%</td>
<td></td>
</tr>
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</table>
Concluding Comments

- Much to learn from full-scale testing of CACC vehicles combined with detailed simulations of traffic impacts
  - Complementary methods for handling different effects
  - Simulation models must be developed and used very carefully to produce realistic results
- Effects are subtle and require careful study
- V2V coordination is key to achieving traffic and energy saving benefits
Connected and Automated Vehicular Flows: Modeling Framework and Data Availability

Jiaqi Ma, Ph.D.
Research Scientist / Project Manager
Leidos, Inc
Outline

• CAV Introduction
• Analysis, Modeling and Simulation
• Field Experiment and Data Collection
  – Field Experiments
  – Hardware-in-the-loop Testing
• Questions and Answers
Background and Understanding I

• CAV systems are likely to be major game changers in traffic and mobility.

• When, in what form, at what rate, and through what kind of evolitional path.

• Agencies at a loss for how to approach the problem, and how to go about planning and designing for new operational regimes in which vehicles are connected to each other and to the infrastructure, and augmented with automated capabilities.

• Present modeling and simulation tools not adequate to capture either demand or supply-side implications for the transportation system.

• *At the root of these impacts are the flow and operational aspects* of CAV vehicles, especially as these become part of the traffic mix served by our transportation infrastructure.

• These aspects are determined by human decisions, as drivers, owners, users of connected/autonomous vehicles.
Background and Understanding II

- Broader planning considerations:
  - Demand side: impact of CAV on individual and household activity patterns
  - Supply side: emergence and growing role for shared mobility fleets, though private ownership not likely to go away.

- Future deployment likely to see slow penetration of connectivity in certain parts of the network, and initial automated vehicle fleets, in selected environments: Need to model CAV capabilities in mixed traffic flows, with both human drivers and robotic ones.
Current Major FHWA Effort

• “Development of an Analysis/Modeling/Simulation (AMS) Framework for V2I and CV Environment”

• The objective of this task order is two-fold:
  1. Lay foundational framework for development of AMS tool capability that includes connected and automated vehicles, and
  2. Engage in small scale V2I AMS development, using this framework, that encourages future development activities, toward a vision where practitioners have CAV-aware tools available.

• The project sets the context for developing the AMS tool framework by introducing a broader methodological framework for evaluating the changes entailed by CAV technology to:
  1. Supply of mobility services
  2. Demand and behavioral changes
  3. Network/facility operational performance
CAV AMS Framework

Potentially major changes in
- Travel and activity behaviors
- Supply side, e.g. new mobility options

Strategic Level Planning Framework with CAV

Source: Mahmassani, et al, 2017
Are Tools Adequate?

- Existing state-of-the-art tools could address *incremental scenario*.
- Flow modeling aspects require additional calibration as technology prototypes appear; interaction between driverless and other vehicles biggest challenge, but traffic modeling community is rising to the task.
- More *uncertainty on behavior side*, though incremental scenarios could be explored under selected assumptions.
- Telecommunications aspects of V2V and V2I missing from existing traffic models.
Gap Analysis II

Are Tools Adequate?

- New mobility supply options under *Less Incremental Scenario II* are not within scope of any existing models.
- There are no models in planning practice that can predict emergence of new modes and forms of mobility.
- Typically provided exogenously to the models, in the form of scenarios to be analyzed.
- Existing models (ABM and supply-side) not up to the task of modeling full implications of these new mobility supply scenarios.
Next Phases

• Use existing datasets or design experiment to collect more data for model calibration
• Select 3 – 5 sites for modeling deployment and testing (of selected CAV applications)
• Develop CAV AMS toolbox
• Work with agencies to conduct case studies, focusing on early deployment opportunities
  – Cooperative Adaptive Cruise Control
  – Intersection Approach and Departure
  – Speed Harmonization
“AV-ready” transport models and road infrastructure for the coexistence of automated and conventional vehicles

Contact: Siegfried Rupprecht, Rupprecht Consult
CoEXist Concept

Facilitate the step-wise introduction of AVs

**Impacts**
- Demonstration of innovative modelling
- Design and engineering of road infrastructure
- Road users’ appreciation
- Concern for safety performance (addressed in all phases)

**Phase 1**
- Elaborate AV-ready framework
- Define use cases & scenarios for AV-ready hybrid infrastructure
- Agree on international cooperation with US

**AV-ready framework (WP 1)**

**Phase 2**
- AV-ready transport models (WP 2)
  - Develop model-based AV default values based on input from AV manufacturer
  - Extend micro- and macroscopic modelling tools
  - Validate models on public test track with AVs
  - Produce Implementers Guide for AV-ready models
- AV-ready infrastructure (WP 3)
  - Develop hybrid road infrastructure assessment tool
  - Produce Design Guide for hybrid road infrastructure

**Phase 3**
- AV-ready road authorities (WP 4)
  - Apply modelling and impact assessment tools on use cases
  - Develop AV-ready road infrastructure action plans
  - Hold AV-ready Stakeholder Forum
- Take-up, exploitation and dissemination of CoEXist results (WP 5)
  - Transport consultant training
  - AV-ready final conference

**Phase 4**
- Guide “How to become an AV-ready road authority”
Work Package 2: CAV-ready microscopic and macroscopic traffic modelling tools

- **Objectives**
  - To develop and validate **modelling tools that enable the transition** towards CAV-ready transport planning
  - To establish a **real-time and realistic connection** between the CAV-control logics, the CAV-simulator and the microscopic modelling tool
  - To develop a **set of model-based default values for CAVs applications**, including passenger car and light-freight vehicles
  - To **collect data of two CAVs** on the **public test site for validation** of microscopic modelling tool
  - To extend **micro- and macroscopic modelling tools to enable analysis of CAV/Conventional Vehicle-coexistence** on the same network
WP2
CoEXist – AMS tools – Vissim and PreScan
Work Package 3: CAV-ready hybrid road infrastructure impact assessment tool and design recommendations

- Objectives
  - To develop an **CAV-ready hybrid road infrastructure impact assessment tool** that utilises CAV-ready traffic models (WP2) and enables the transition towards CAV-ready road transport and infrastructure planning
  - To develop an impact assessment tool that **enables road authorities to measure, assess and compare the impact of different CAV-scenarios** (i.e. CAV penetration rates, automation levels, and levels of connectivity)
  - To adapt and develop **impact assessment metrics for traffic performance, infrastructure space efficiency** and **road safety** for the CAV context
  - To **draft CAV-ready hybrid road infrastructure design** recommendations based on eight use cases (WP4) in four European cities
Work Package 4: Demonstration of CoEXist tools in road authorities

- **Objectives**
  - To demonstrate how road authorities can conduct AV-ready transport and infrastructure planning
  - To apply CoEXist modelling and assessment tools in partner road authorities to analyse the local AV impact
  - To develop concrete AV-ready actions plans in close cooperation with key stakeholders from road authorities
  - To support introduction (funded outside CoEXist) of “AV-ready hybrid road infrastructure” in partner road authorities through AV-ready hybrid infrastructure action plans
Data Efforts at Saxton Lab

• Saxton lab introduction
  – Capabilities

• Data collection and field experiments
  – Eco-drive on rolling terrains
  – CACC
  – Lane change/merge
  – Eco approach and departure
Connected Automated Vehicles

- Proof of Concept Vehicles
- Research Fleet Communications
  - 5.9GHz DSRC
  - Cellular/LTE
  - Corrected GPS
- On-board Technology
  - Connected Vehicle Data Collection and Processing
  - Radar and Ultra-Sonic Sensors
  - Front and rear-facing cameras
Vehicle Control Systems

Data Flow of the Vehicle Control Systems
Data Collection Device
Connected Infrastructure

- CCTV
- DSRC
- Signalized intersection with SPaT / MAP
- Fixed time or actuated traffic signal control with pedestrian / bike displays
- Dedicated Ethernet & Wi-Fi communications
- Cabinet space with power & comms, available for future research
- Cadillac SRX with OBU, GPS, CAN bus integration
- Vehicle Pedestrian & Bike Detection
IAA with US Army
Aberdeen Test and Evaluation Command
Eco-Drive on Rolling Terrains
This vehicle controller optimizes fuel consumption by giving speed and powertrain commends to CAVs.
### Field Test Results

#### WESTBOUND WRENCH EFFORT, PID=10,0.01,0.1, PROFILE A10S45I1

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<tr>
<th>Filename</th>
<th>Total (l)</th>
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<th>Min (ml/min)</th>
<th>Average (ml/min)</th>
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<th>Savings</th>
<th>Run Time (s)</th>
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<tr>
<td>exp1_028*</td>
<td>0.193</td>
<td>200.7</td>
<td>14.09</td>
<td>59.8</td>
<td>0.160</td>
<td>21.2%</td>
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<td>68.7</td>
<td>0.175</td>
<td>13.8%</td>
<td>163.6</td>
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*Braking eliminated from this run*

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<td>0.211</td>
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<td>0.175</td>
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<td>exp1_032</td>
<td>0.214</td>
<td>222.0</td>
<td>2.115</td>
<td>66.3</td>
<td>0.177</td>
<td>12.8%</td>
<td>162.7</td>
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#### WESTBOUND WRENCH EFFORT, PID=10,0.01,0.1, PROFILE A10S45

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<th>Max (ml/min)</th>
<th>Min (ml/min)</th>
<th>Average (ml/min)</th>
<th>Total (cut) (l)</th>
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<th>Run Time (s)</th>
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<td>exp1_036</td>
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<td>225.4</td>
<td>1.988</td>
<td>66.9</td>
<td>0.177</td>
<td>12.8%</td>
<td>162.5</td>
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<tr>
<td>exp1_037</td>
<td>0.217</td>
<td>225.4</td>
<td>1.296</td>
<td>67.3</td>
<td>0.180</td>
<td>11.3%</td>
<td>162.6</td>
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</table>

Road segment surrounding stoplight was cut from all datasets
More Data: Fuel Consumption

Georgetown Pike Fuel Consumption (2017-02-22)

Georgetown Pike CAN Bus Fuel Consumption (2017-02-22)
More Data: Acceleration

Georgetown Pike Vehicle Acceleration (2017-02-22)

Georgetown Pike Brake Percentage (2017-02-22)
More Data: Vehicle Status

Georgetown Pike CACC Status (2017-02-22)

Georgetown Pike Brake Status (2017-02-22)
Speed Harmonization
Spotlight on Speed Harmonization

Real-Time Traffic Conditions

Real-Time Application Processing

Real-Time Speed Control

Smother Traffic Flows with Controlled Speed Harmonization
Field Experiment
Experiment Set-up

Small Connected-Automated Vehicle Experiment
- Inputs from:
  - Upstream and Downstream
- Control Vehicles (Central Control)
- Probe Vehicles (Sensor)

The experiment is performed on I-66 using:
1) Three vehicles, equipped with I2V, to control the traffic speed
2) A lead probe vehicle placed in the traffic flow approximately 100 meters ahead of the control vehicles
3) Two probe vehicles approximately 50 meters behind the control vehicles
Results

Experimental Measurements

Detrended Measurements
Results

Leading Probe

Following Probe

Time Domain

Low-Pass Filter

Frequency Domain
Cooperative Adaptive Cruise Control (CACC) + Cooperative Lane Change/Merge
Cooperative Adaptive Cruise Control (CACC) Evolution

Three different types of cruise control

Current Market Penetration

Standard Cruise Control
Throttle

Adaptive Cruise Control
Throttle Radar

Future of Cruise Control
Cooperative Adaptive Cruise Control
Throttle Radar Communication
CACC Physical Performance Testing

- Saxton Lab fleet
  - 5 vehicle platoon, all same make and model
  - Testing under various operating conditions
  - Improving algorithms

- Crash Avoidance Metrics Partnership (CAMP)
  - 4 vehicle platoon
  - Each a different make and model
  - First step – hardware in the loop simulation
Experiment
Data

Merging Vehicle Gap Error over Time.

Following Vehicle Gap Error over Time
Data

Speed over Time

Acceleration over Time
Eco Approach and Departure at Signalized Intersections
Eco-Approach and Departure at Signalized Intersections

Application Overview

• Collects signal phase and timing (SPaT) messages and MAP messages using vehicle-to-infrastructure (V2I) communications

  ▪ Receives V2I and V2V (future) messages, the application performs calculations to determine the vehicle’s optimal speed to pass the next traffic signal on a green light or to decelerate to a stop in the most eco-friendly manner

  ▪ Provides speed recommendations to the driver using a human-machine interface or sent directly to the vehicle’s longitudinal control system to support partial automation
Eco-Approach and Departure at Signalized Intersections
GlidePath Prototype Application
Preliminary Results

Table 1. Example driver’s fuel consumption (g/mi) for different entry time (speed 20 mph)

<table>
<thead>
<tr>
<th>Phase</th>
<th>Green</th>
<th>Red</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s)</td>
<td>2</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>Stage 2 vs. Stage 1 (DVI vs. Uninformed Driver)</td>
<td>-11.80</td>
<td>-11.75</td>
<td>7.59</td>
</tr>
<tr>
<td>Stage 3 vs. Stage 1 (Automated vs. Uninformed Driver)</td>
<td>4.67</td>
<td>7.55</td>
<td>35.25</td>
</tr>
<tr>
<td>Stage 3 vs. Stage 2 (Automated vs. DVI)</td>
<td>14.73</td>
<td>17.27</td>
<td>29.93</td>
</tr>
</tbody>
</table>

- Four different drivers were part of the experimentation, each conducting Stage I, II, and III at two different speeds (20 mph and 25 mph)
- General Results thus far:
  - DVI (Stage II) improved fuel economy over uninformed driving (Stage I) by only 5% on average, with a wide range of responses (18% standard deviation)
  - Some drivers with the DVI (Stage II) performed worse than uninformed driving (Stage I)
  - Automation (Stage III) improved fuel economy over uninformed driving (Stage I) by 20% on average, within a narrow range of responses (6% standard deviation)
Hardware-in-the-Loop Testing
HIL System Architecture
HIL System Components

• Hardware testing environment
  – DSRC equipment: Roadside unit (RSU) and On-Board unit (OBU)
  – Real Vehicle: could be connected vehicle and/or automated vehicle
  – V2I Hub: a message hub for DSRC messages and an interface between actual and simulated environment
  – Traffic signal controller: NTCIP compatible

• Software testing environment:
  – A traffic simulator: VISSIM
  – A windows PC
  – CAV Applications: implemented in traffic simulator
• Initial Results shows significant improvement (16% on average) over Adaptive Cruise Control
Concluding Remarks

• Need a set of new tools for CAV development
• Need data to calibrate key model components
• More CAV deployments generating valuable datasets
• Keep tuned
  – FHWA CAV AMS
  – EU CoExist
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  http://jiaqima.wixsite.com/jiaqi