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Enabled Analysis, Modeling, and Simulation (AMS) for Cooperative Automated Vehicle (CAV) Applications

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Project Objectives

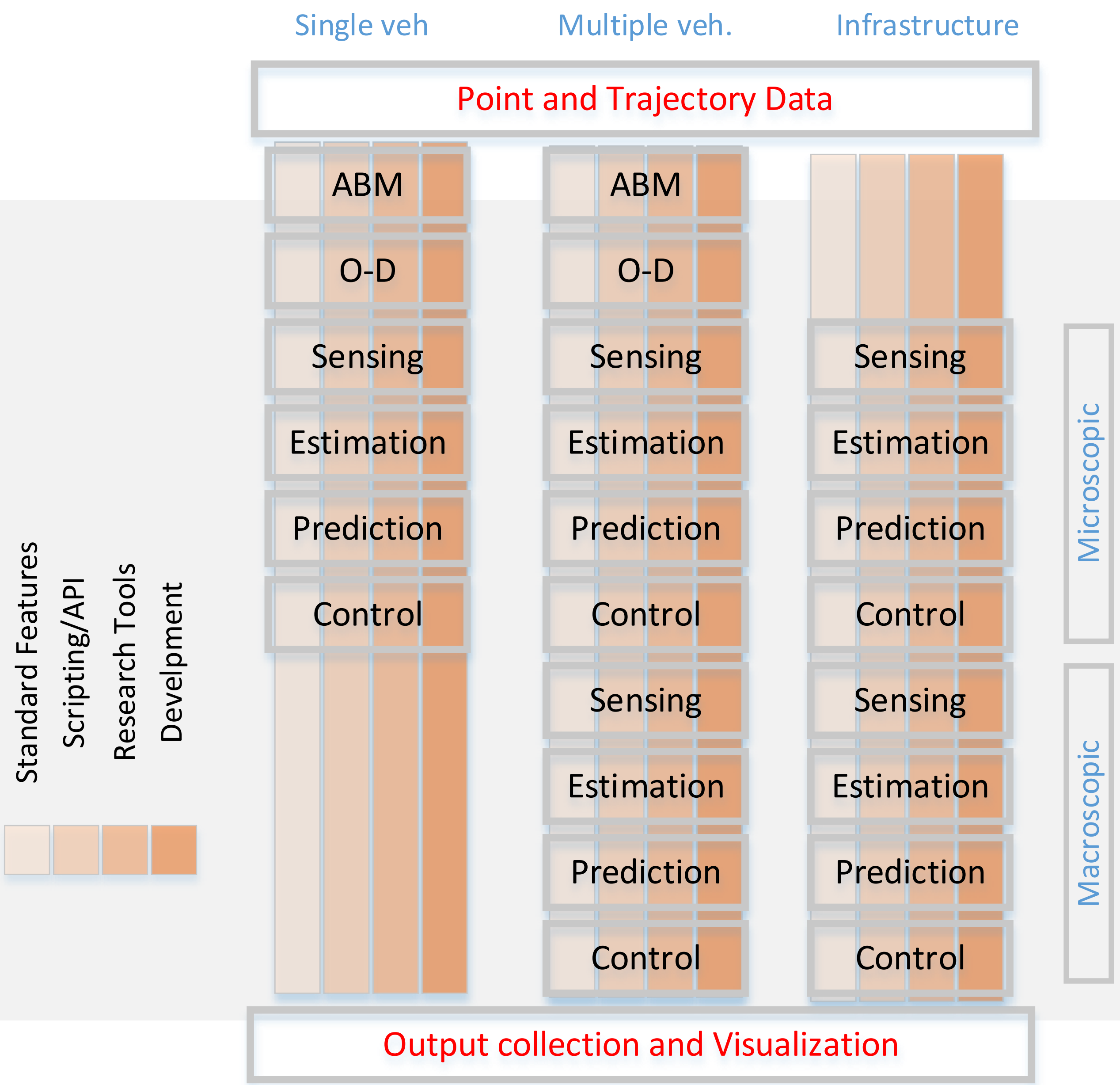
- Provide information on how to enable Analysis, Modeling, and Simulation (AMS) tools to evaluate Connected and Automated Vehicle (CAV) applications to:
  - Allow transportation professionals using AMS to assess the safety, mobility, and environmental and energy benefits of CAVs.
  - Assist transportation agencies in the safe deployment and operation of CAVs.
  - Support agencies in making informed decisions for infrastructure investments.

Framework Information

- Information for enabling CAV AMS applications:
  - Clearly define scope and research questions before embarking on the analysis.
  - Consider all transportation system components relevant to CAVs before defining project tasks.
  - Consider in-house capability and understand/commit to the necessary level of effort.

Pillar Diagram

- Intended to facilitate brain-storming process.
- Three pillars (components), two analysis levels, four development efforts.



ABM – Activity Based Models
O-D – Original Destination

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Analysis Steps

1. List the questions that need to be answered.
2. Identify where the needs are in the pillar diagram, considering the available AMS tool(s).
3. Determine the required extra steps/tasks to enable the AMS tool to conduct the analysis.
4. Brainstorm and iterate steps (1) to (3) until a consensus is reached on conducting the analysis, considering the technical capabilities of the agency and available resources.
5. Complete the enabling tasks.
6. Perform the analysis.
7. Answer the questions identified in step (1).
8. Provide information on the safe deployment and operation of CAVs.
9. Make informed decisions for infrastructure investments based on these results.

Case Study: Eco-Drive with Transit Signal Priority (TSP)

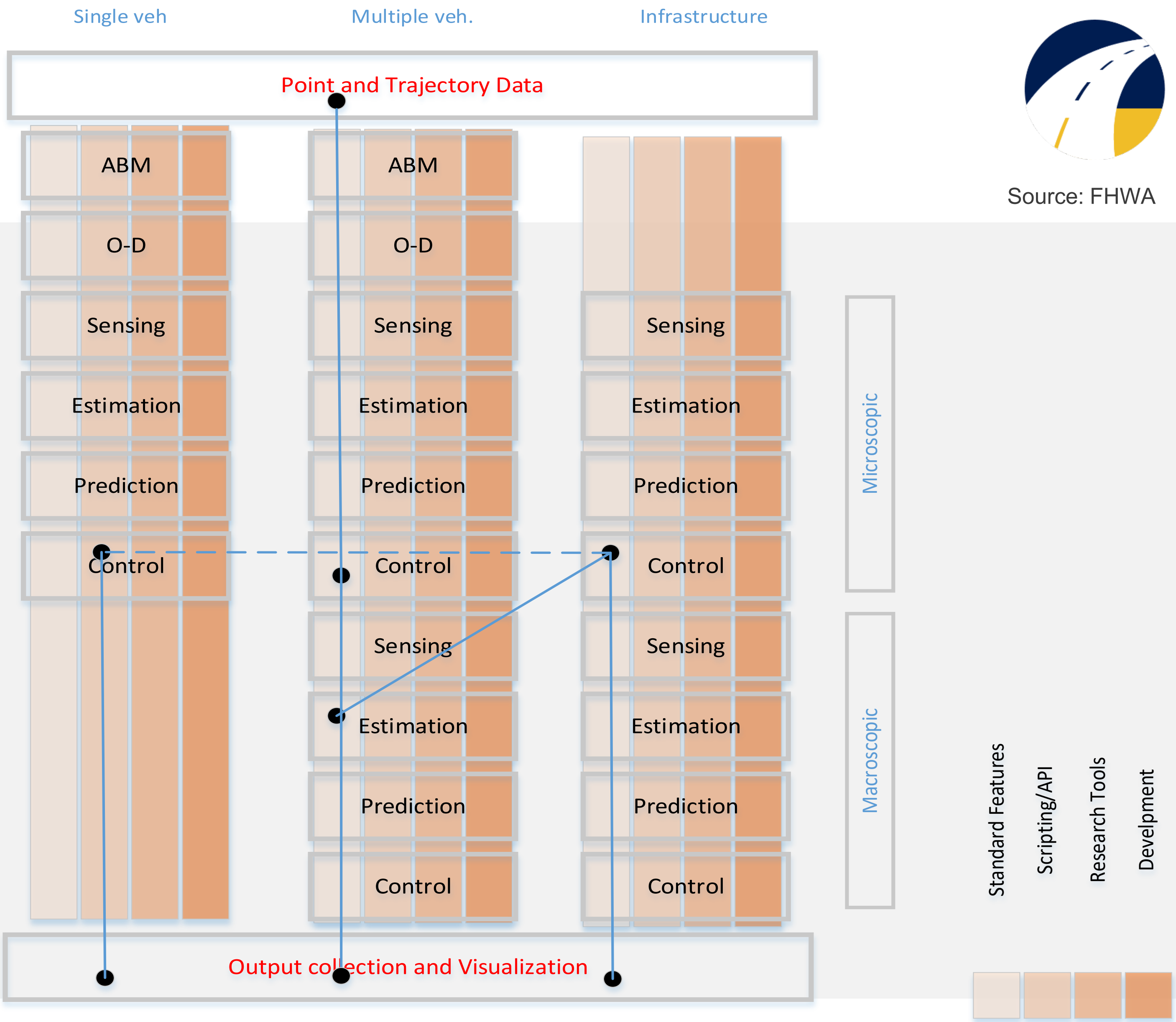
- Scope:
  - Impact of CAV operation with smart TSP application (TSP, vehicle-to-infrastructure, vehicle-to-vehicle, autonomous vehicles, equipped buses).
- Questions:
  - What is the impact of CAV eco-driving operation with TSP strategies at the signalized intersection?
  - What is the impact of CAV penetration rate on the overall system delay?
  - What is the impact of the application on bus bunching?

Case Study (continued)

- Simulation requirements:
  - CAV eco-driving operation.
  - CAV interaction with mixed traffic (blocking, slowing down).
  - CAV vehicle-to-infrastructure operation/communication.
  - Transit priority algorithms at signalized intersections.

Connect Elements

- Connect modeling elements in the AMS tool.
- Solid lines mean the AMS tool provides this link.
- Dashed lines mean the link is possible via scripting.



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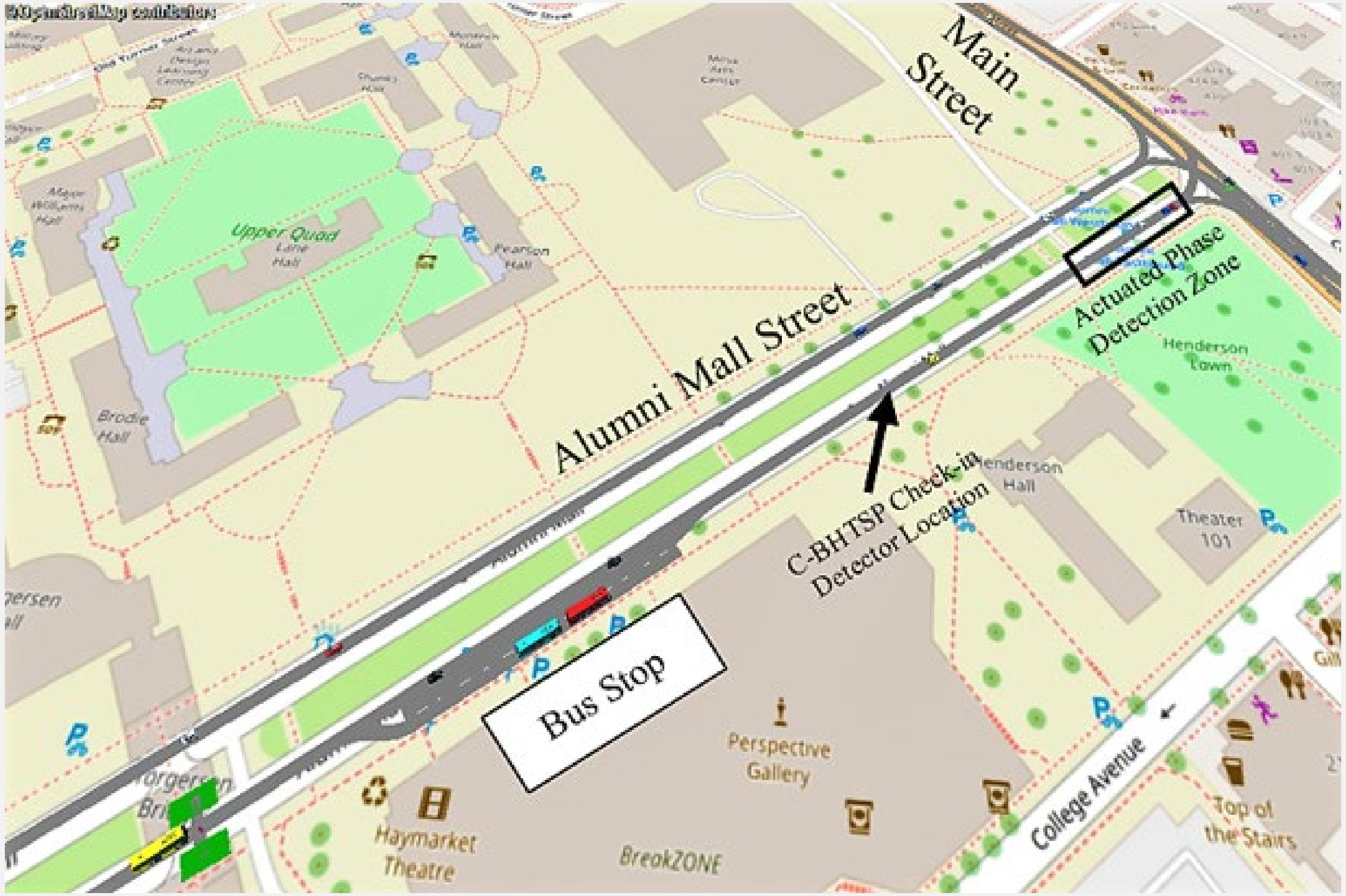
Blacksburg Example

Source: OpenStreetMap

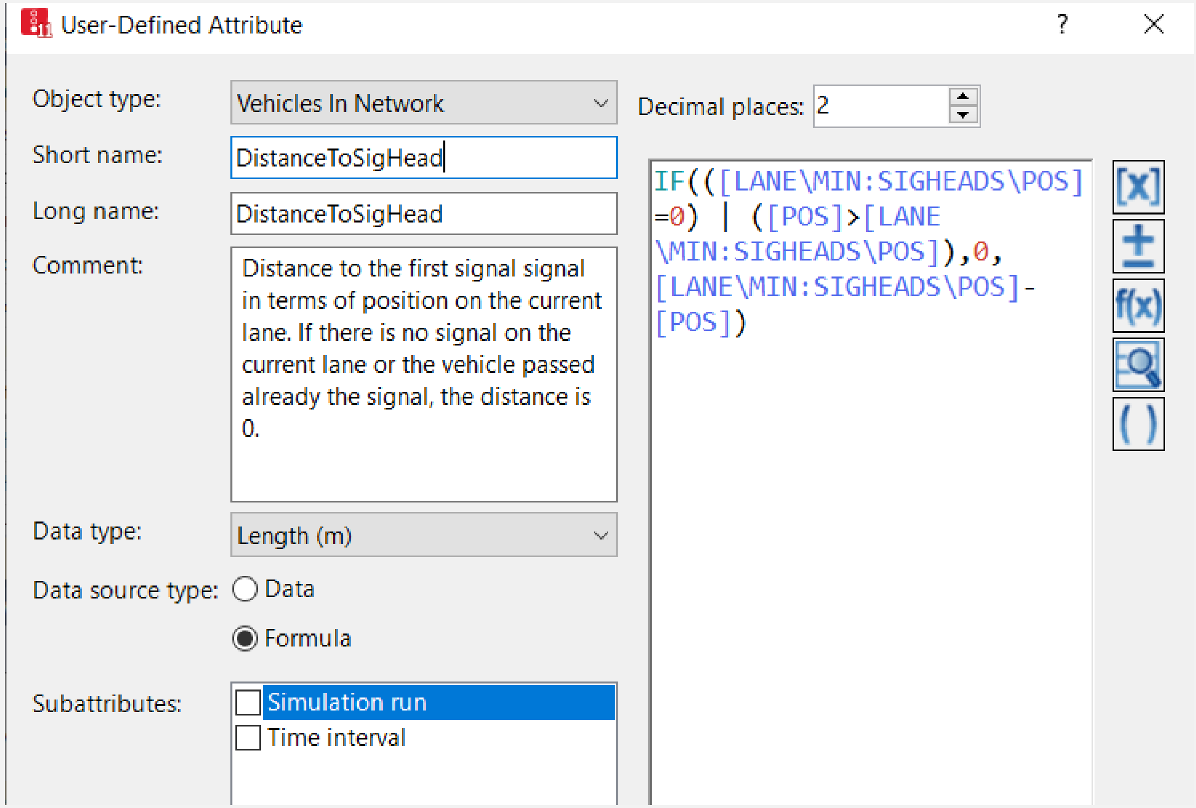
Blacksburg Example (continued)



Source: OpenStreetMap

Modeling CAVs in the Blacksburg Example

- Calculations can be added to user-defined attributes and are automatically carried out for all object types producing the desired output stated in “Data Type.”
- This is much faster compared to accessing objects and object containers through scripting at every step of simulation.



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Modeling CAVs (continued)

Source: FHWA

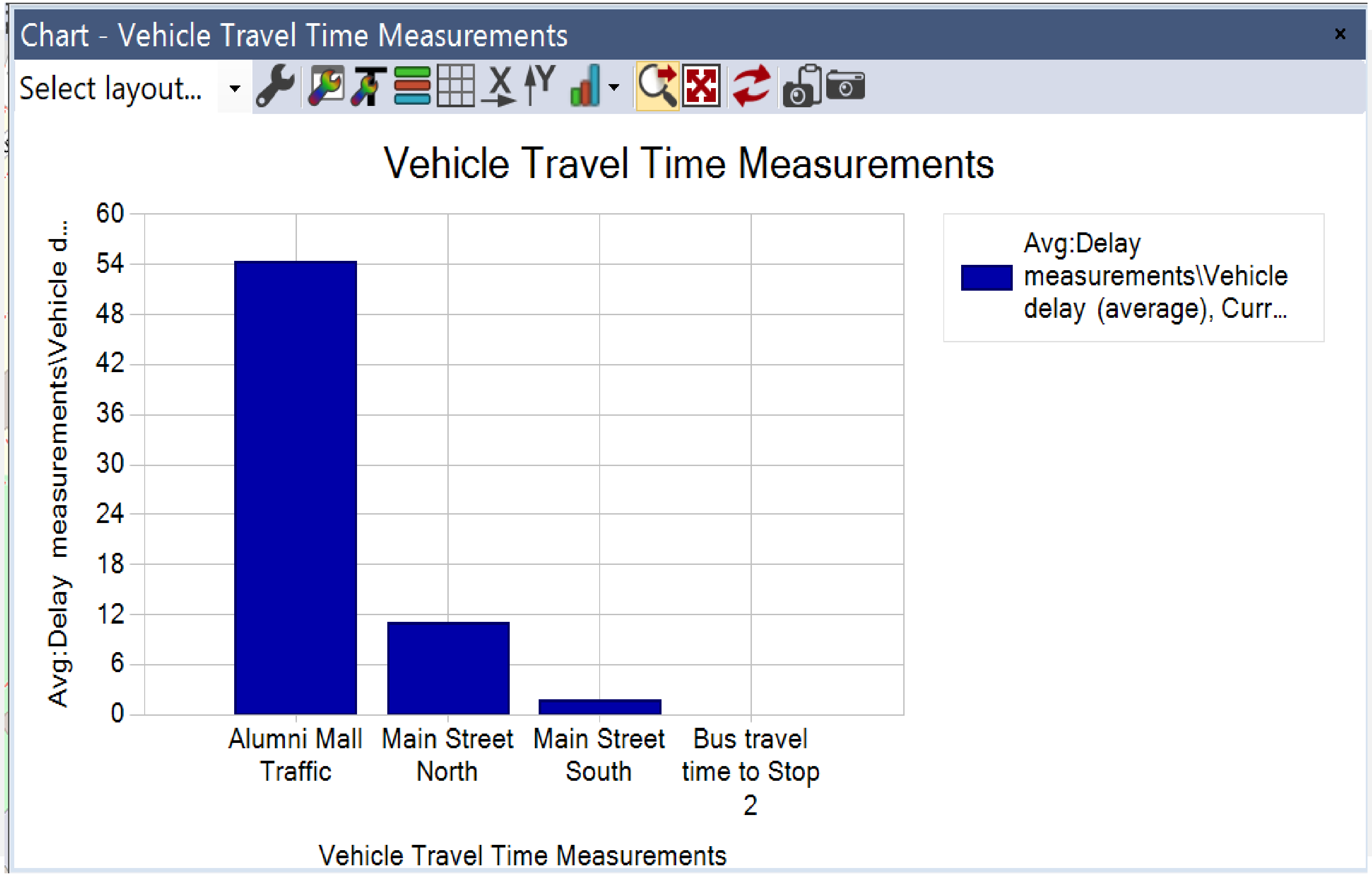
Scripts

Select layout...

Count: 2	No	Name	RunType	FromTime	ToTime	Period	Scope	ScriptFile	FuncName
1	4		After simulation start	0.00	MAX	5	Simula	CAV.py	Init
2	5		At time step end	0.00	MAX	5	Simula	CAV.py	ChangeSpe

- We now have CAVs in the network with distinct driving behavior and attributes that allow communication with the signals. Similarly, more attributes can be created as needed.
- Finally, we can use scripting externally or internally to perform our study.
- Here, we created a python script (CAV.py) with a ChangeSpeed function that is run at the end of every simulation time step to adjust the speed of CAVs based on the signal information that CAVs were modeled to receive.

Results



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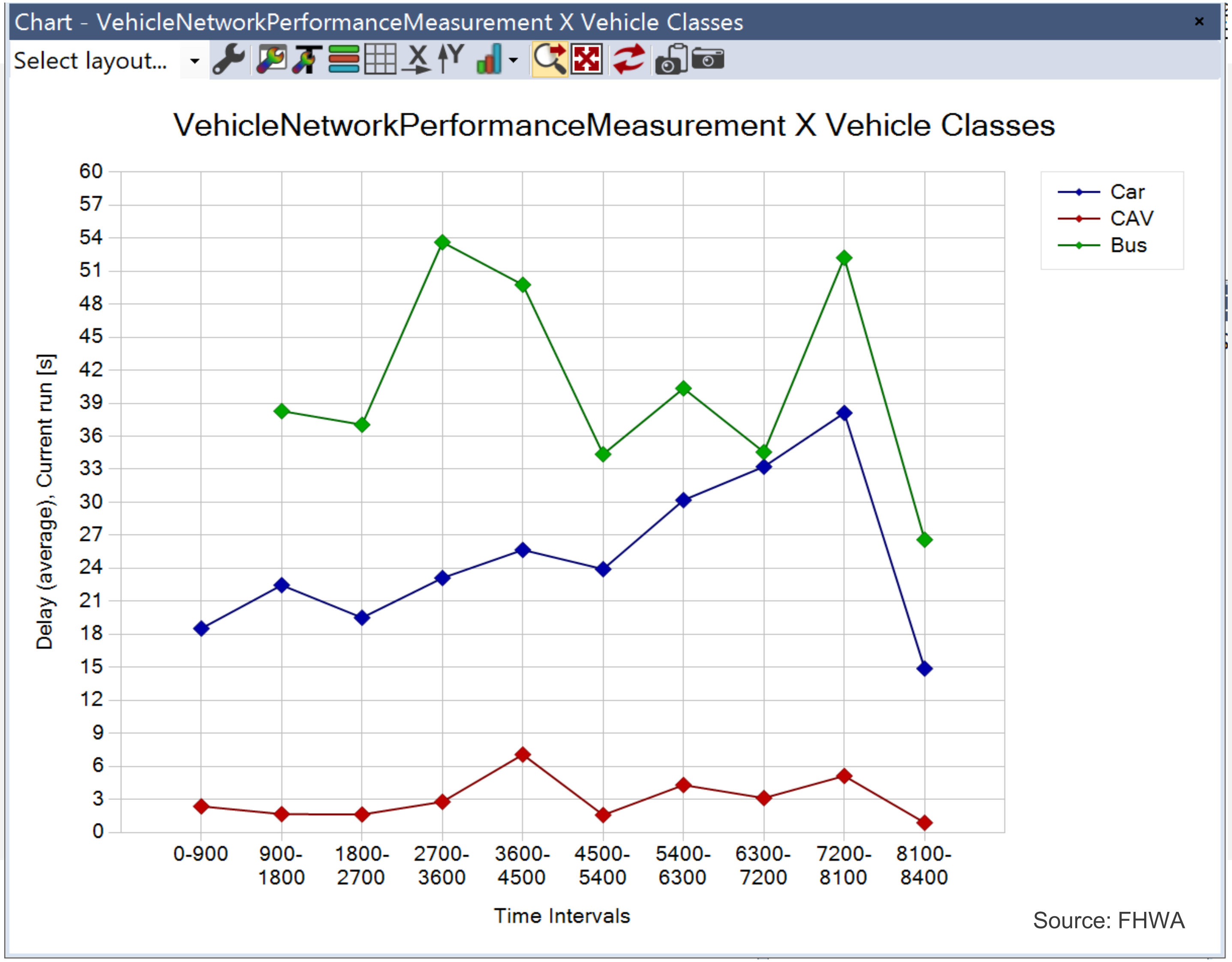
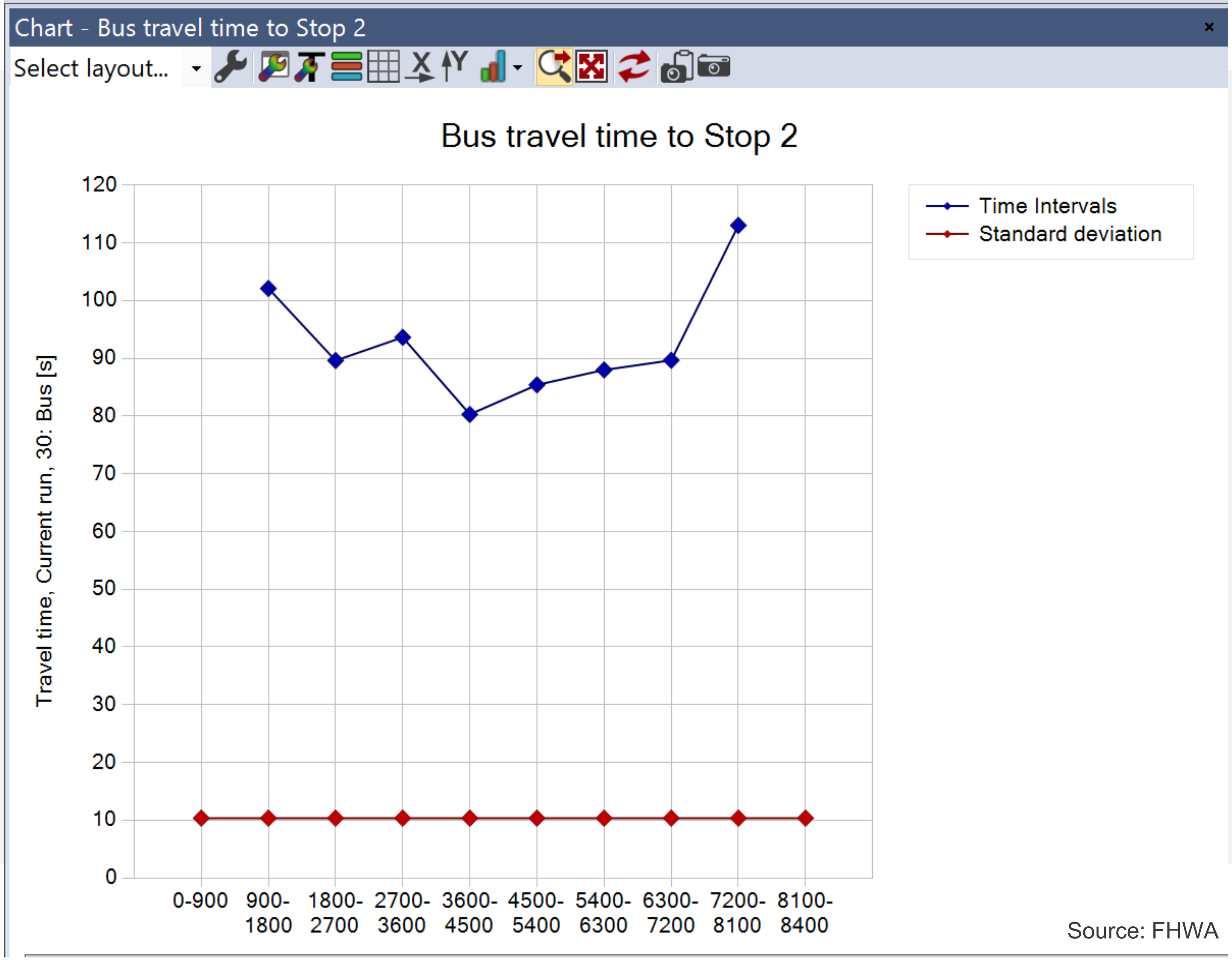
Results (continued)



Results (continued)



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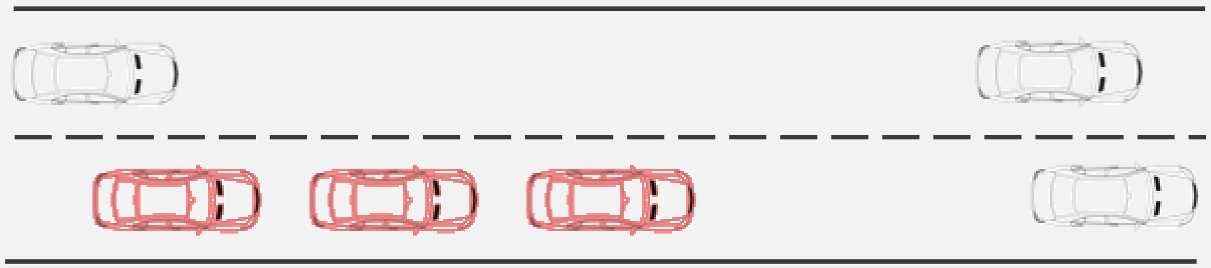
Answering the Questions

- What is the impact of CAV eco-driving operation with TSP strategies at the signalized intersection?
  - CAVs will experience much less delay than normal traffic, but normal traffic delays will increase.
- What is the impact of CAV penetration rate on the overall system delay?
  - Increase in penetration rate will increase normal vehicle delays.
- What is the impact of the application on bus bunching?
  - There is no significant impact on bus bunching.

Case Study 2: End-to-End Platooning

- End-to-End Platooning: Driving from an origin to a destination in a platoon.
  - Involves both cooperative adaptive cruise control (CACC) and lane-changing for the entire platoon.



Source: FHWA

- Potential benefits: maintain platoon integrity, prevent shockwaves.

Case Study 2: Scope and Questions

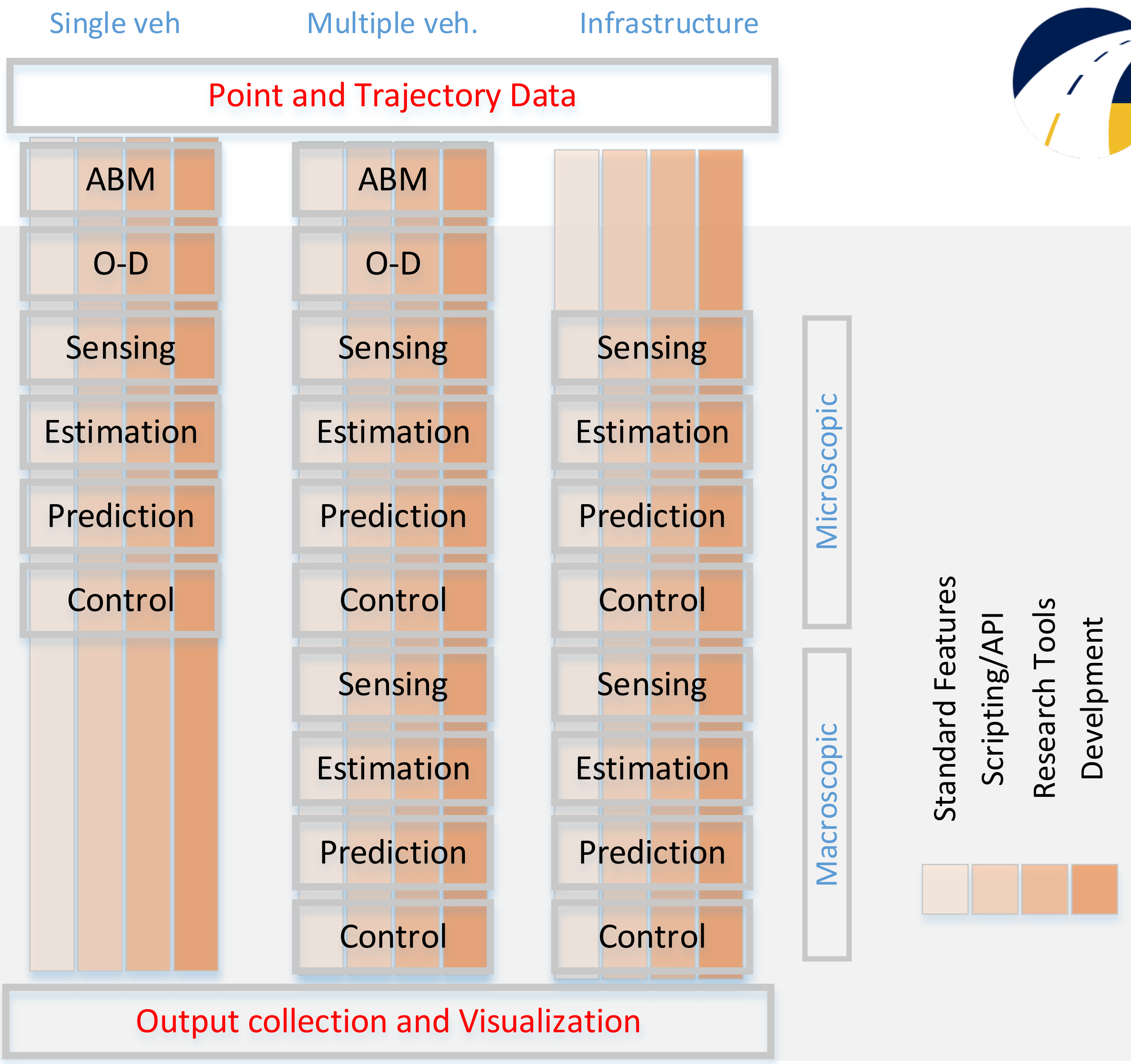
- Scope:
  - Impact of sensing on CAV operations in a platoon:
    - Sensor range.
    - Sensor fusion for detection and path prediction (false positives and false negatives).
- Questions:
  - How important is it to simulate sensors?
  - What is the impact of end-to-end platooning on traffic operations and traffic flow dynamics?

Case Study 2: Requirements

- Simulation requirements:
  - CAV sensors.
  - Cooperative adaptive cruise control (CACC) operations.
  - Lane-changing.
  - Interactions between CAVs and human-driven vehicles.

Brainstorming Session

- Which pillar will we be focusing on?
- Which of the microscopic components are we working with?
- What level is the needed effort?



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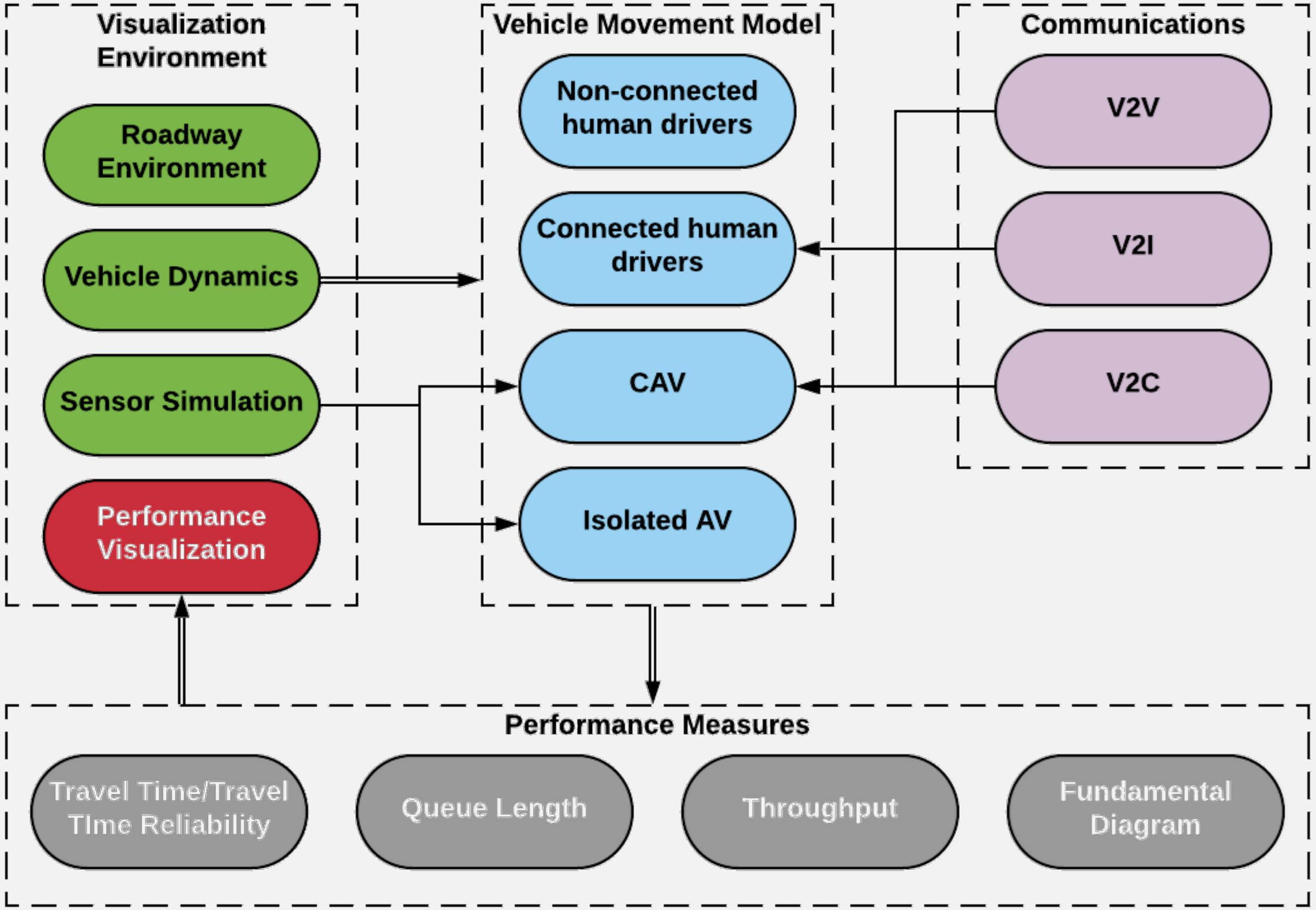
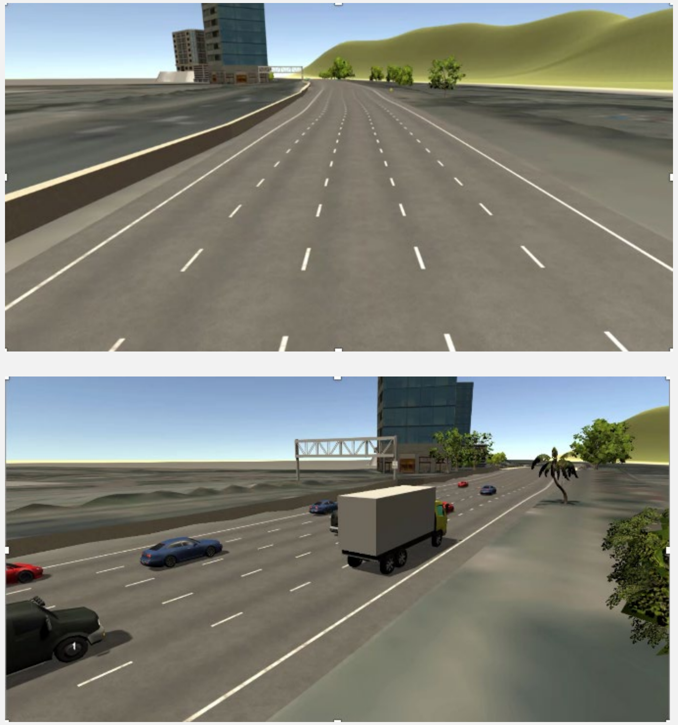
Case Study 2: Simulation Tool





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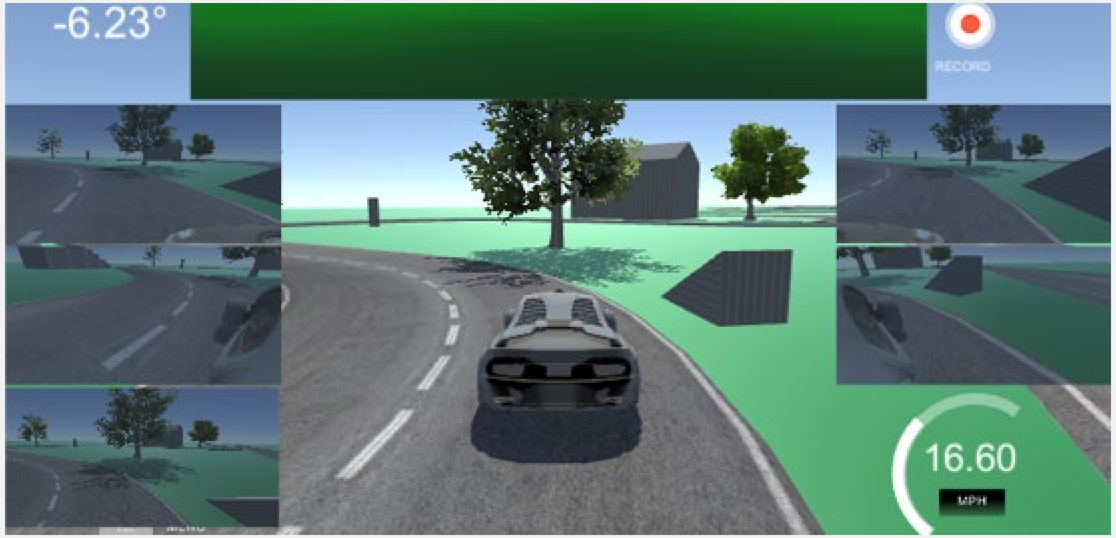
Case Study 2: Simulation Tool

- A note on the simulation environment:
  - The presented framework is based on a game engine platform.
  - Most steps presented above are transferable to other game engines.
  - The communications between vehicles is assumed to exist to reduce the computation time.

Case Study 2: Building the Environment

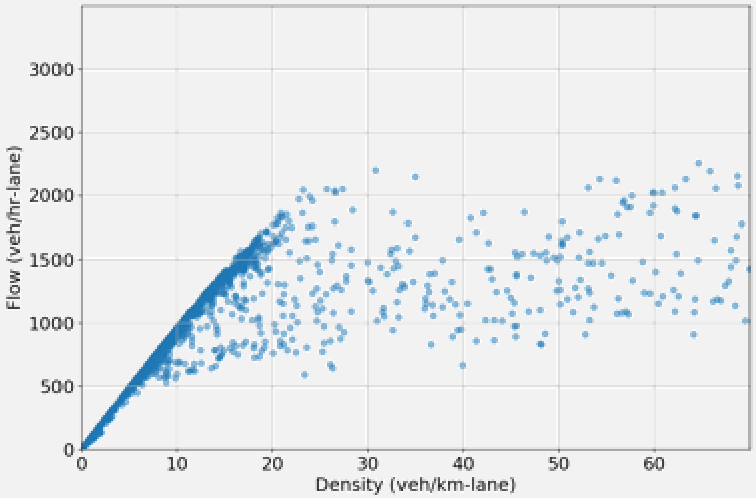
- **Spline-based road builder:**
  - Can generate a smooth road along a user-created spline.
  - Can adjust curvature and elevation.
  - Generates waypoints along road for testing control algorithms.



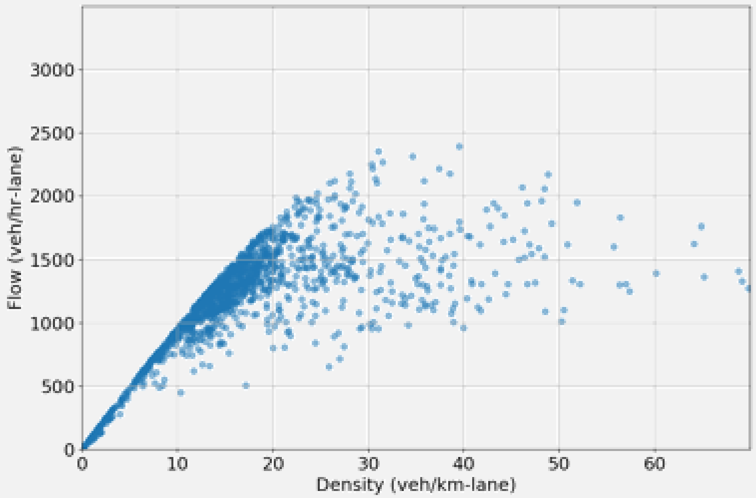
Source: FHWA

Case Study 2: Results

- 10% CAV, 50% Platoons, mainline inflow = 1500 veh/hr/lane, ramp inflow = 500 veh/hr.



Platoon size = 1

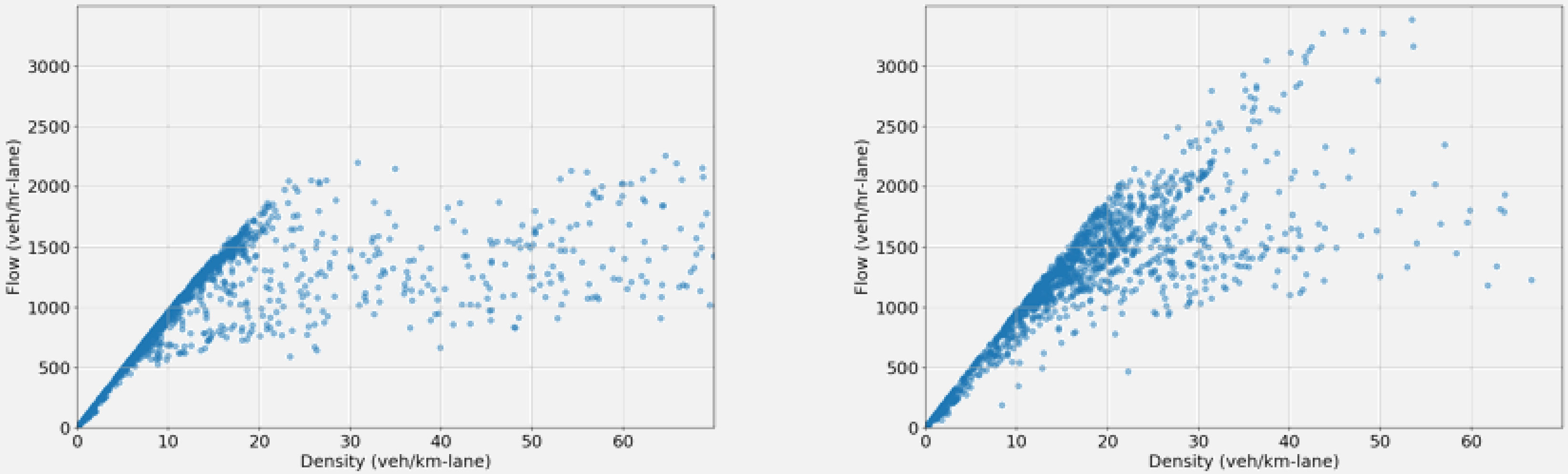


Platoon size = 2

Source: FHWA

Case Study 2: Results (continued)

- 10% CAV, 50% Platoons, mainline inflow = 1500 veh/hr/lane, ramp inflow = 500 veh/hr.



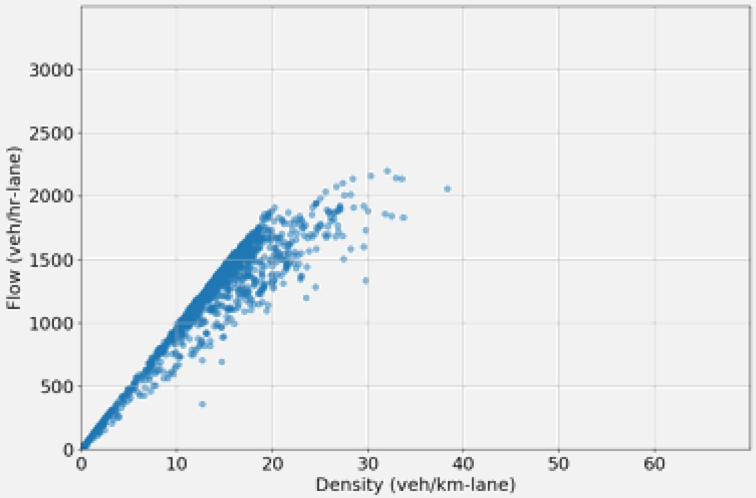
Platoon size = 1

Platoon size = 10

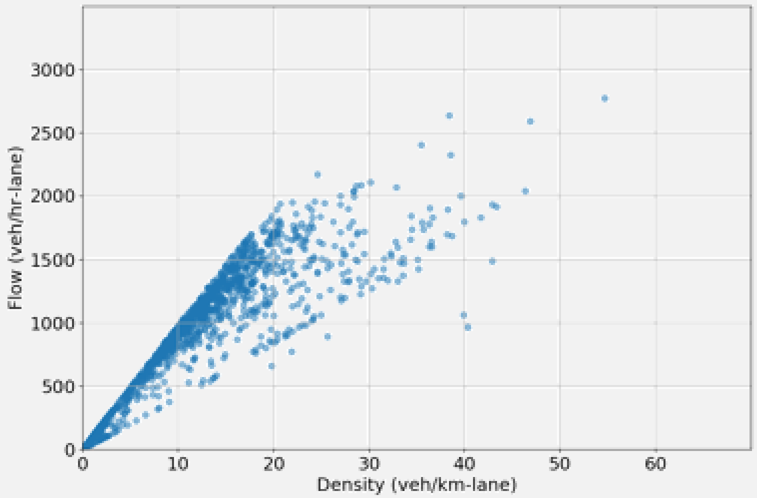
Source: FHWA

Case Study 2: Results (continued)

- 60% CAV, 50% Platoons, mainline inflow = 1500 veh/hr/lane, ramp inflow = 500 veh/hr.



Platoon size = 1



Platoon size = 5

Source: FHWA

Answering the Questions

- Is End-to-End platooning a viable solution?
  - At low penetration rates of CAV, End-to-End platooning can reduce congestion.
- Should we simulate sensors?
  - It is complicated.
  - Depends on the application.

Summary

- Proposed Framework:
  - Application of the pillar diagram to understand what the agency is and is not committing to do.
  - Nine steps to complete the analysis.
- Case Studies:
  - Eco-driving case to illustrate single vehicle, multiple vehicles, and infrastructure control applications in signalized arterial application.
  - End-to-end platooning to illustrate vehicle sensing and control in freeway application.

Conclusions

- Conducting detailed microscopic traffic analysis of CAVs may require using AMS application programming interface (API) and scripting tools.
- Analysts can consider the overall transportation system operation, with its interacting components, in tandem with the questions they are trying to address.
- There is a trade-off between conducting detailed microscopic analysis with a high degree of assumptions, versus conducting a higher level mesoscopic/macroscopic analysis in the absence of rich data sets or programming advanced features.

Interactive Session

- Questions, comments, or suggestions?

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Questions?

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Source: FHWA.