



Connected and Automated Vehicles --what we learned at UM/Mcity

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Uncertainties in Energy Impact of CAVs

The Transforming Mobility Ecosystem: Enabling an Energy-Efficient Future



U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy

DOE report: [The Transforming Mobility Ecosystem: Enabling an Energy-Efficient Future](#)

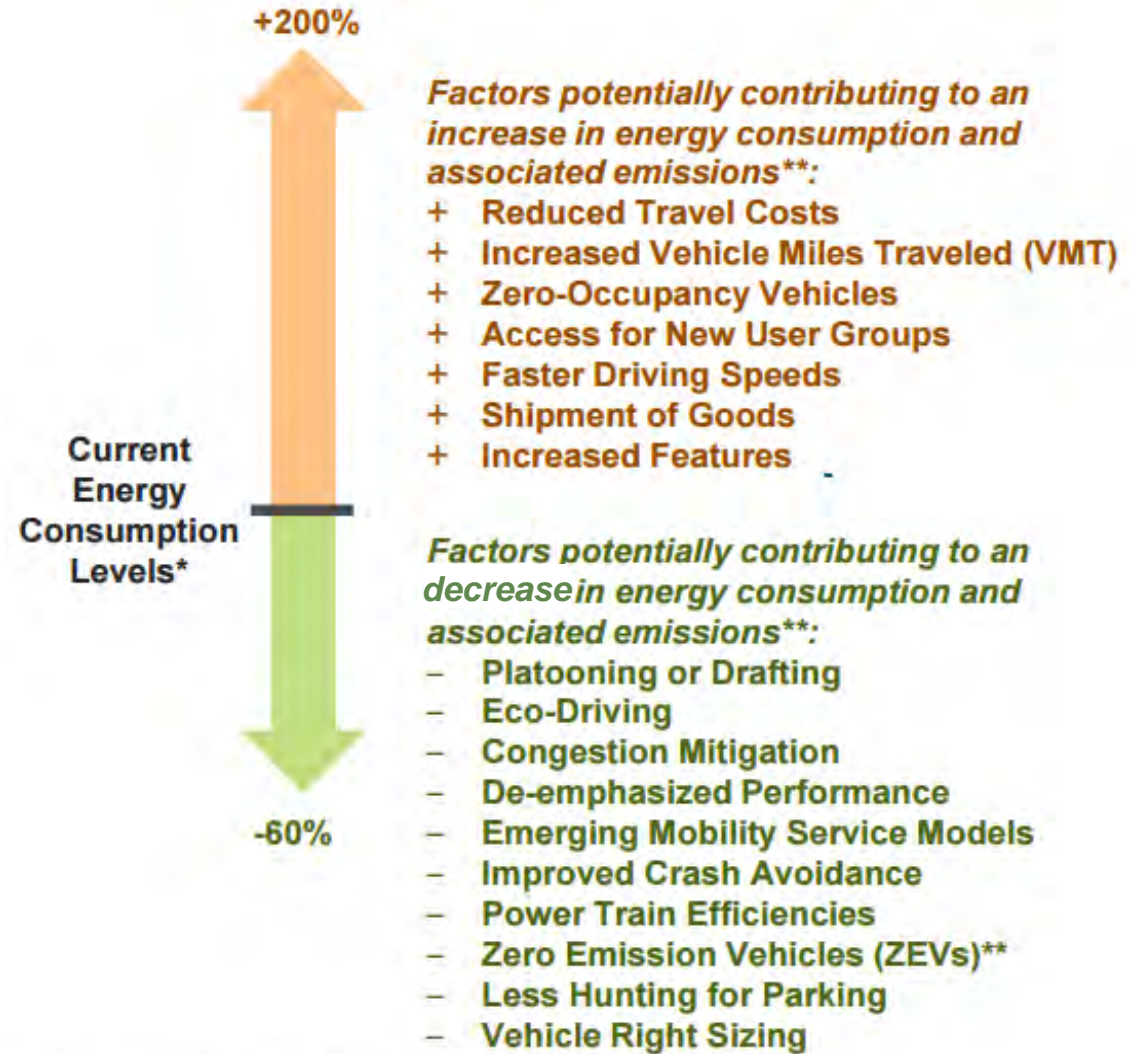
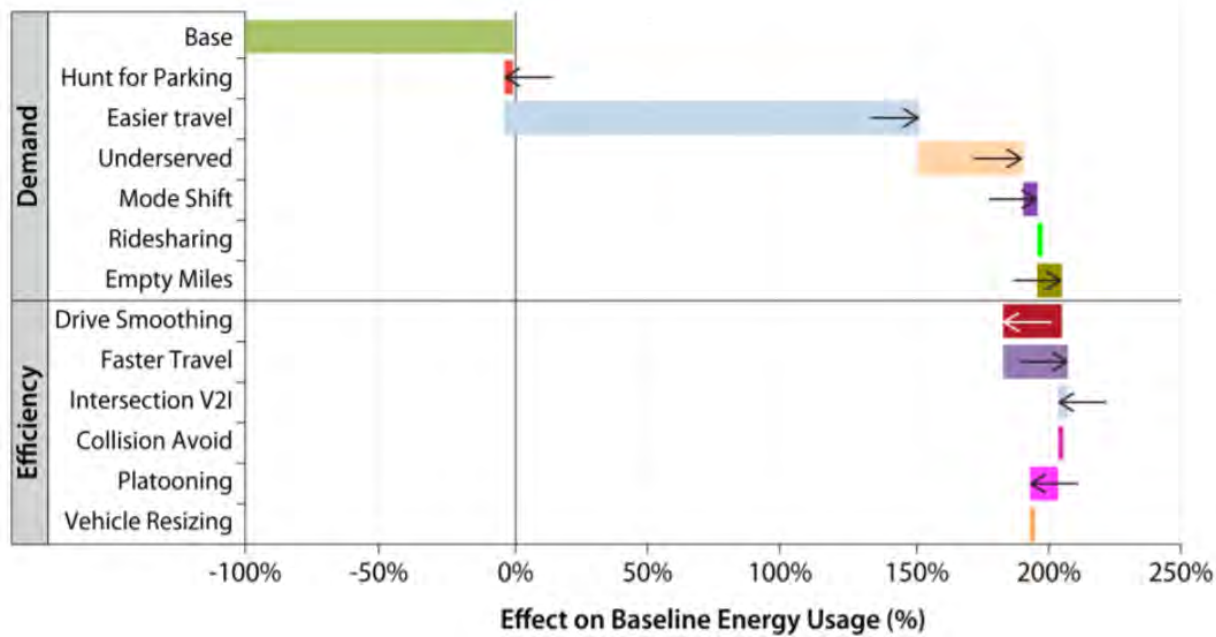


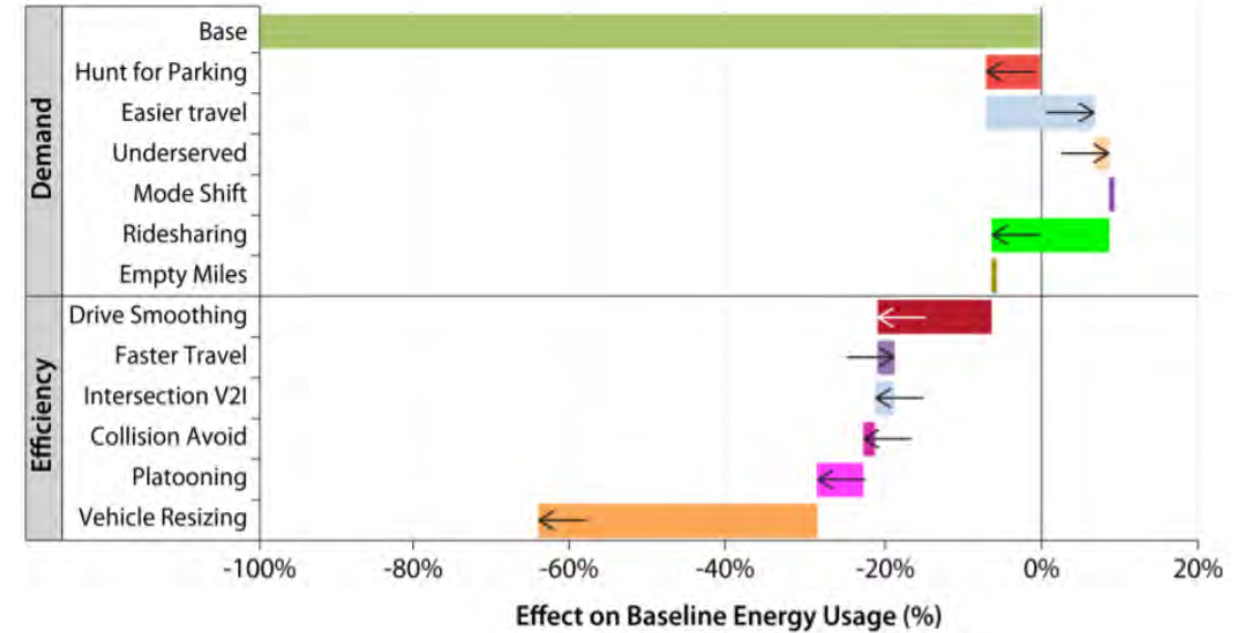
Figure 2. Energy Impacts of Connectivity and Automation

Influence on Fuel Use



Upper Bound



Lower Bound



What Did We Learn?

- Many factors  
- Large uncertainties AND opportunities
- Develop the **technologies**, need to mitigate “problematic **human behavior change**”

	Base
Demand	Hunt for Parking
	Easier travel
	Underserved
	Mode Shift
	Ridesharing
Efficiency	Empty Miles
	Drive Smoothing
	Faster Travel
	Intersection V2I
	Collision Avoid
	Platooning
	Vehicle Resizing

Activities and Learning From Three Projects

- DOE EERE Incubator project
- ARPA-E NEXTCAR project (PI: Andreas Malikopoulos UD)
- Driverless shuttles at UM

DOE EERE Incubator project

Energy Implications of Connected and Automated Vehicles

PI: Huei Peng (UM)

Co-PI:

UM: Andre Boehman, Mark Gilbert, Dave LeBlanc, Henry Liu,
James Sayer

ANL: Josh Auld, Erik Rask, Aymeric Rousseau, Ann Schlenker

INL: John Smart

Data



Task 1
Fleet testing

Task 4
Simulations



Task 5
Adaptive
Traffic
Signals

Simulation

Energy
impacts
of CAVs

Testing



Task 3
Traveler model

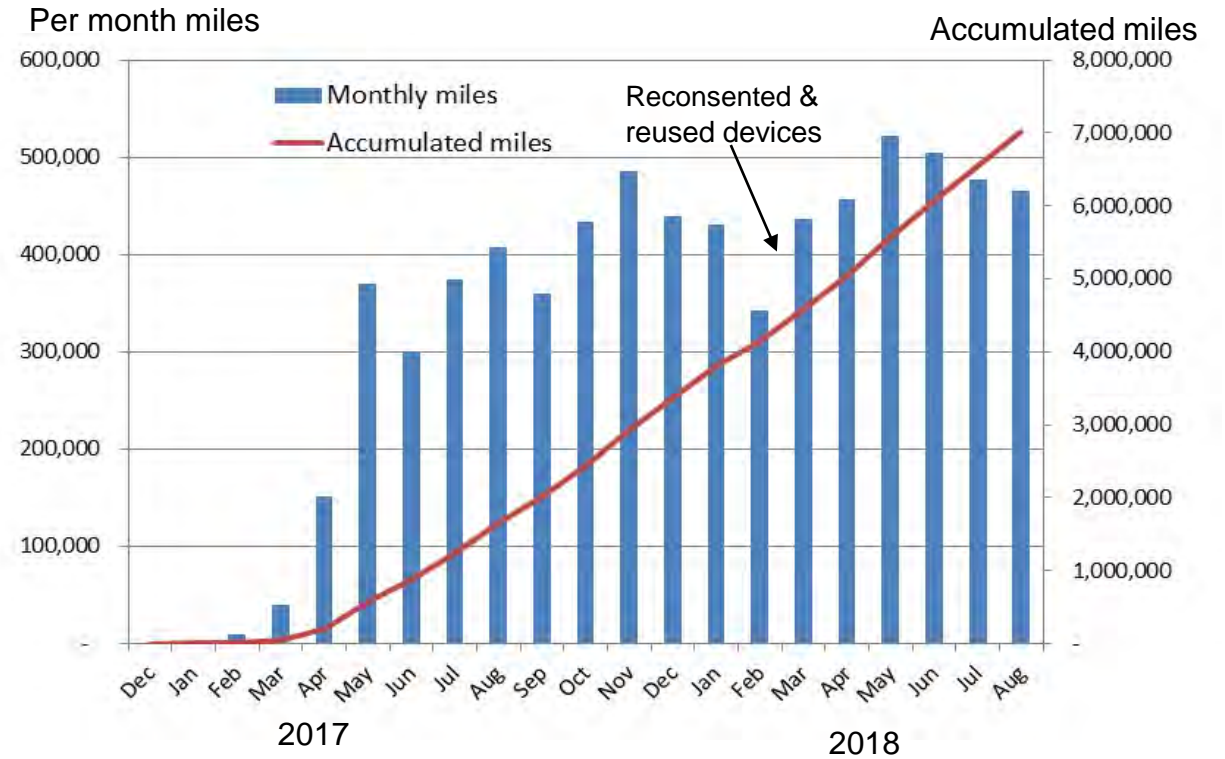
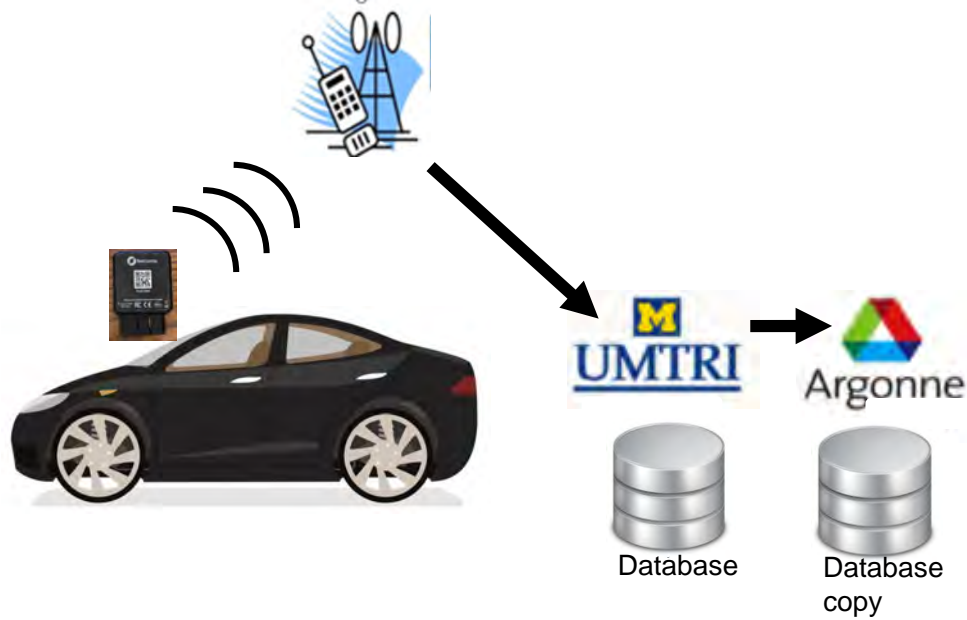
Task 2
Driver behavior



Major Work/Outcome

- Collected energy consumption data + GPS from ~500 vehicles
- A calibrated Ann Arbor model in Polaris (ANL)
- Eco-Routing in Ann Arbor
- Human behavior model (How they follow advises from CAV functions?)
- Human driver etiquette
- Adaptive Traffic Signal Control Algorithm

Data Collection (500 vehicles, 8 million miles)



Powertrain type	Number of vehicles(09/10/18)
ICE & HV	300 (91.7%)
PHEV & EV	27 (25 PHEV, 2 EV) (8.3%)
Total	327

Updated on 09/10/18 :

- 739,535 trips with nonzero travel
- 7,127,289 miles in total
- **8.1 million miles** – projected total mileage for project (device cellular plans expire 11/10/18)

Calibrated Ann Arbor model in Polaris (ANL)

Example: Vehicle ID 247 and Trip ID 215

Vehicle Instance

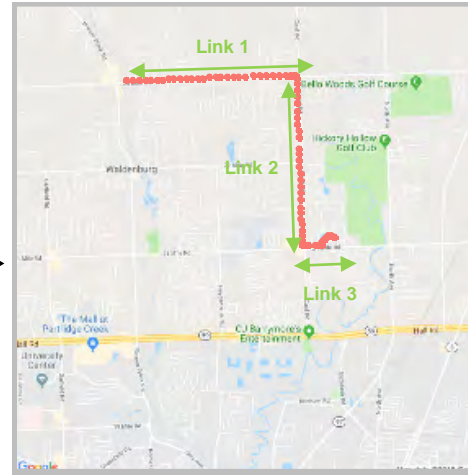
Assign

- Powertrain Type
- Engine Type
- Transmission Type
- Number of gears
- Engine Power
- Drag Coefficient
- Rolling resistance
- Vehicle Weight
- Vehicle Performance
- ...

Extract

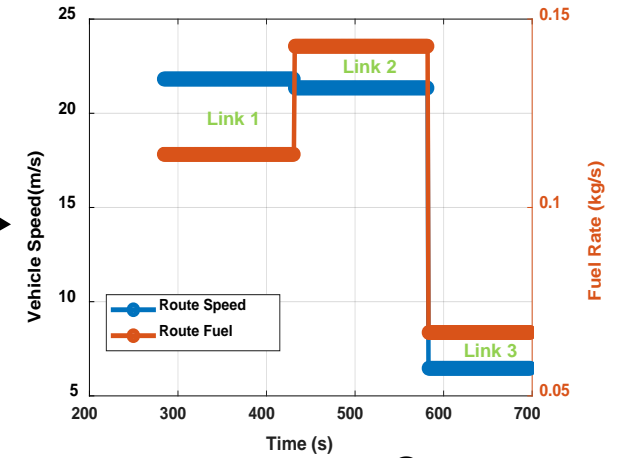
- Time
- Vehicle Speed
- Fuel consumed
- GPS position (lon/lat)

Map Matching



Process route data

(POLARIS "like")



Generate route like features

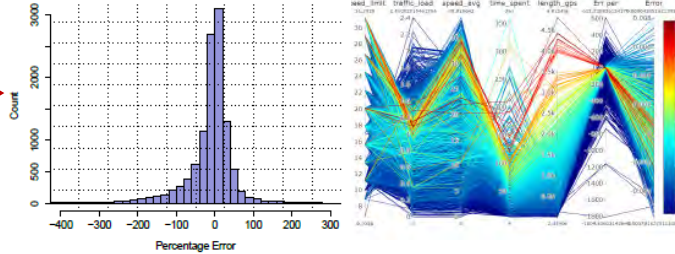
Data wrangling
Outlier detection

Model

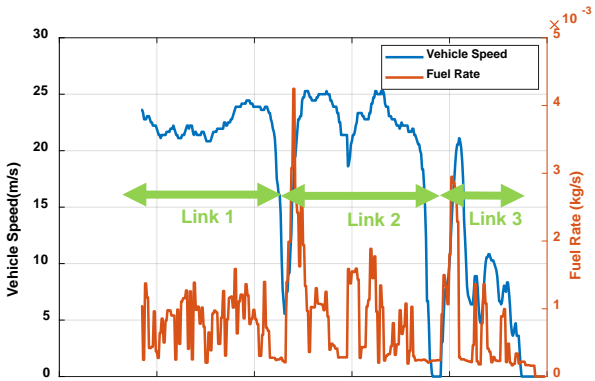
$$y_0 = f_0 \left(\sum_{h_2} w_{h_2 0} f_{h_2} \left(\sum_{h_1} w_{h_1 h_2} f_{h_1} \left(\sum_i w_i x_i \right) \right) \right)$$

Prediction

Error Circulation Analysis

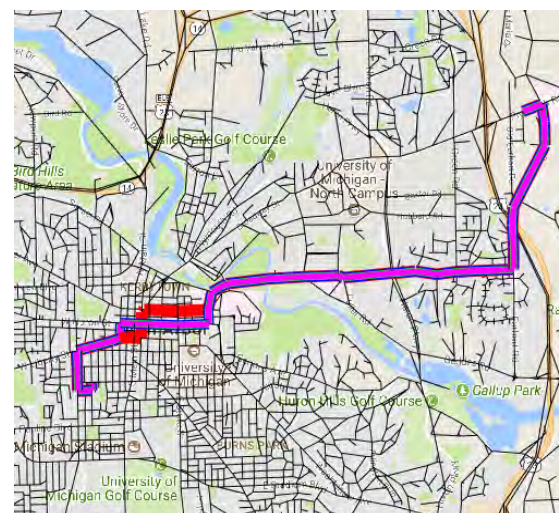
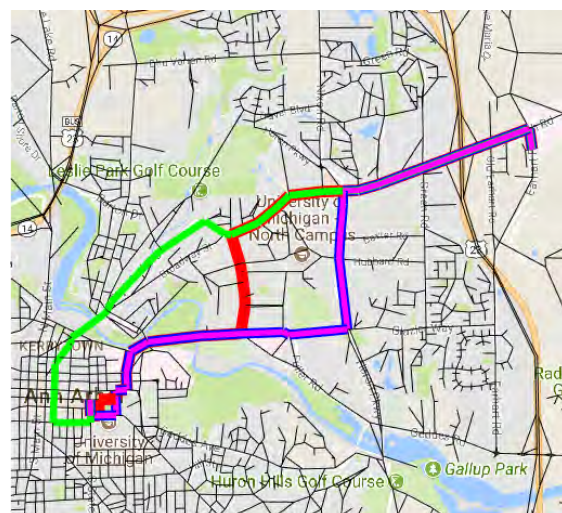
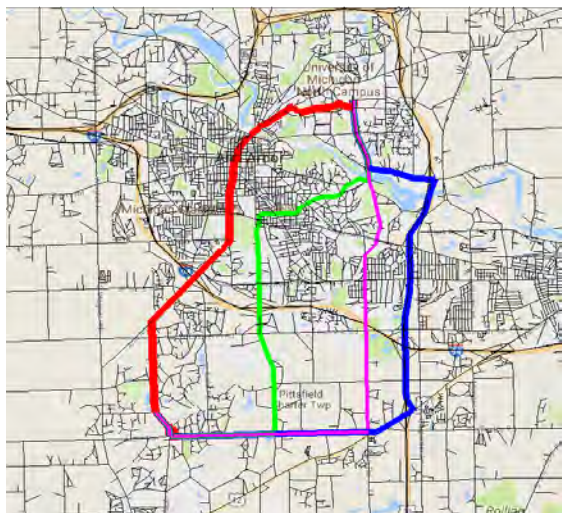


Cross-Validation
(different data sets)

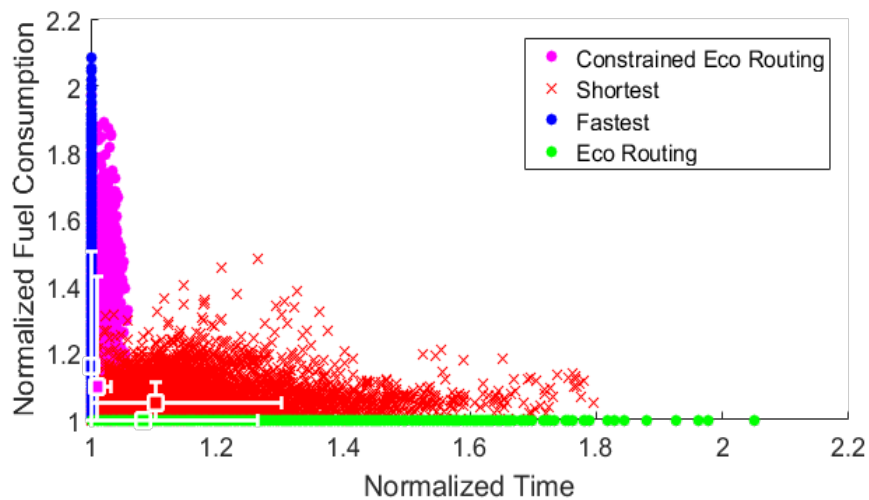


- Distance covered
- Length Link
- Time traveled on Link
- Time stop on Link
- Average Speed on Link
- Speed Limit of Link
- Distance covered previous link
- Distance covered next link
- Average Speed previous link
- Average Speed next link
- Speed Difference previous link
- Speed Difference next link
- Traffic load
- ...

Eco-Routing for Ann Arbor (fuel ↓ 6%, time ↑ 1%)

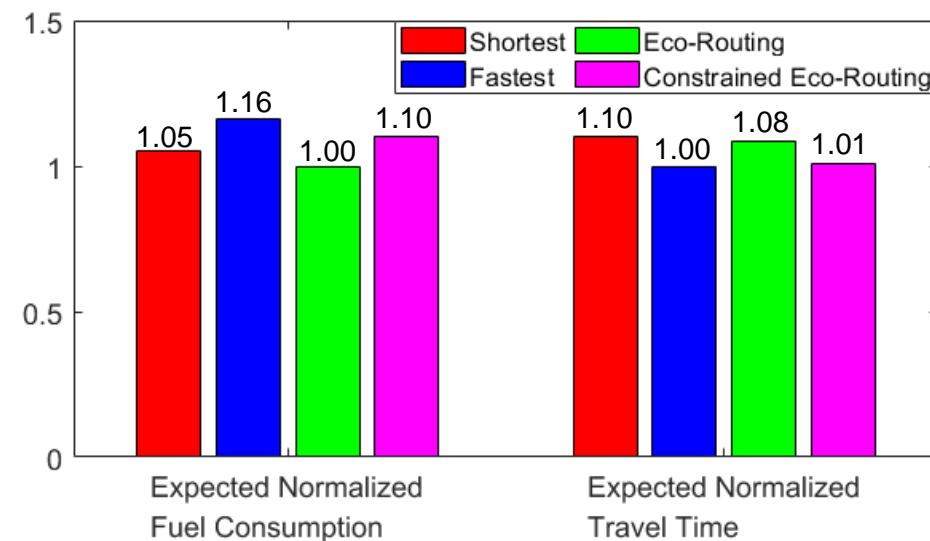


- Shortest Route
- Fastest Route
- Eco Route
- Time-Constrained Eco Route



$$f_{C_{normal}} = \frac{f_c}{f_{C_{Eco-Routing}}}$$

$$t_{normal} = \frac{t}{t_{Fastest}}$$



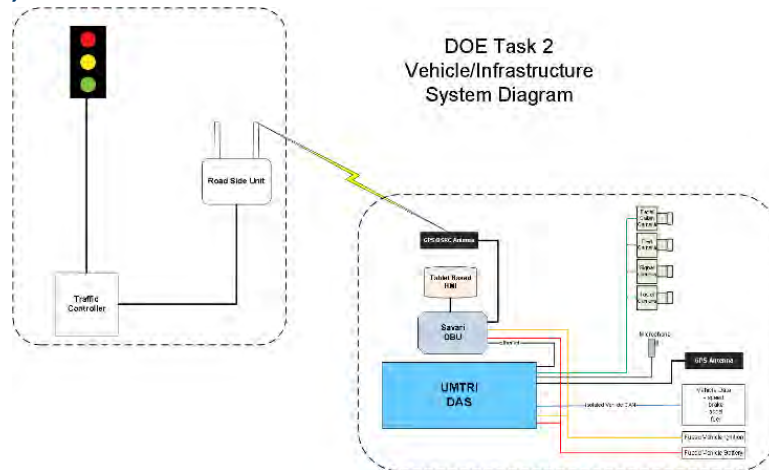
How human drivers follow advises from CAV functions?

— Experiment conducted at MCity

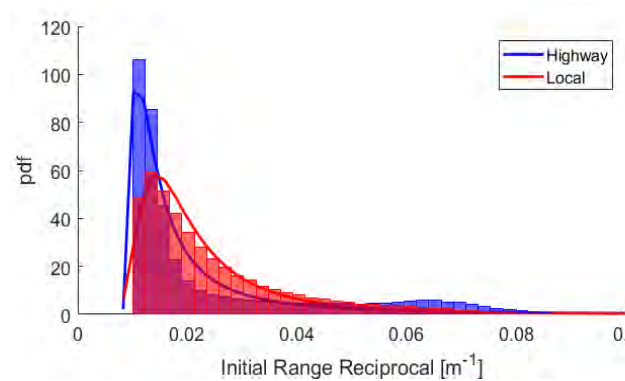
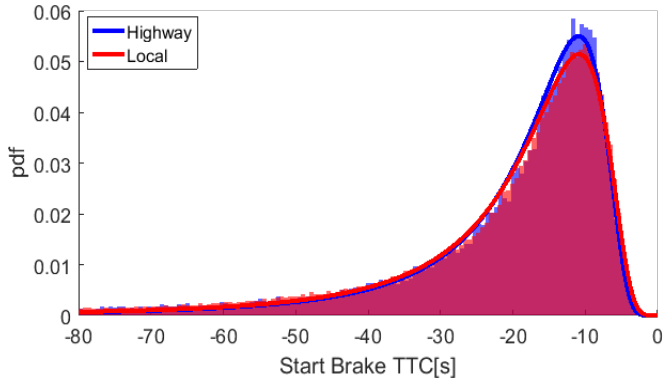
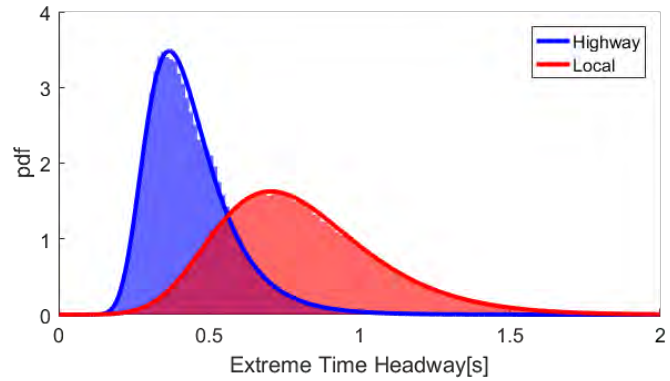
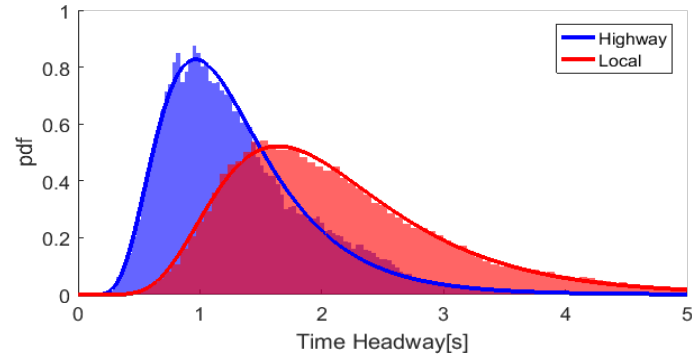
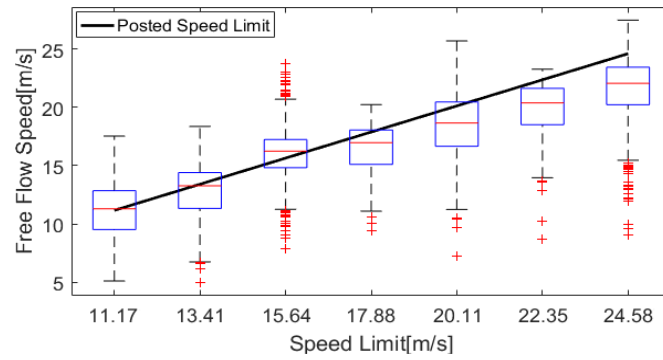
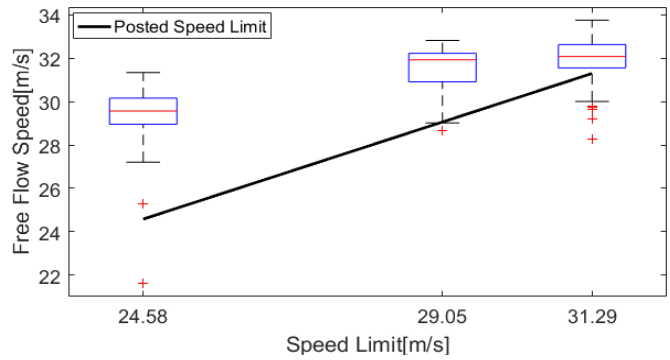
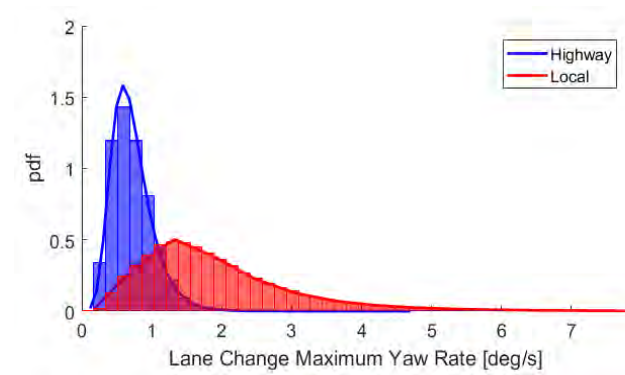
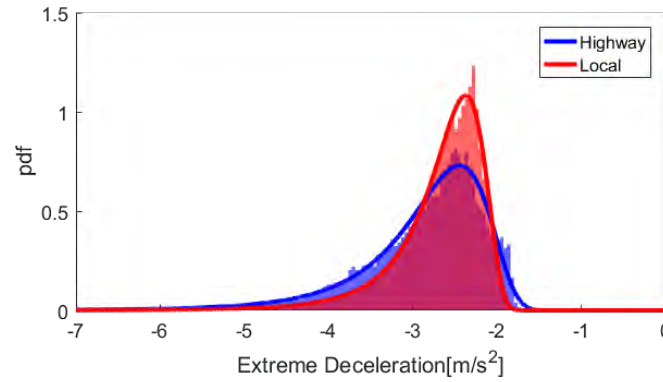
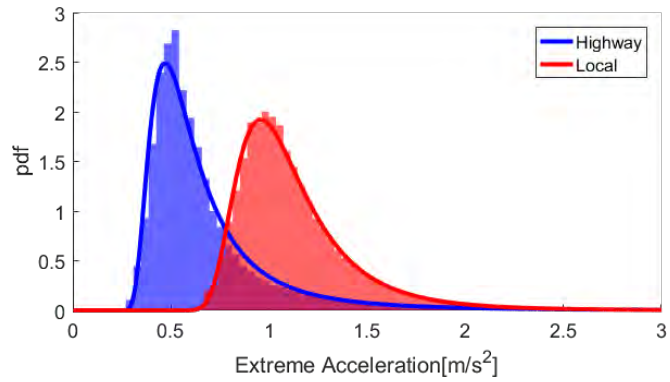
- 32 participants
- 16 younger (between 20 and 30 years old) and 16 middle-aged (between 40 and 50 years old)
- Some college or lower (19%), bachelor's degree (47%), master's degree or higher (34%)

— Vehicle instrumentation

- Honda research vehicle
- Four cameras (front view ,driver face ,over the shoulder, and rear view)
- DAS, GPS and HMI tablet



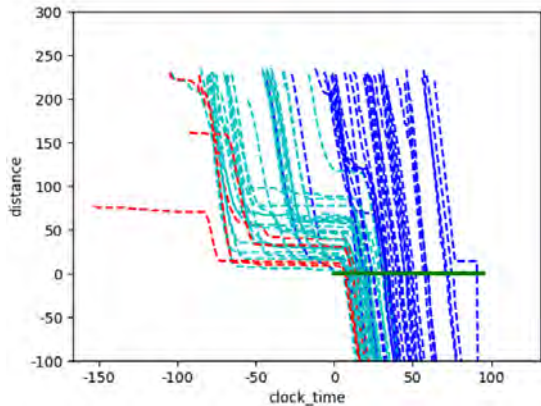
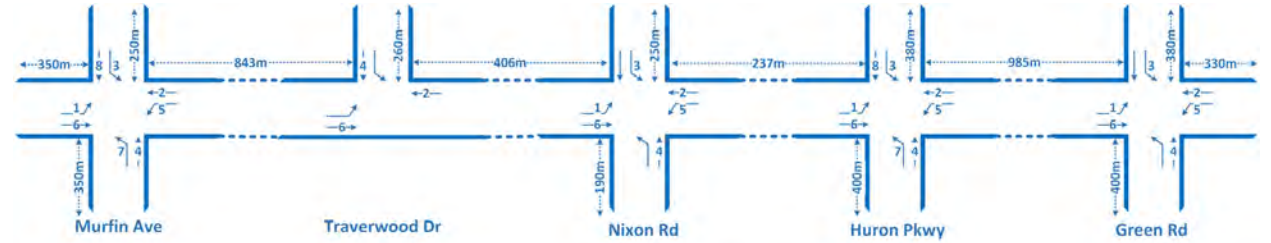
Human driver etiquette



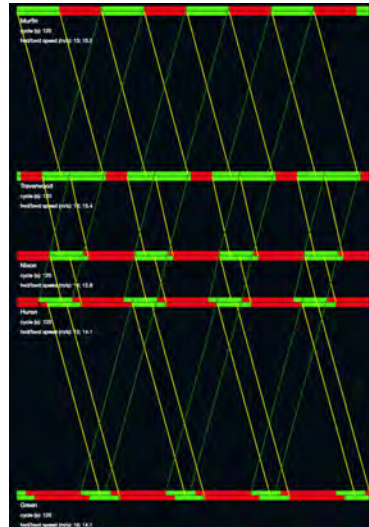
Adaptive Traffic Signal Control Algorithm



abstraction



Example field data



Optimization to reduce delay



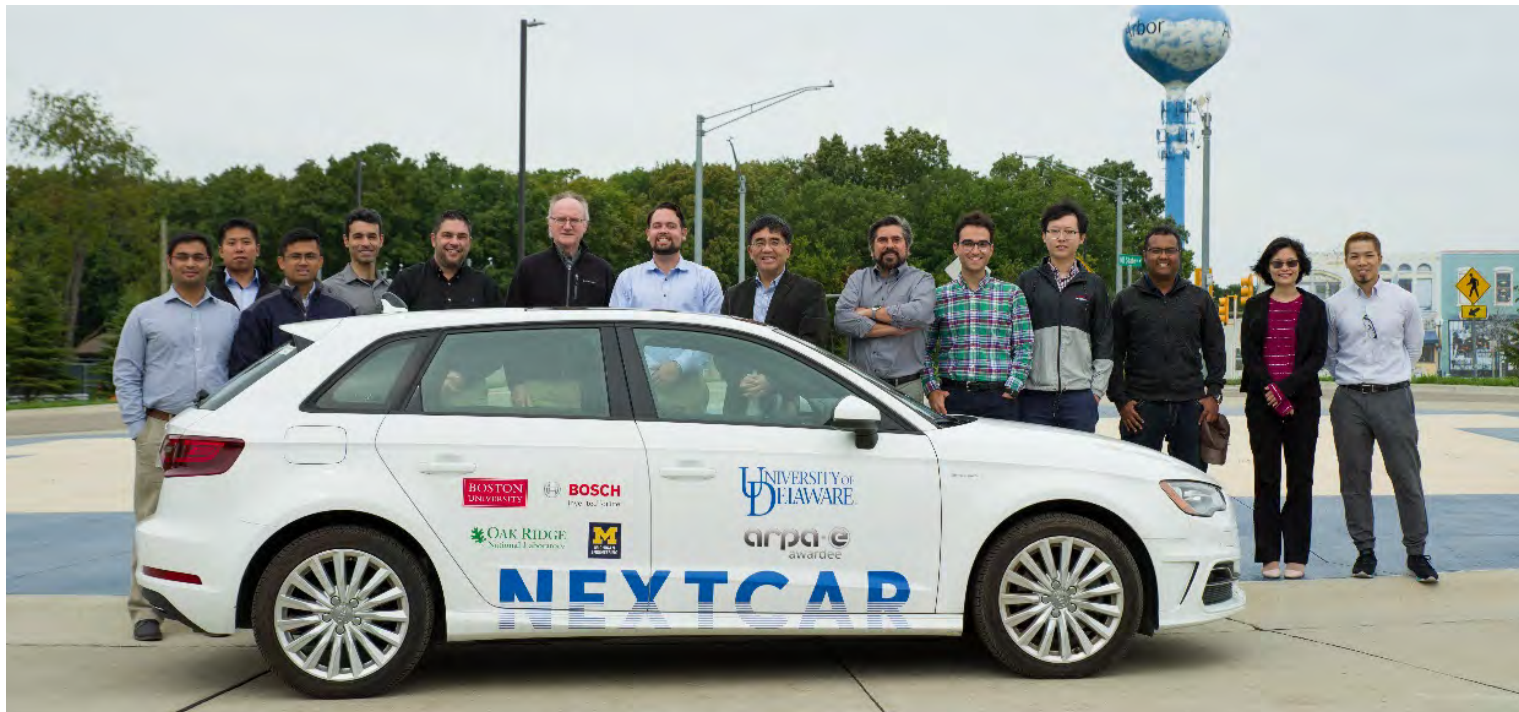
Intersection	ID	Start	Duration	ID	Start	Duration	ID	Start	Duration	ID	Start	Duration
Murfin	2	0	60	6	0	60	1	60	12	5	0	12
Traverwood	2	0	90	6	0	90						
Nixon	2	0	54	6	0	48	1	54	12	5	48	18
Huron	2	12	48	6	0	48	1	0	12	5	48	12
Green	2	12	42	6	0	42	1	0	12	5	54	12

Generate new signal timing table for the Plymouth road corridor

Simultaneous Optimization of Vehicle and Powertrain Operation Using Connectivity and Automation

University of Delaware (Lead Organization)

Bosch, Boston University, University of Michigan, and Oak Ridge National Laboratory



Principal Investigator:

Andreas A. Malikopoulos



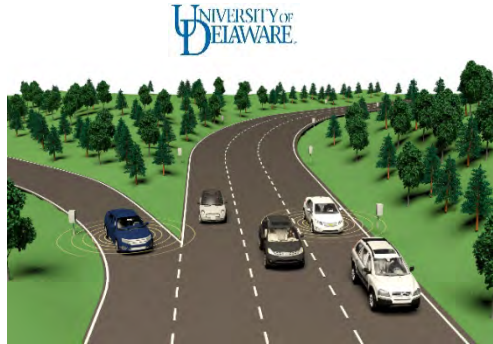
Major Work/Outcome

- Beneficial combination of CAV functions and powertrain control functions
- Cost effective CAV testing through Augmented reality
- SUMO model for Ann Arbor to study macroscopic effects of CAV functions

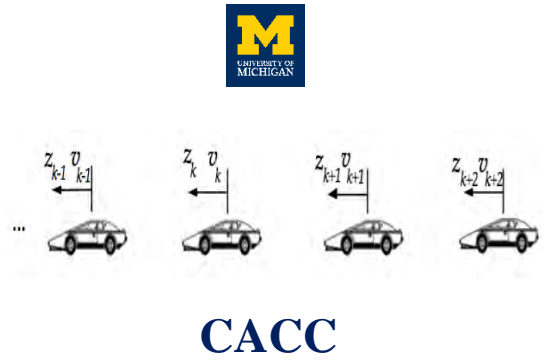
Beneficial Combination of CAV and Powertrain Controls



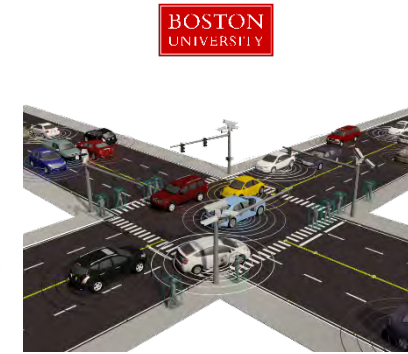
Eco-routing



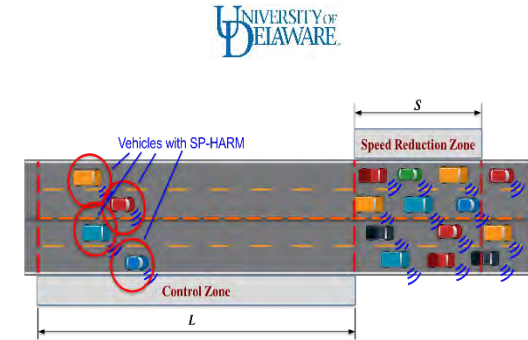
Vehicle Merging



CACC



Eco-AND

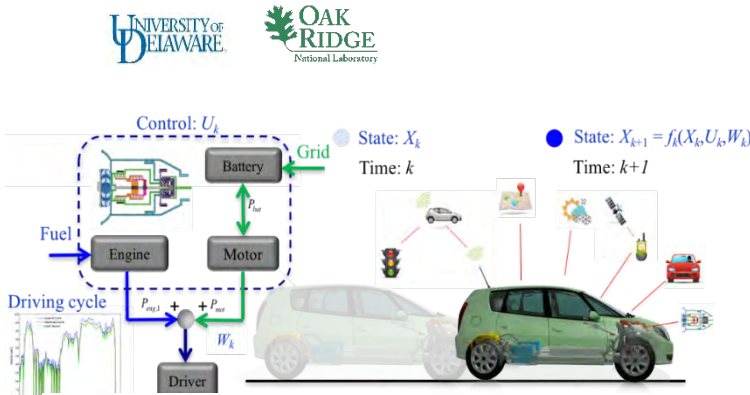


SPD-HARM approach

M1. B Table of Efficiency Improvements

Updated September 2018

Projection of the reduction attributable to supervisory, VD and PT controllers



Online optimization of the powertrain

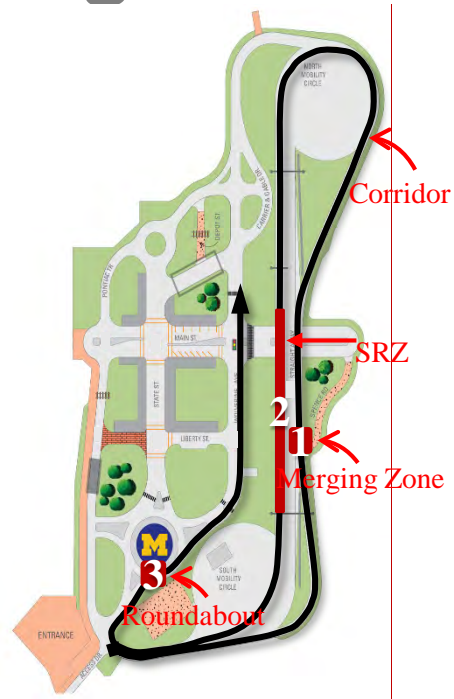
Application

Contributions on the X% Energy Consumption Improvement

Application	Confidence	Contributions on the X% Energy Consumption Improvement		
		< 15%	15% to 25%	25% to 35%
Eco-routing (Supervisory controller)	H	0		
Vehicle coordination (VD controller)	M			0
CACC (VD controller)	M		0	
SPD-HARM (VD controller)	M	0		
Eco-AND (VD controller)	L		0	
Powertrain (PT controller)	M		0	

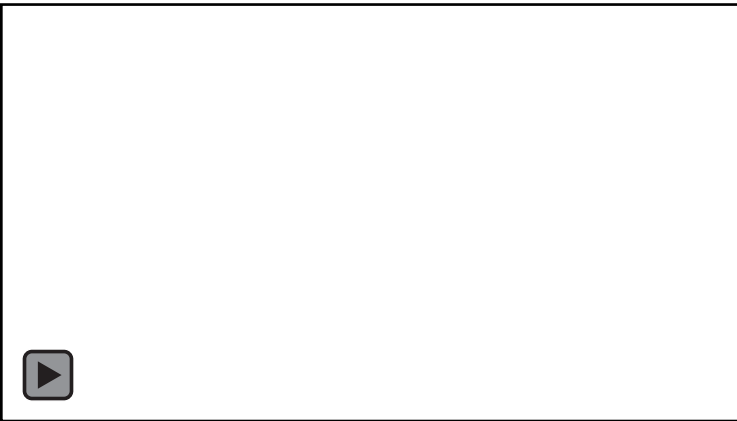
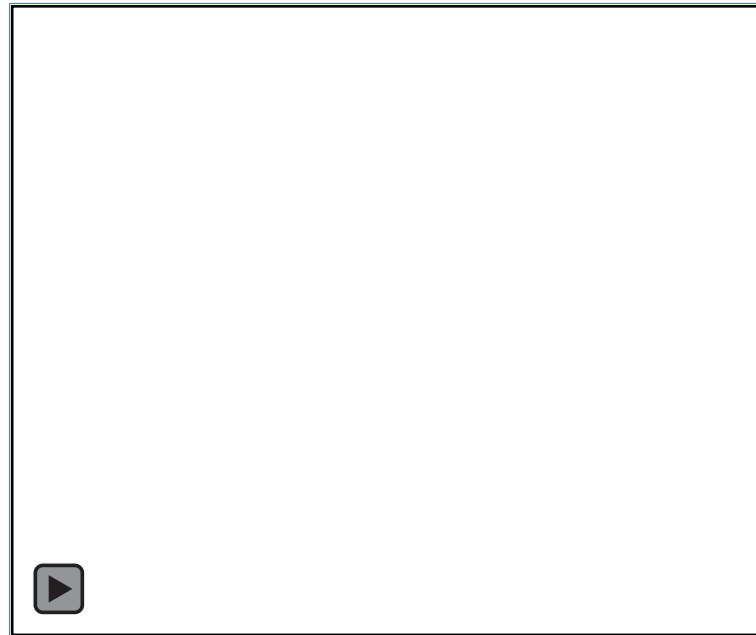
Levels of Confidence: L=Low, M=Moderate, H=High

Augmented reality for cost effective CAV testing at Mcity



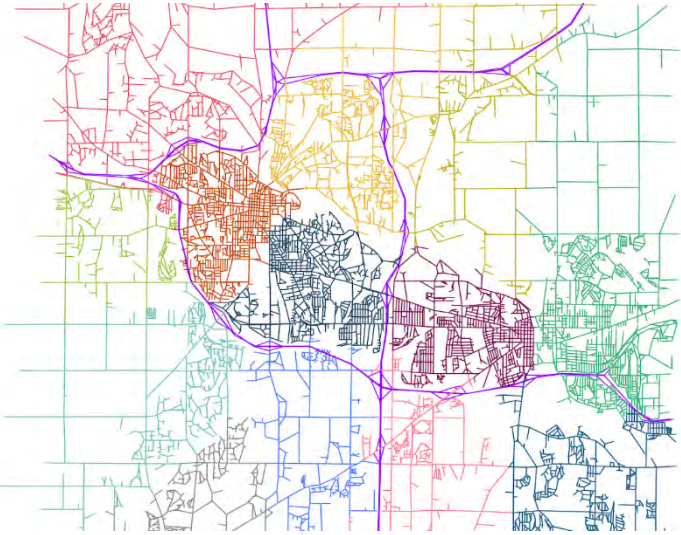
Baseline

VD Controller

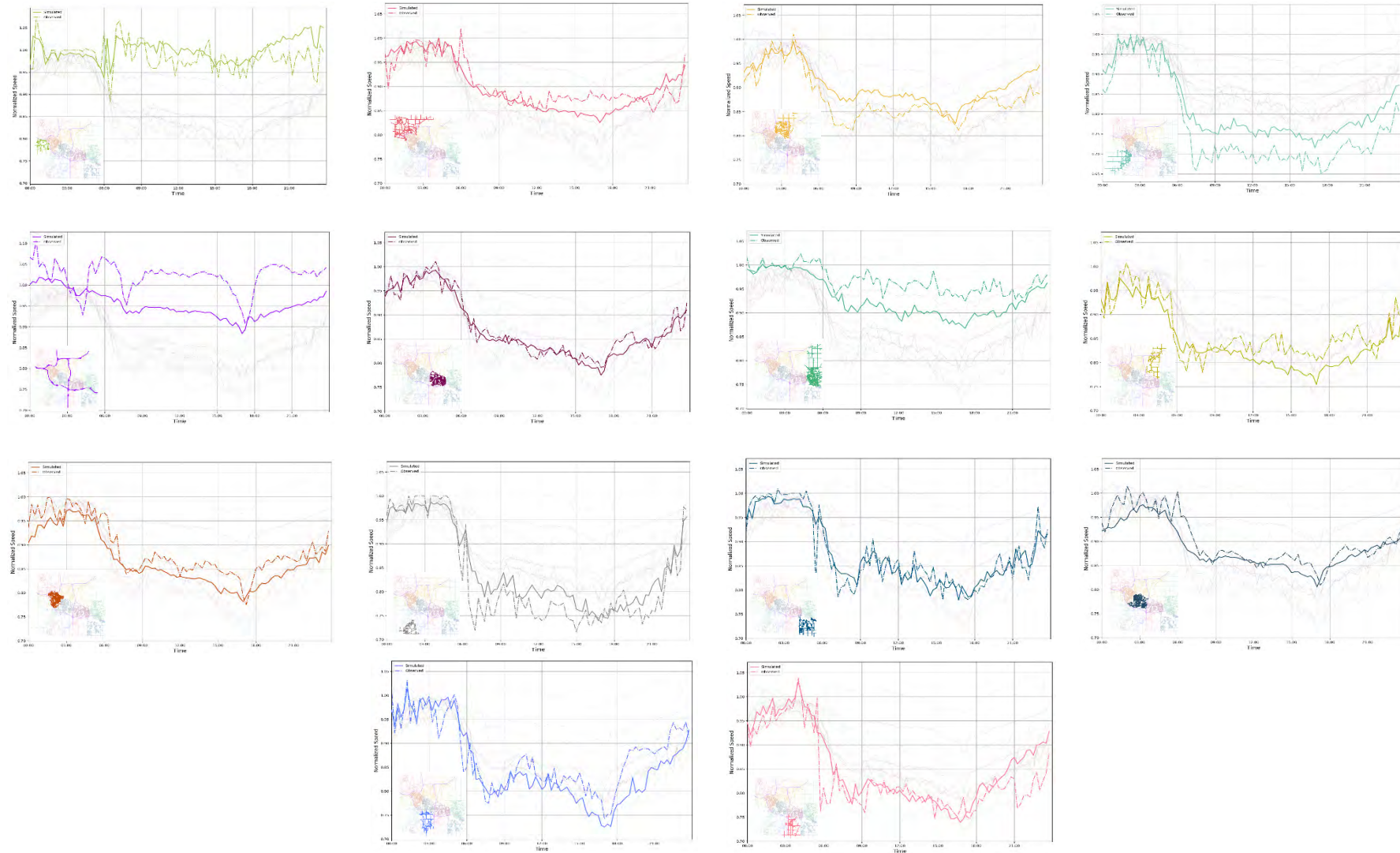


SUMO model for Ann Arbor (Calibrated by real data)

— Simulated and Observed average speed in each zone from 00:00 to 23:59

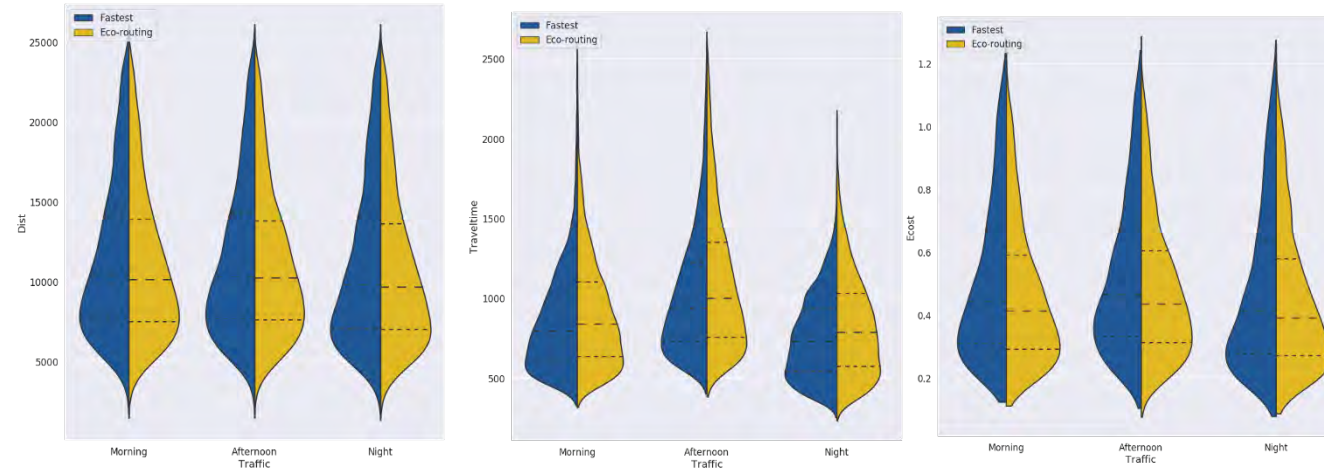


Simulated and Observed average speed



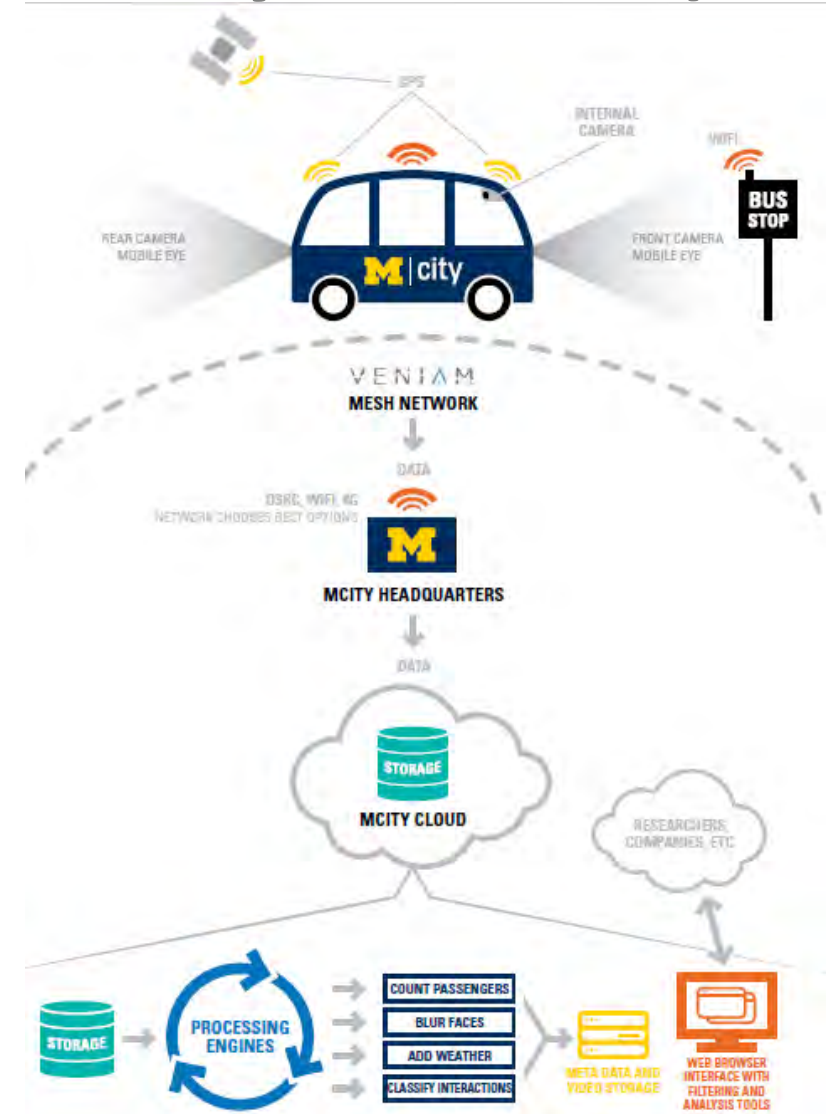
Time from 00:00 to 23:59

SUMO model for Ann Arbor (Eco-Routing results)



Method	Distance [m]			Travel Time [s]			Energy cost [\$]		
	Mor.	Aft.	Night	Mor.	Aft.	Night	Mor.	Aft.	Night
Fastest	10234	10120	9437	793 Est.(731)	936 Est.(835)	726 Est.(680)	0.44	0.46	0.41
Eco-routing	9949	10055	9263	836 Est.(782)	999 Est.(880)	785 Est.(733)	0.41 Est.(0.36)	0.43 Est.(0.38)	0.39 Est.(0.34)
Energy Saving [%]							6.5%	6.3%	5.3%

Mcity Driverless Shuttles (funding from Mcity members)



Mcity Driverless Shuttle Experience

- Video data shared with Mcity members
- User survey conducted by JDPower

Mcity Driverless Shuttle

A Case Study



M | city
UNIVERSITY OF MICHIGAN

Executive Summary 1
From the Mcity Director

01 Project Description 3
Research project description

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Legislation, policies, and exemptions

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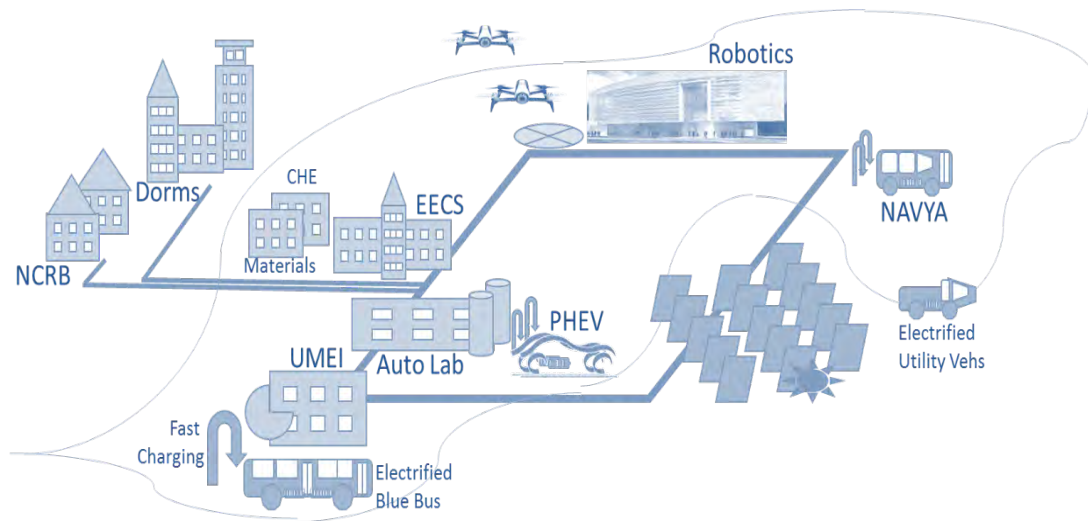
Lessons from Mcity 42
Summary

<https://mcity.umich.edu/wp-content/uploads/2018/09/mcity-driverless-shuttle-case-study.pdf>

Conclusion

- **Through DOE/DOT and Mcity members' investment, Mcity/Ann Arbor have become world's premier assets for CAV research**
- **Mcity**
 - Testing of CAV (HD-map, RTK, MKZ, V2X, 5G)
 - Augmented reality to simulate hundreds of other vehicles
 - In 5 software (Carsim, Prescan, Matlab/Simulink, Righthook, ANSYS)
- **Ann Arbor**
 - Driving data (500 vehicles, 8M miles + SPMD data 50M miles)
 - Plymouth + Washtenaw corridors smart signals instrumented
 - Calibrated model in Polaris and SUMO

How to leverage these unique assets for the next CAV/Mobility research?



Leadership Circle Members

With Support From

