Assessing the Effectiveness of Managed Lane Strategies for the Near-term Deployment of Cooperative Adaptive Cruise Control

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Background

- Safety
  - 35 thousand highway deaths & 3.6 million crashes in 2015*
  - 9.48 million out of 10.2 million of all the car crashes in the U.S. are caused by driver's mistakes**
- Mobility***
  - 6.9 billion hours of travel delay
  - $160 billion congestion cost
- Environment***
  - 3.1 billion gallons of fuel wasted
  - 60 billion pounds of additional CO_2

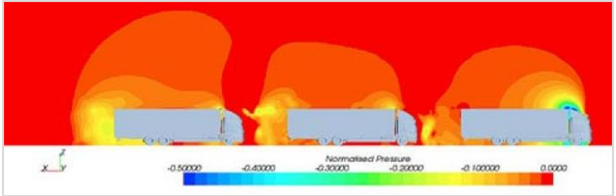
* Traffic Safety Facts, National Highway Traffic Safety Administration
**NHTSA 2008 Survey
***2015 Urban Mobility Scorecard, Texas A&M Transportation Institute and INRIX

Cooperative Adaptive Cruise Control

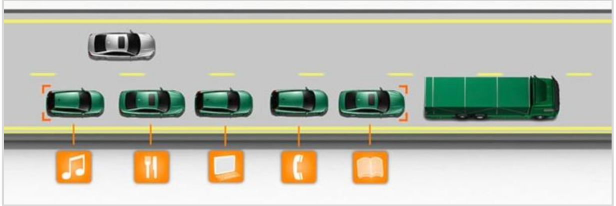
Cooperative Adaptive Cruise Control (CACC) is an extension of the adaptive cruise control with an extra layer of vehicle-to-vehicle communication. The motivations for CACC deployment includes:

1. To reduce traffic congestion by improving highway capacity and attenuating traffic flow disturbances
2. To reduce fuel consumption by decreasing air resistance via tightly coupled vehicle platoons
3. To improve safety, comfort, and convenience for users

source： 2016 Euro Truck Platooning Challenge



source: Japan ITS Energy Project



source: KONVOI

Near-term CACC Deployment

- The field testing of CACC has been accelerated in recent years.
- There are still questions:
  - The network-wide traffic impact of CACC vehicles under mixed traffic conditions
  - The induced lane changing due to active platoon formation
  - The deployment strategies to accommodate and incentivize CACC adoption under low market penetration
  - Cooperative driving framework
  - Imperfect DSRC communication

Level 1


Level 2

Here Today


Level 3


Level 4

In Testing


Level 5

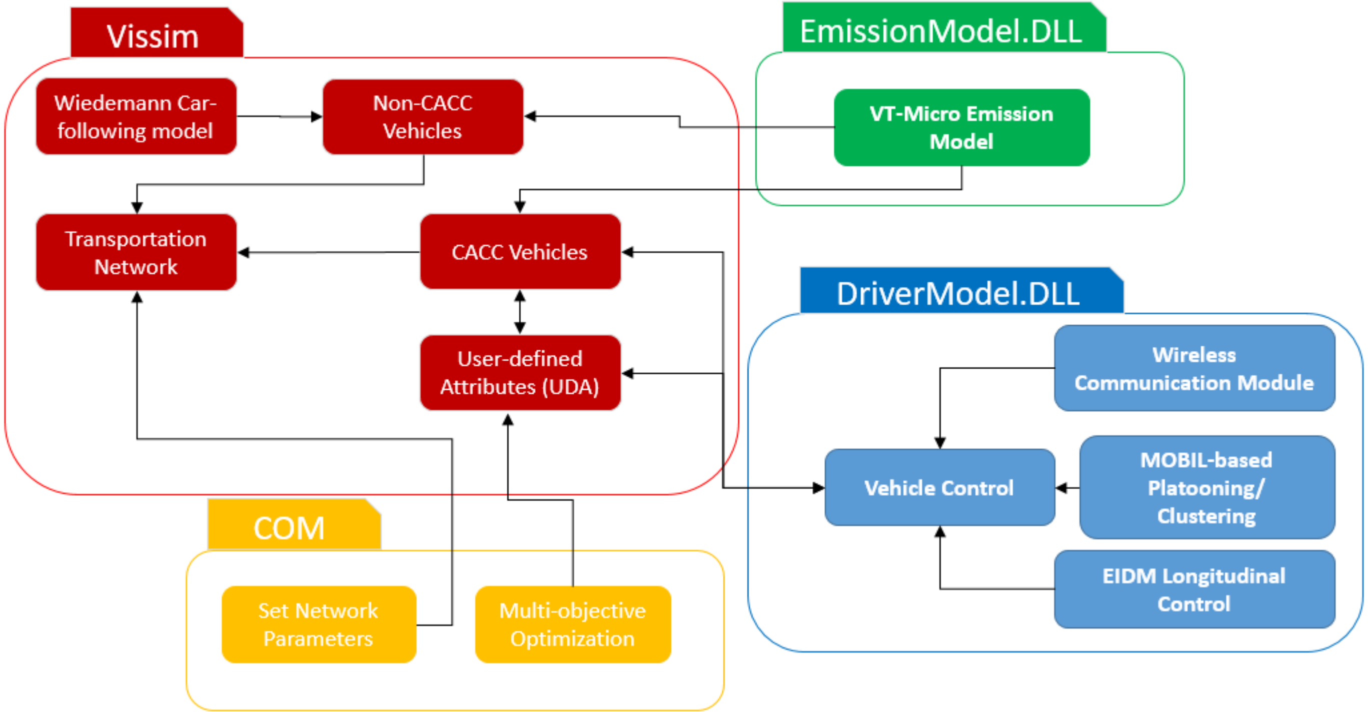
Level 5 Someday(?)

Research Goal & Objectives

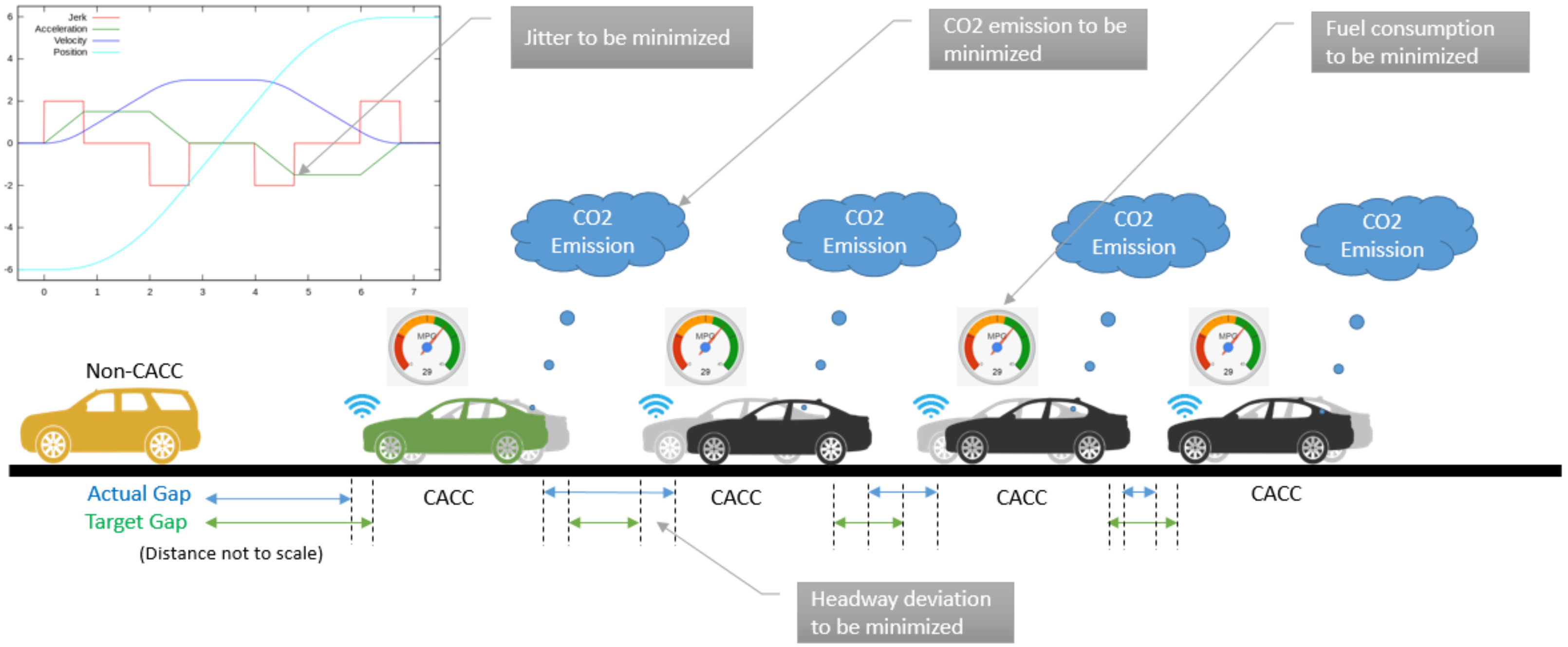
- Research Goal
  - To evaluate the impacts of deploying CACC vehicles into mixed traffic with managed lane strategies

- Objectives
  - a flexible microscopic simulation testbed
  - a multiobjective optimization control algorithm for cooperative driving
  - managed lane strategies
  - imperfect wireless communication

Evaluation Framework

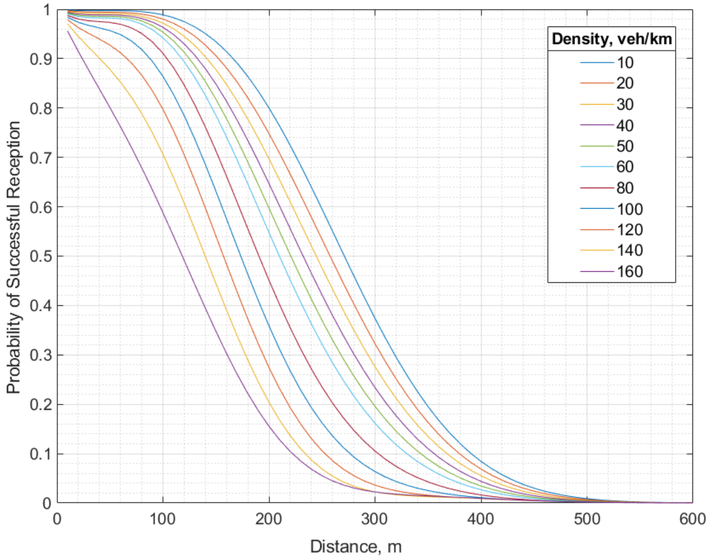


Multiobjective Cooperative Driving



DSRC Packet Reception Model

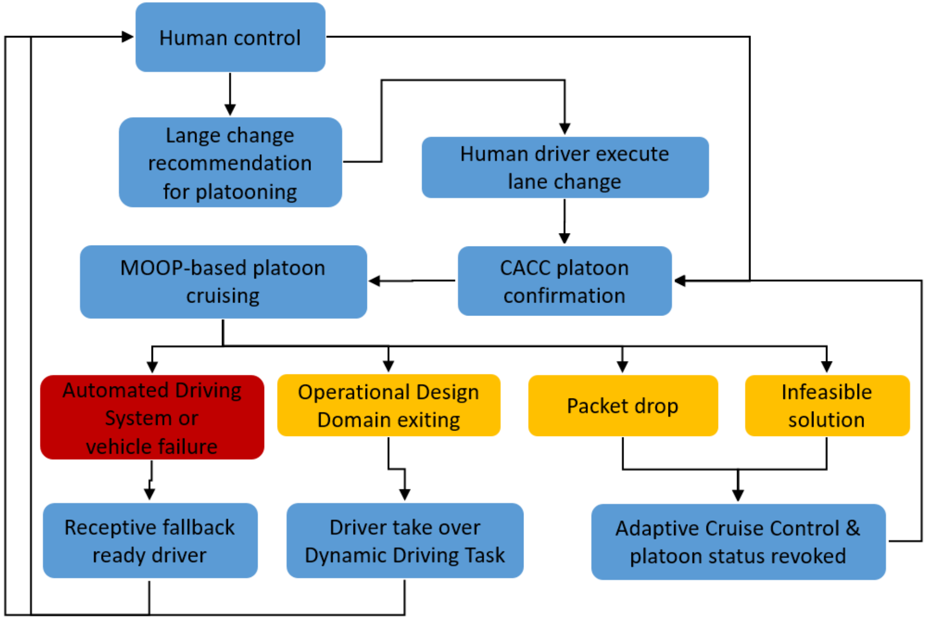
- The analytical DSRC packet reception model was derived from the ns-2, a packet-level network simulator, with DSRC communication protocol (Killat & Hartenstein, 2009)
- Model only considers packet reception at the physical (PHY) layer
- The packet reception probability is based on transmission distance and communication density
- The communication density is the product of transmission power (m), vehicle density (veh/km), and transmission frequency (Hz)



probability density curve for packet reception

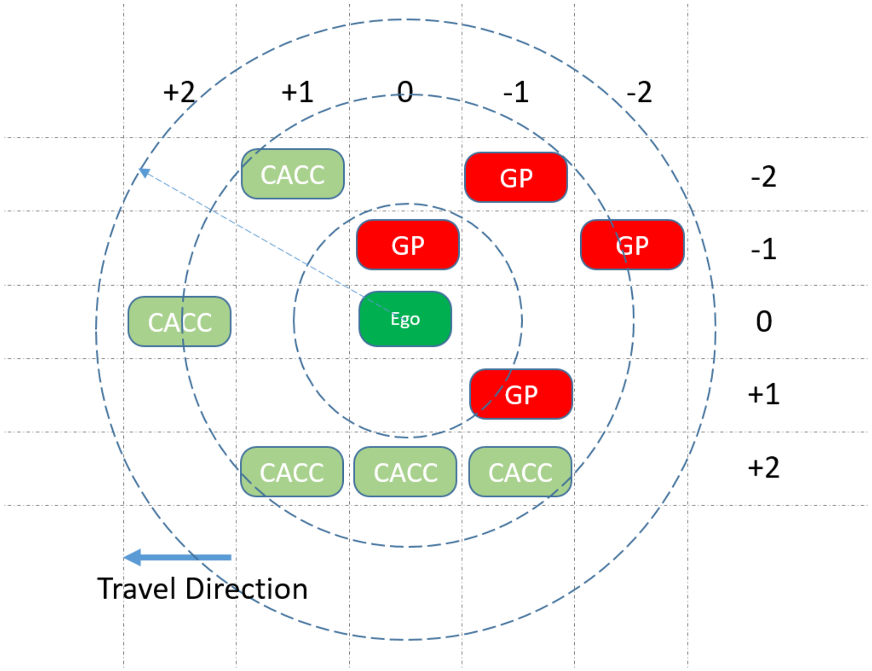
CACC Fallback Logic

- Operational Design Domain exiting
  - A CACC vehicle reaches its destination and performs lane change to exit a platoon
  - Under congestion where speed is lower than the pre-defined speed
- Packet drop or infeasible solution
  - CACC falls back to Adaptive Cruise Control
  - Platoon status is revoked temporarily



Functions of the DriverModel.DLL

- Execute active platoon formation algorithm
  - scan the surrounding at each simulation time step for platoon formation opportunity
  - select the lane change with least impact based on MOBIL (Kesting et al., 2007)
  - initiate the lane change
- Update the optimal acceleration obtained from Vissim COM
- Implement DSRC packet reception model



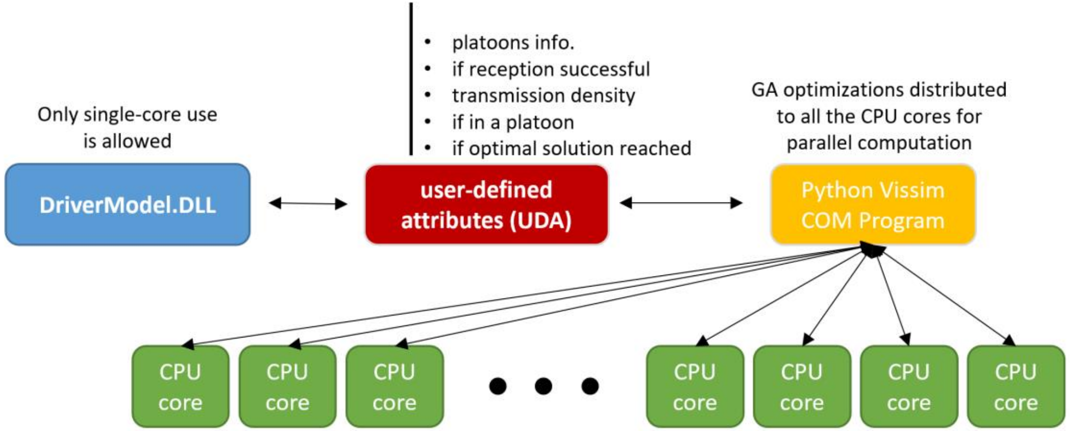
DriverModel.DLL vehicle visibility

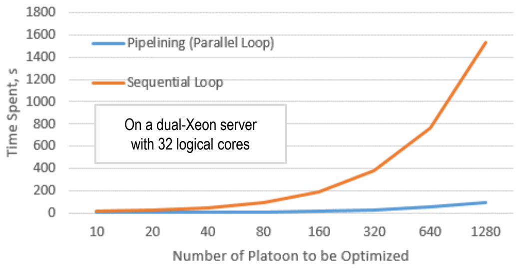
UNIVERSITY OF DELAWARE

NJIT New Jersey Institute of Technology

Scalability of the Testbed

- The hybrid approach with the analytical DSRC module for large-scale networks.
- Optimizations distributed to multiple CPU cores for parallel computation
- Minimization of the information being exchanged at the COM interface
- Disable GUI updating and enable Quick Mode via the COM interface





I-66 Simulation Testbed

- The I-66 Segment, VA
  - A major commuter corridor outside of the beltway of Washington D.C. with recurring congestion during peak hours
  - The chosen segment is 8-km (5-mile) long with 2 interchanges and 4 lanes in each direction
  - An HOV lane implemented in the leftmost lane
  - Driving behaviors calibrated by TMC data (travel time) and RTMS (speed-flow) data of PM-peak hours

Managed Lane Strategies

Strategy	ID	1st Lane	2nd Lane	3rd Lane	4th Lane (leftmost)	MP, %	Access Control
Base case	BASE	GP+ HOV	GP+ HOV	GP+ HOV	HOV	N/A	No
Unmanaged lane	UML	GP + CACC	GP + CACC	GP + CACC	GP + CACC	10~50	No
Mixed managed lane	MML	GP + CACC	GP + CACC	GP + CACC	CACC + HOV	10~50	No
CACC lane w/o access control	DL	GP + CACC	GP + CACC	GP + CACC	CACC	10~50	No
CACC lane w/ access control	DLA	GP + CACC	GP + CACC	GP + CACC	CACC	10~50	Yes

Simulation Assumptions

- The calibrated vehicle behaviors in Vissim realistically represent the road users' driving behaviors.
- Only the physical layer is considered for the success of packet reception
- The vehicle controller is free of control errors.
- The lateral control for platoon formation is conducted by human drivers with recommendations for lane change from the CACC system.
- Human-driven vehicles treat CACC vehicles as another human-driven vehicles. (no indication whether a vehicle is equipped with CACC system)

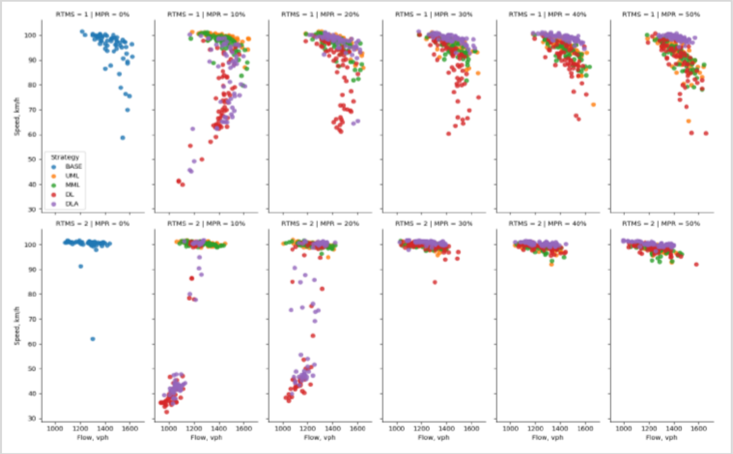
Simulation Data Collection

- Aggregated Data
  - data collections
  - links
  - vehicle network performance
  - vehicle travel time
- Direct Output
  - vehicle travel time (raw data)
  - data collection (raw data)
  - lane changes
  - vehicle record
- Animation

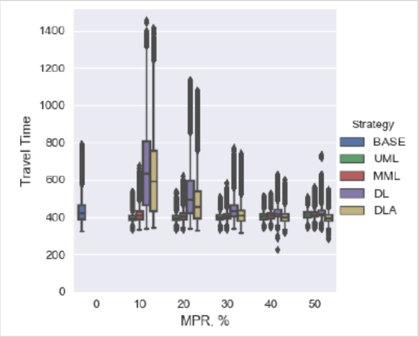
→

- Common MOEs
  - VMT, VHT
  - throughput
  - fuel consumption
  - travel time speed variance
- **Communication MOEs**
  - **transmission density**
  - **packet reception probability**
- **CACC Platoon MOEs**
  - **average platooned ratio**
  - **average platoon depth**
  - **vehicle-hour platooned**

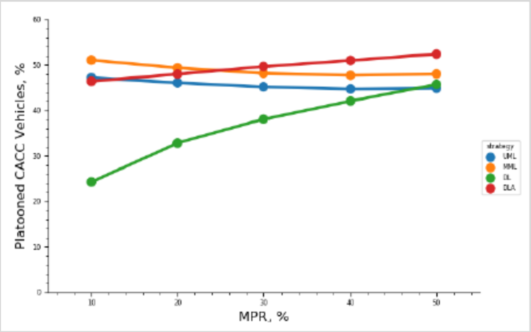
Measures of Effectiveness



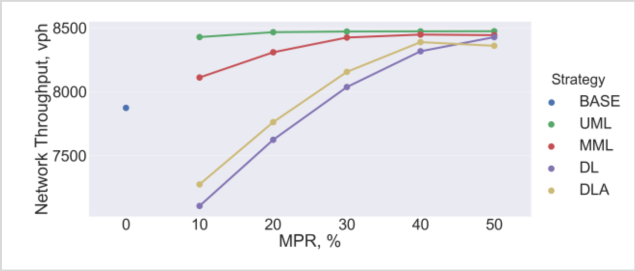
speed-flow diagram (point measure)



corridor travel time

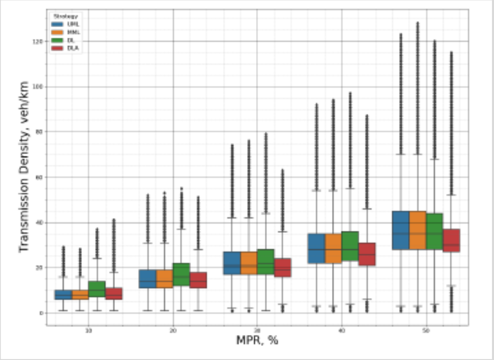


percentage of platooned CACC



network throughput

mean corridor travel time
(vehicle type specific)



transmission density

Evaluation Score Matrices

	10%	20%	30%	40%	50%
UML	4	4	4	3	3
MML	4	4	4	4	3
DL	-4	-4	1	4	4
DLA	-4	-4	1	4	4

mobility scores

	10%	20%	30%	40%	50%
UML	1	1	1	1	1
MML	1	1	1	1	1
DL	-1	-1	0	1	1
DLA	-1	-1	0	1	1

equity scores

	10%	20%	30%	40%	50%
UML	1	1	1	1	1
MML	1	1	1	1	1
DL	-1	-1	0	1	1
DLA	-1	-1	1	1	1

safety scores

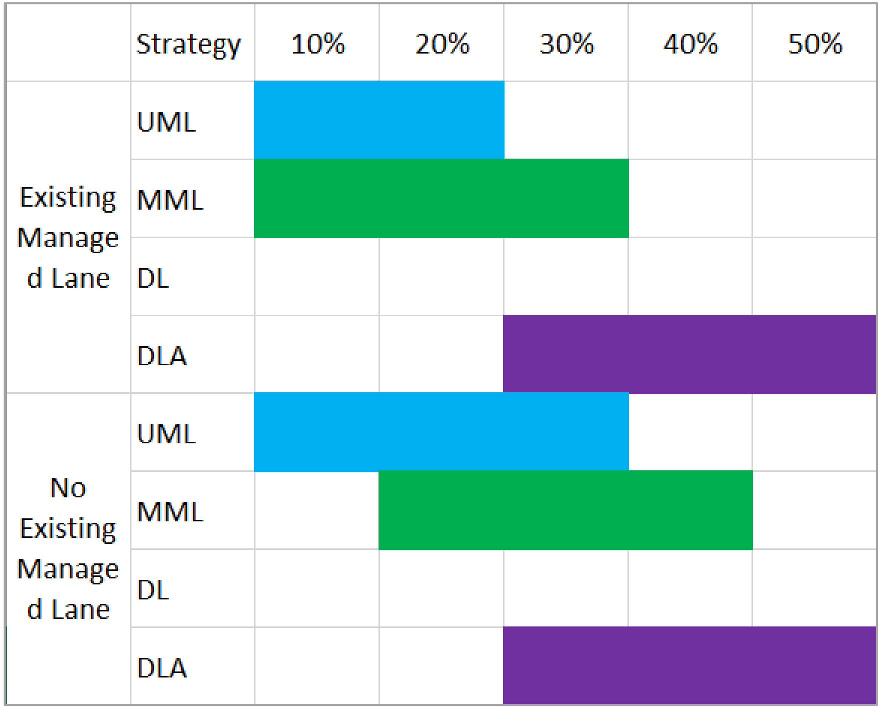
	10%	20%	30%	40%	50%
UML	10	8	6	7	7
MML	10	10	10	9	9
DL	7	4	3	4	6
DLA	4	8	10	9	10

platoon formation scores

MOEs	Evaluation Score Assignment
Mobility, safety, equity, and environmental impact	improvement: 1 neutral: 0 degradation: -1
CACC platooning	ranked among 4 strategies 1st : 4 (best) 2nd: 3 3rd: 2 4th:1 (worst)

Conclusions

- Roadways with an existing managed lane facility
  - mixed managed lane is a suitable strategy, but unmanaged lane still produces acceptable results.
- Roadways without an existing managed lane
  - the unmanaged lane is preferred at low MP, until mixed managed lane or dedicated lane with access is warranted by the MP of CACC.
- Dedicated lane with access control recommended for scenarios with MP over 30%



Future Research

- Operational strategies to accommodate the induced weaving activity during the platoon formation
- Optimization-based lane change decision algorithm for platoon formation
- Objective prioritization based on roadway characteristics (e.g., heavy merging area, work zones)
- Vehicle dynamics model in longitudinal control
- Communication topology of for the intra-platoon communication

CACC Related Publications

- Z. Zhong, J. Lee, "Simulation Framework for Cooperative Adaptive Cruise Control with Empirical DSRC Module (forthcoming)," in 44th Annu. Conf. of IEEE Ind. Electron. Soc., Washington DC, USA, 2018
- Z. Zhong, J. Lee, and L. Zhao, "Multiobjective optimization framework for Cooperative Adaptive Cruise Control vehicles in the automated vehicle platooning environment," Transp. Res. Rec. J. Transp. Res. Board, vol. 2625, pp. 32–42, 2017.
- Z. Zhong, J. Lee, and L. Zhao, "Evaluations of managed lane strategies for arterial deployment of cooperative adaptive cruise control," in 96th Transp. Res. Board Annu. Meeting, Washington, DC, USA, 2017.
- J. Lee, Z. Zhong, and L. Zhao, "Multi-objective Optimization Controller for Cooperative Adaptive Cruise Control," in 95th Transp. Res. Board Annu. Meeting, Washington, DC, USA, 2016.

Thank you for your attention
Q&A

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