A Prioritized Trajectory Planning Algorithm for Connected and Automated Vehicle Mandatory Lane Changes

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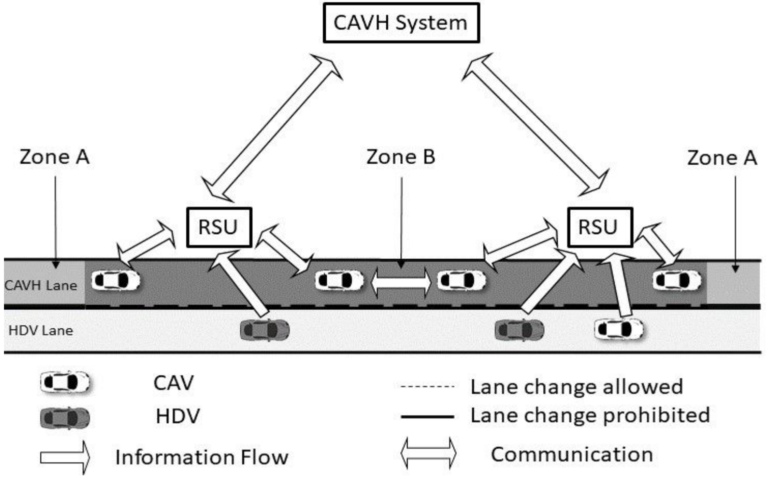
Authors: Nachuan Li*, Austen Z. Fan, Riley Fischer, Wissam Kontar and Bin Ran

Presenter: Nachuan Li (+1) 608 590 2155 nli63@wisc.edu

University of Wisconsin-Madison Department of Civil and Environmental Engineering

Setting



-Macroscopic routing decision given for each CAV

- -Mandatory lane changes (MLCs) guided by routing decisions

-Geometry

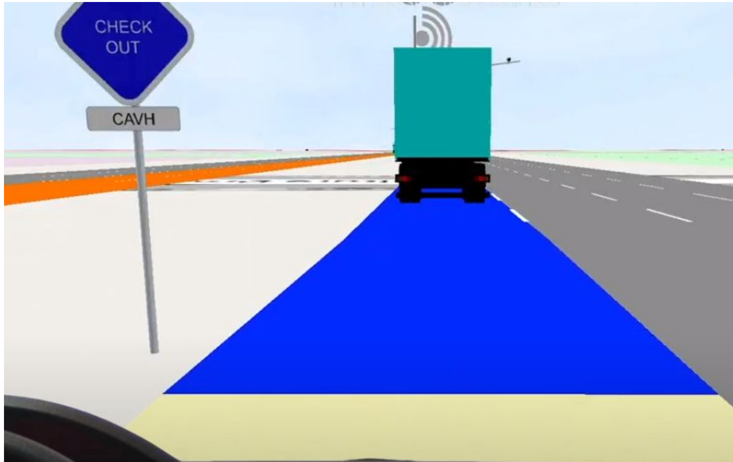
- -An innermost CAVH dedicated lane with CAVs only
- -Other HDV lanes with mixed traffic
- -A diverging zone (Zone B) allowing only lane changes of CAVs from dedicated lane into HDV lane

-CAVH intelligence level 3

- -Partial Automation
- -Driver Assistance System
- -Hands off in dedicated lane

-V2V and V2I communication

- -Roadside units detect instantaneous information of all vehicles
- -System communicates with and controls CAVs in dedicated lane



Problem Statement

Customers: CAVs executing MLCs from diverging zone into HDV lane

Service: Trajectory Planning, Preparation for MLCs

Our Algorithm

- **Prioritized:** CAVs near the end of the diverging zone given priority in planning
- **System-Optimal:** Minimizes the total travel time for CAVs in the diverging zone for each decision making
- **MLC-Aware:** Gives time and space for consecutive MLCs into the off-ramp
- **Safety-Guaranteed:** Ensures collision avoidance and gap acceptance

Motivation: MLC

Importance:

-Guided by routing decisions

-A major reason for congestion at bottlenecks

Challenges:

-Limited length of the the diverging zone

-Urgency posed by routing decision

-Unpredictability of HDVs on the adjacent lane

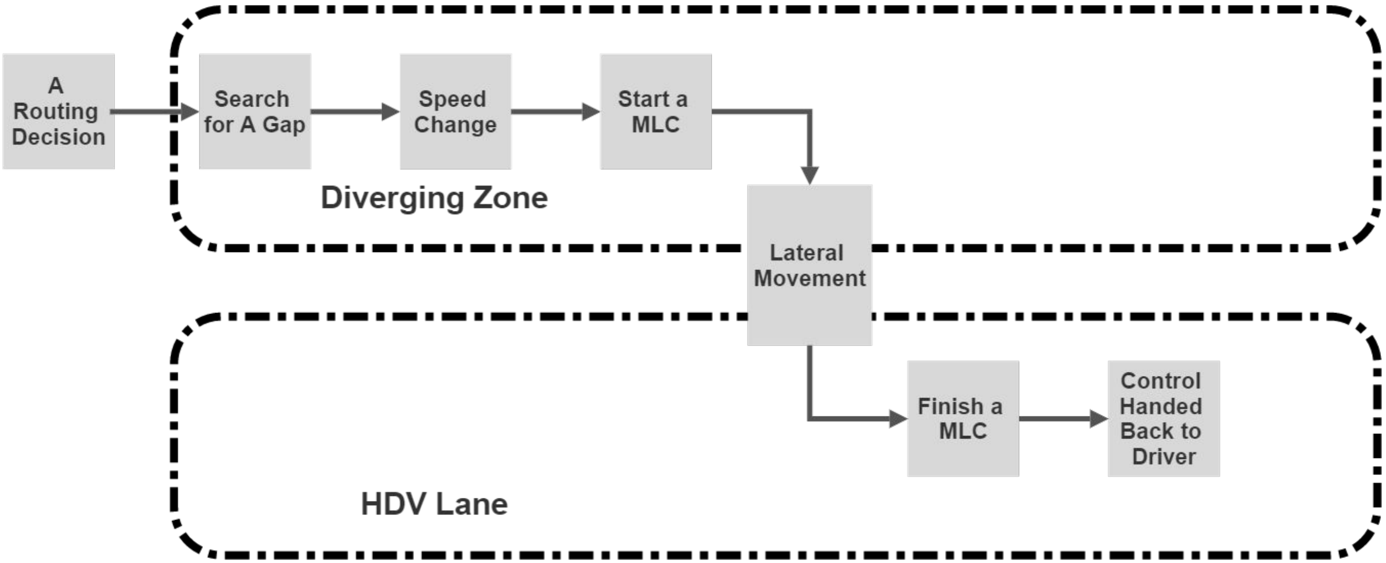
-Lacks data set

-Few studies considering MLC for CAVs on a system level

Assumptions

-Passenger cars only in the network

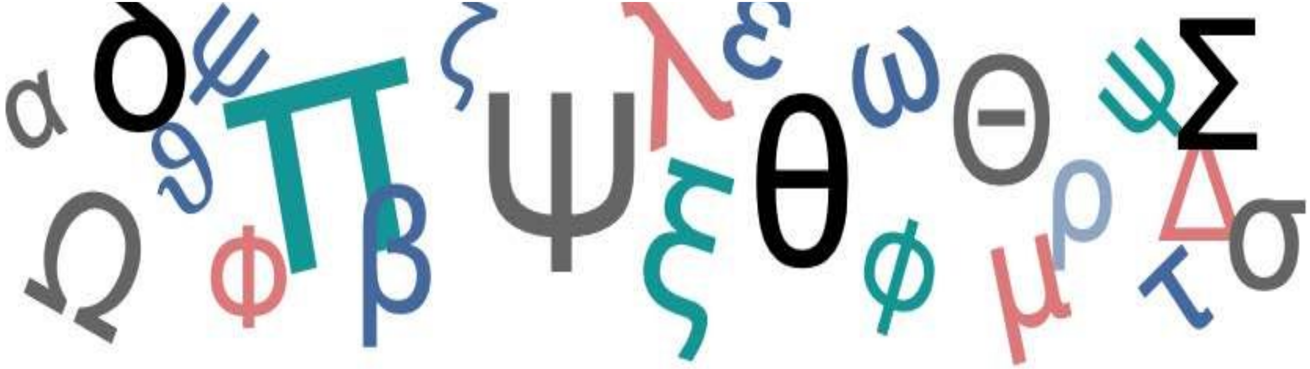
-Offers planning for only processes in the diverging zone



Definitions: Kinematic Parameter

Kinematic Parameter: A parameter chosen by a vehicle that affects its motion

Sufficient Tuple of Kinematic Parameters: A tuple of kinematic parameters given which the position is a function of time



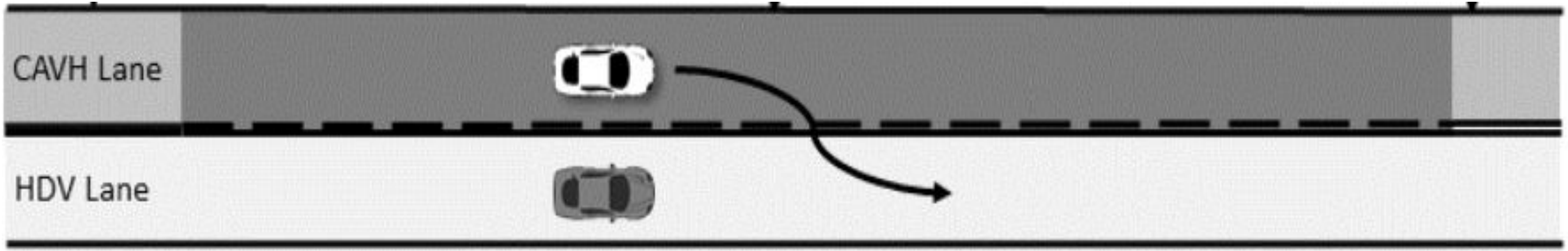
Definitions: Space Time Slot (STS)

Space Time Slot (STS): An ordered pair of time and position

Category\Factors to be satisfied	Central Vehicle Kinematic Parameters	Longitudinal Collision Avoidance	Gap Acceptance on HDV Lane
Reachable STS	Exists at least 1 sufficient tuple	N/A	N/A
Attainable STS	N/A	Satisfied	N/A
Joinable STS	N/A	N/A	Satisfied
Candidate STS	Exists at least 1 sufficient tuple	Satisfied	Satisfied

Definitions: Trajectory

Feasible Trajectory: A trajectory whose STS's are all reachable, attainable under the same sufficient tuple of kinematic parameters, and ends with a candidate STS.



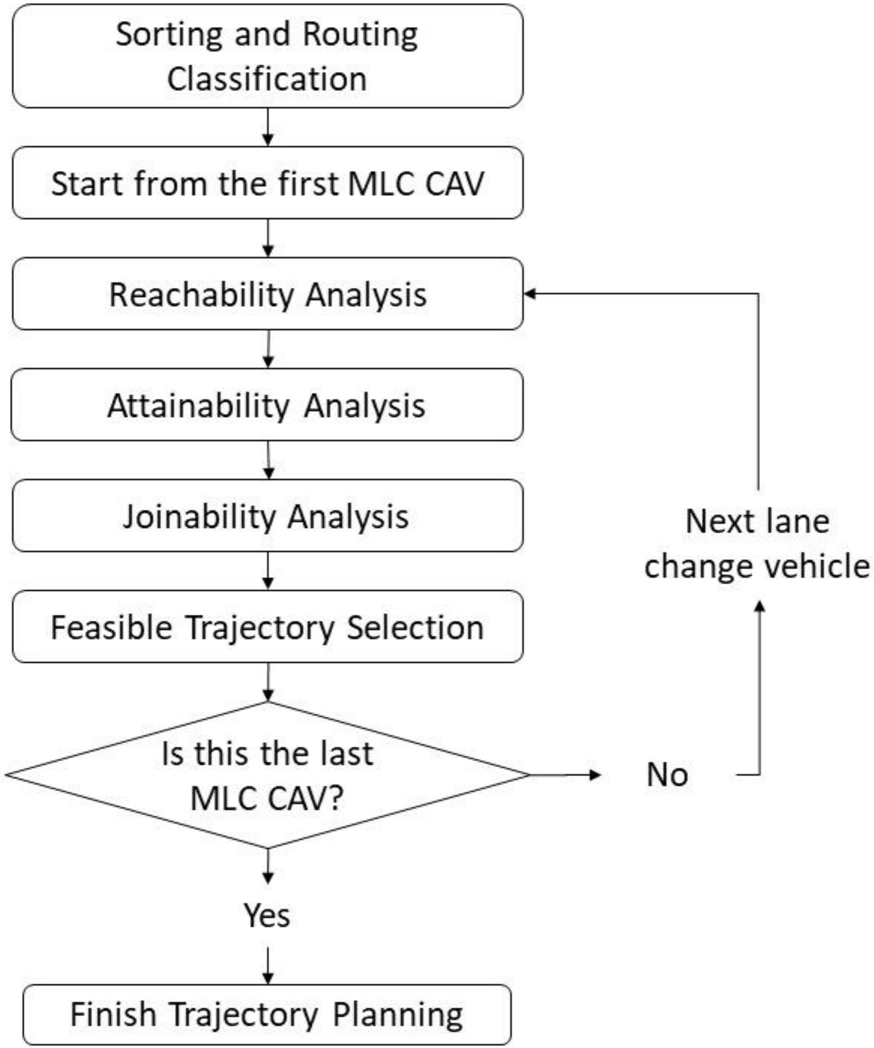
Algorithm: Framework

Sorting and routing Classification:

- **Sorting:** Sort the position of CAVs in the diverging zone with descending order
- **Classification:** Classify the routing decisions of CAVs
- **Extract HDVs:** Based on HDVs' location, extract those that could influence MLC CAVs' decisions
- **Predict HDVs:** Predict or Interpolate the future positions of HDVs

Start iteration:

- Start iterating over each MLC CAV in the diverging zone



Algorithm: Framework

Reachability Analysis:

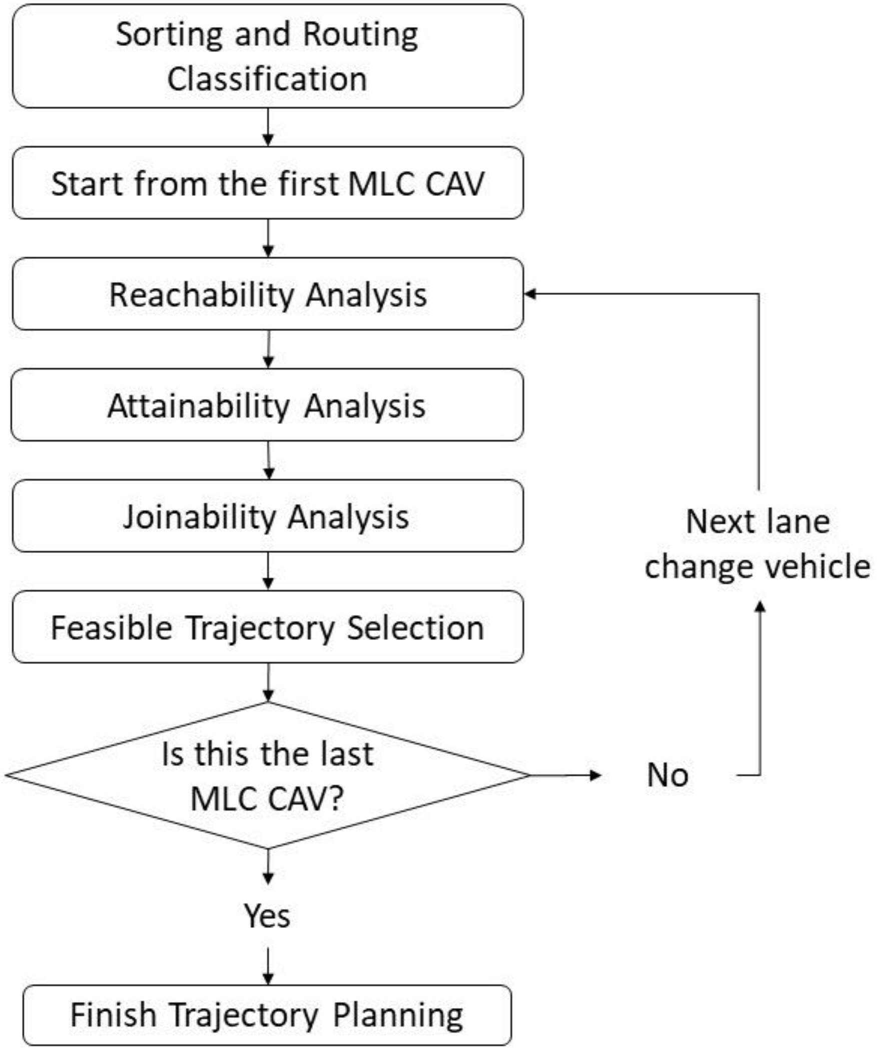
- Get all possible sufficient tuples of kinematic parameters
- Get all reachable STS's of a MLC CAV
- Organize reachable STS's by kinematic parameters

Attainability Analysis:

- Get all attainable STS's based on leading MLC CAVs' optimal trajectory, leaving space for non-MLC CAVs

Joinability Analysis:

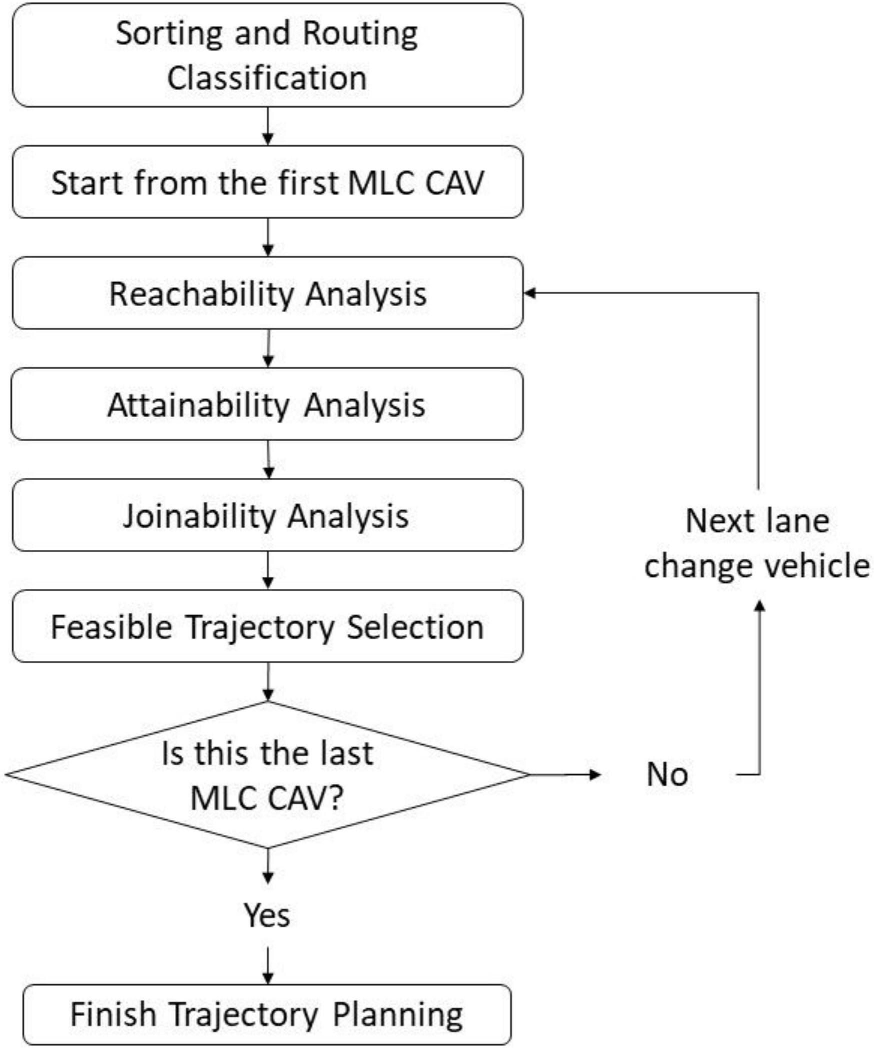
- Based on the interpolated trajectories in HDV lane, get all joinable STS's



Algorithm: Framework

Feasible Trajectory Selection:

- Get all candidate STS's by taking the intersection of reachable, attainable and joinable STS's
- Extract feasible trajectories that ends at each candidate STS's
- Among the feasible trajectories, select the optimal trajectory based on a cost function
- Interpolate the motion in the HDV lane after the CAV's MLC, and reserve the spacing



Algorithm: Framework

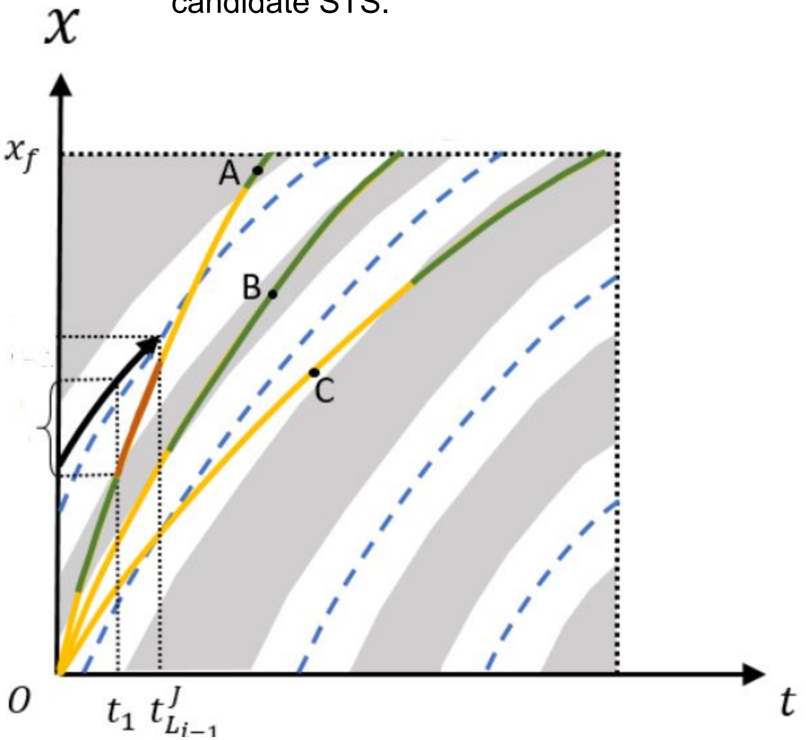
Feasible Trajectory: A trajectory whose STS's are all reachable, attainable under the same sufficient tuple of kinematic parameters, and ends with a candidate STS.

Example:

- 3 sufficient tuples of kinematic parameters available

- **Dashed Line:** HDV trajectories
- **Black Arrow:** Leading CAV in the Diverging Zone
- **Shaded Area:** Joinable STS's
- **Red Line:** Reachable, but not Attainable
- **Yellow Line:** Reachable, Attainable but not Joinable
- **Green Line:** Candidate STS's

- **OB:** A Feasible Trajectory



Case Study

Car Following Model: Spring Mass Damper Model with no Leader

- Only 1 element in each sufficient tuple of kinematic parameter

Cost Function:

1) Total delay in the diverging zone

   +

2) Expected detour time if a CAV fails to exit at the target off-ramp

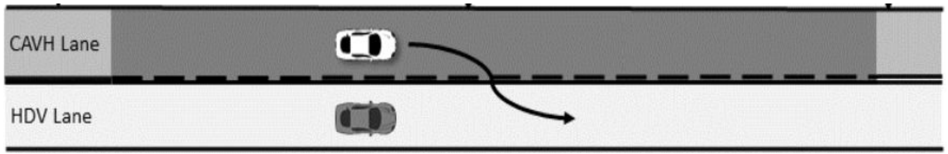
HDV Speed Prediction Model: Uniform Speed Prediction

- Advantage: Do not need to perform training
- Disadvantage: Lacks Accuracy

Simulation

Geometry:

- An inner CAVH dedicated lane
- An outer HDV lane
- 1500m of diverging zone



Initialization:

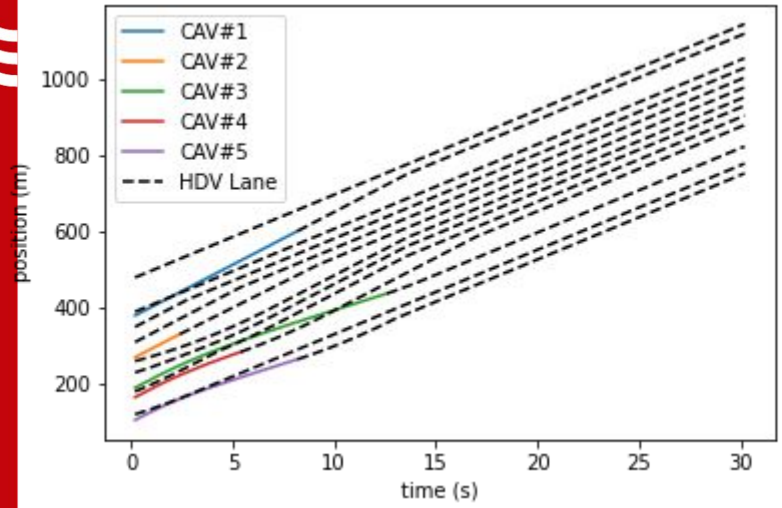
- 5 CAVs with initial speed of 100km/h and position randomized in the first 500m of diverging zone
- 8 HDVs with initial speed between 60km/h and 100km/h, desired speed between 80km/h and 100km/h, and random initial position in the HDV lane
- Vehicles in HDV lane use Newell car-following model

Comparison:

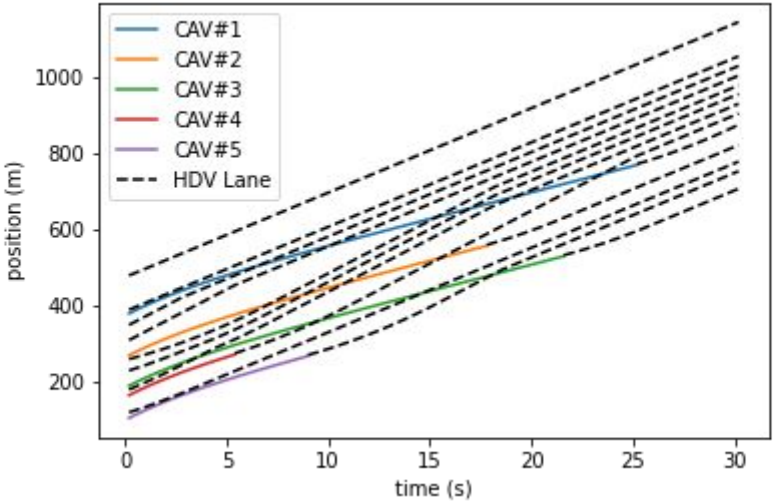
- Prioritized System-Optimal Algorithm **vs.** Gap Acceptance Model

Results: Position-Time Diagram

Prioritized System-Optimal Algorithm

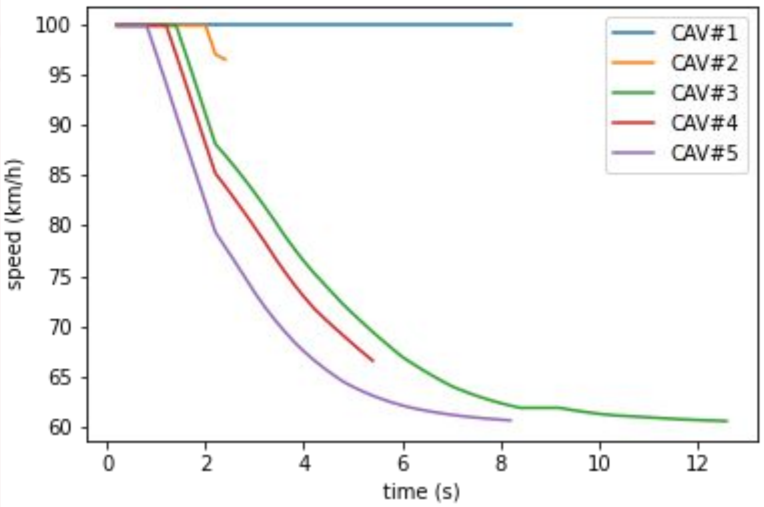


Gap Acceptance Model (Theoretical)

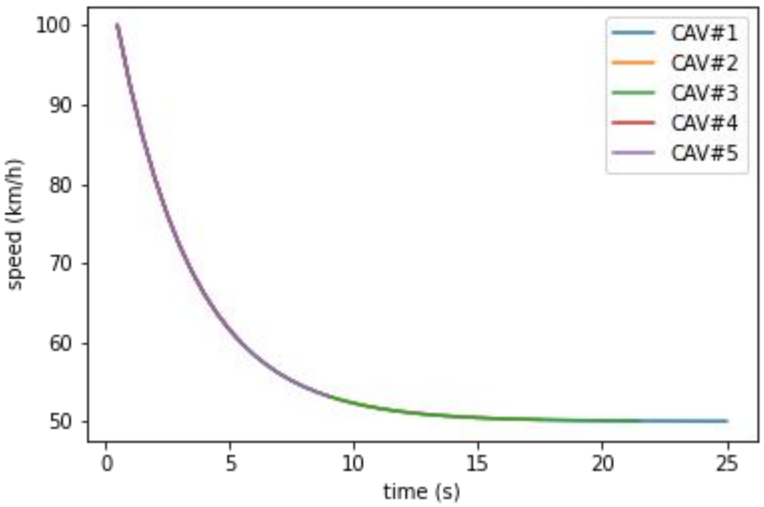


Results: Speed-Time Diagram (Diverging Zone)

Prioritized System-Optimal Algorithm



Gap Acceptance Model (Theoretical)



Results: Metrics

Metric/Model	Gap Acceptance Model	Prioritized System- Optimal Algorithm
Average Speed in Diverging Zone	63km/h	85km/h
Average Distance Driven before a MLC	257.82m	162.1m
Average Time Driven before a MLC	15.60s	7.16s
Calculation Time per CAV	N/A	0.03s

Results: Discussions

Advantages of Prioritized System-Optimal Algorithm:

- Produced relatively smooth speed change
- Earlier time taken before MLC executions
- Earlier distance driven before MLC executions
- Higher average speed in the diverging zone
- Efficient utilization of spacing in HDV lane
- Relatively low run-time

Future Research

Sources of Improvements:

- Examine the application of other car-following models
- Test on other cost functions
- Apply machine learning to forecast trajectories in the HDV lane
- Carry out a larger-scaled simulation to further examine the efficiency
- Consider semi-trucks and buses in the algorithm

Thanks for Listening!

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