Autonomous Lane-Changing System at Congested Merging Area

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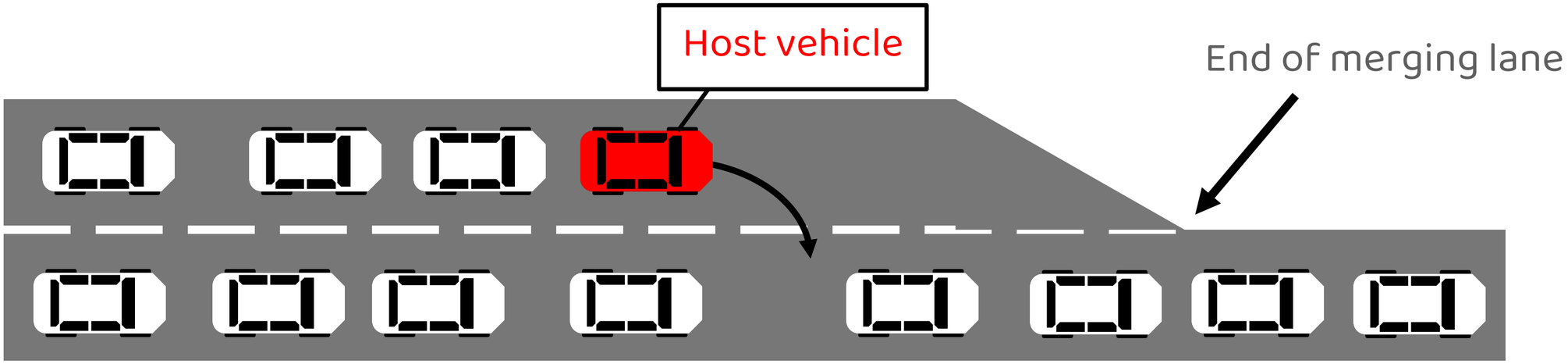
Introduction

Lane change is one of main factors of car accidents



- Giving too much priority to avoid collisions can cause congestion in merging lane
- Risky lane changes can cause collisions with vehicles in main lane

Lane-changing decision requires complex situational awareness

Previous Studies

- Gap acceptance mode [Toledo et al., 2003]

  : evaluates possibility of lane changes based on critical gap

  : Critical gap is calculated based on predetermined parameters

  : **does not consider characteristics of surrounding drivers**

  : **gives too much priority to avoid collisions**

- Vehicle-to-vehicle (V2V) communication for lane chagne at merging area [Yajima et al., 2019]

  : All vehicles need to have a communication system for sharing their intentions

  : **cannot be applied to vehicles without V2V system**

Objectives

Autonomous lane-changing system

considering characteristics of surrounding drivers

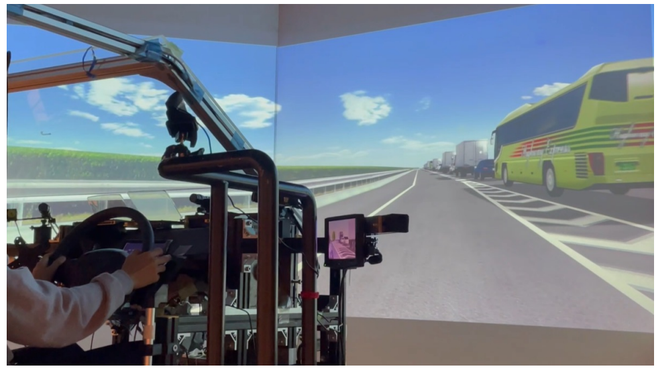
without V2V system

Approach

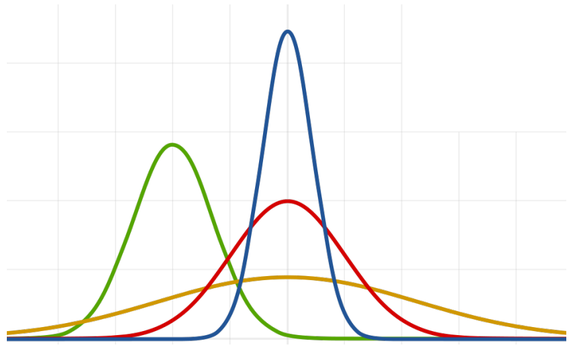
Our apporach is to

- **measure operation of human drivers** through driving simulator (DS)
- construct lane-changing decision algorithm by **imitating human's operation**

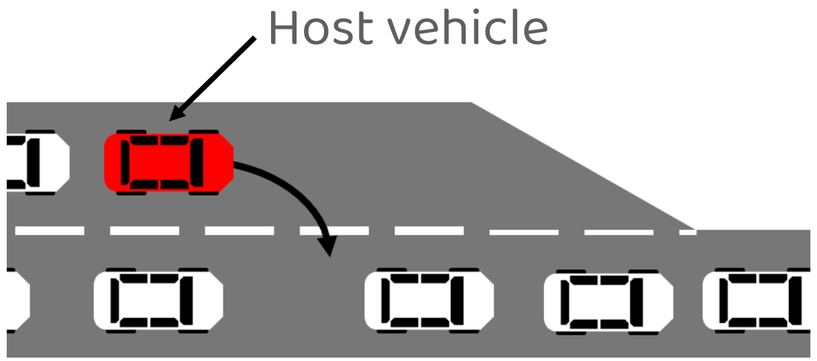
DS experiments



Analysis

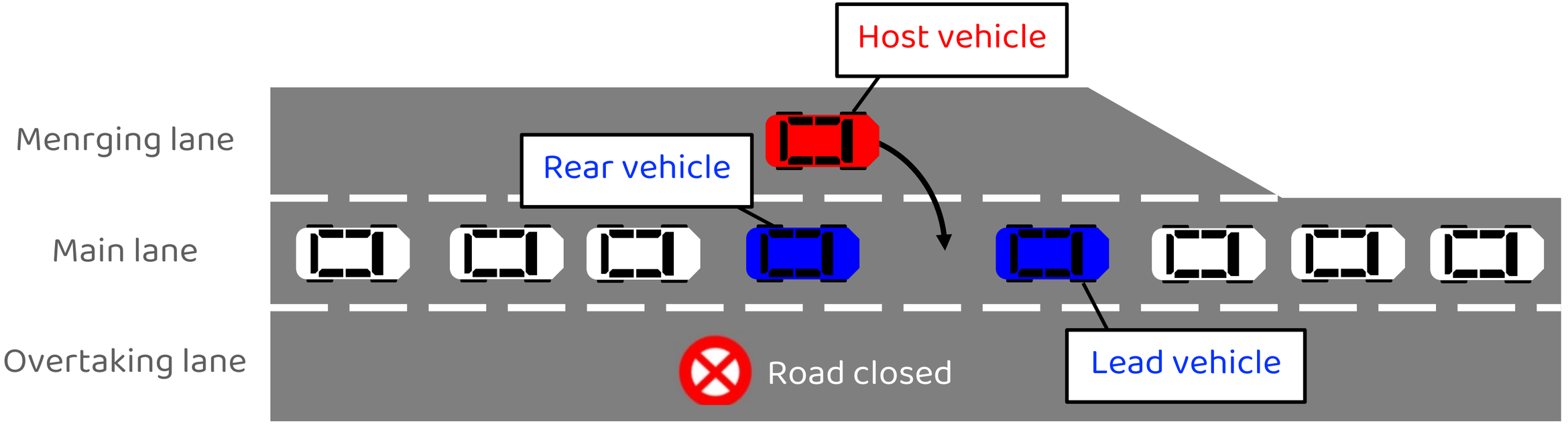


Implementation



Problem Definition

- Number of lanes at merging area is 3: merging, main, and overtaking
- Overtaking lane is closed
- Host vehicle needs to change lane before reaching end of merging lane
- Host vehicle has measurement devices such as LiDARs, radars, or cameras

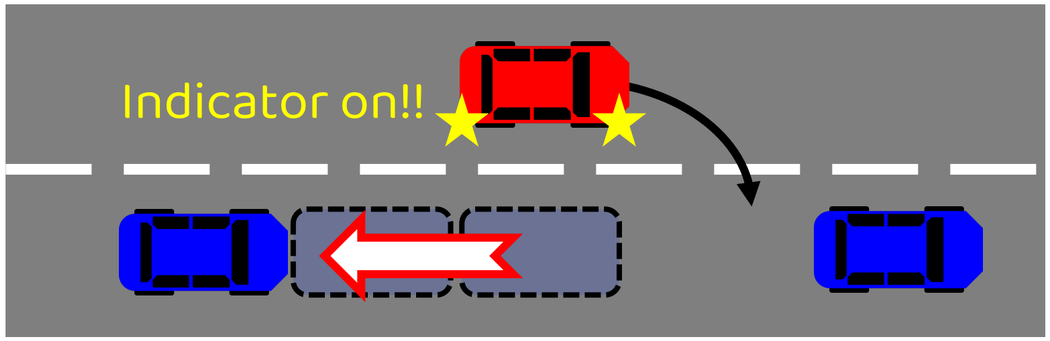


Difficulty Level of Lane Changes

There are various drivier in real world

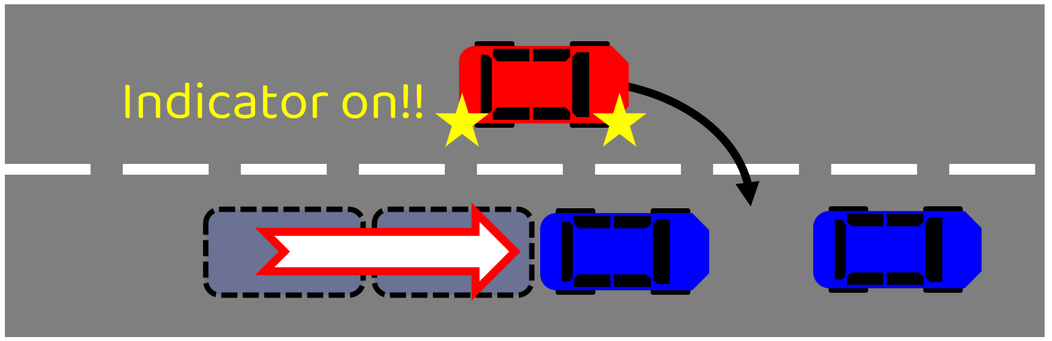
To reflect this situation, **difficulty level of lane changes is defined as several stages**

Example of generous driver



Accept lane change

Example of strict driver



Refuse lane change

Construction of autonomous lane-changing system

Proposed method consists of 2 modules:

Lane-Changing Decision

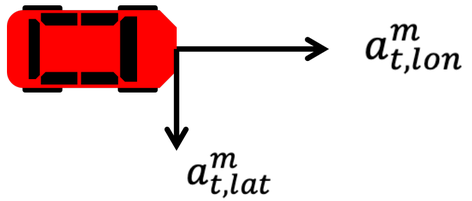
- **outputs probability**
  that lane change can be performed w/o collisions
  based on movements of rear vehicle

- **uses Gaussian probability density model**
  : time headway and inter-vehicle gap are used
  as explanary variables

- **defines distributions of explanary variables**
  based on DS experiments results

$$f(x|\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma^2}}\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

Path Planning



- calculates logitudinal acceleration
  based on **adaptive cruise control algorithm**

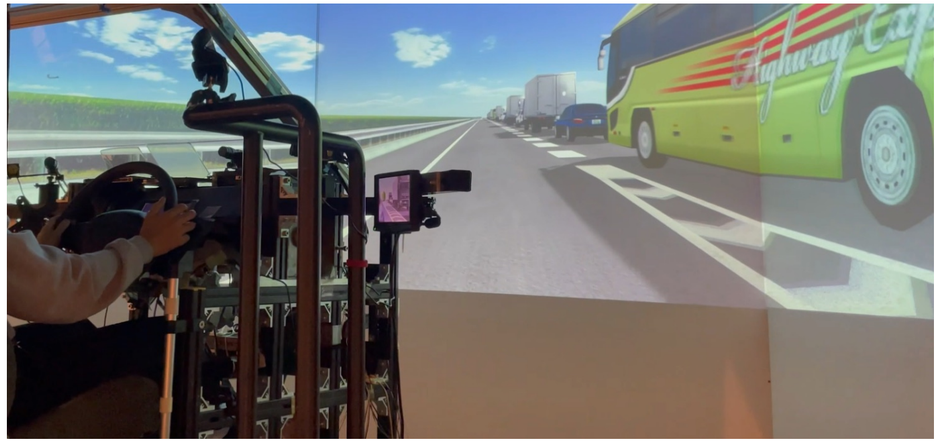
$$a^m_{t,lon} = k_1\left(x^l_t - x^m_t - t_{hw}v^m_t\right) + k_2\left(v^l_t - v^m_t\right)$$

- calculates lateral acceleration
  based on **sinusoidal model**

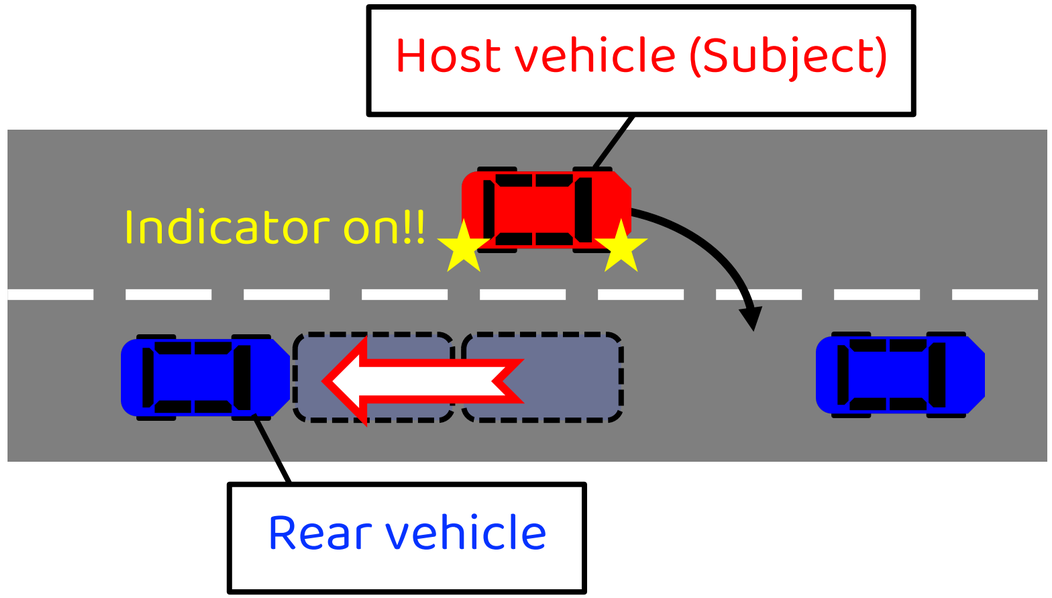
$$a^m_{t,lat} = \frac{2\pi H}{\Delta t^2_{lc}}\sin\frac{2\pi}{\Delta t_{lc}}(t - t_e)$$

DS Experiments

- Data were collected using DS
- **We divided give way conditions into 4 levels**

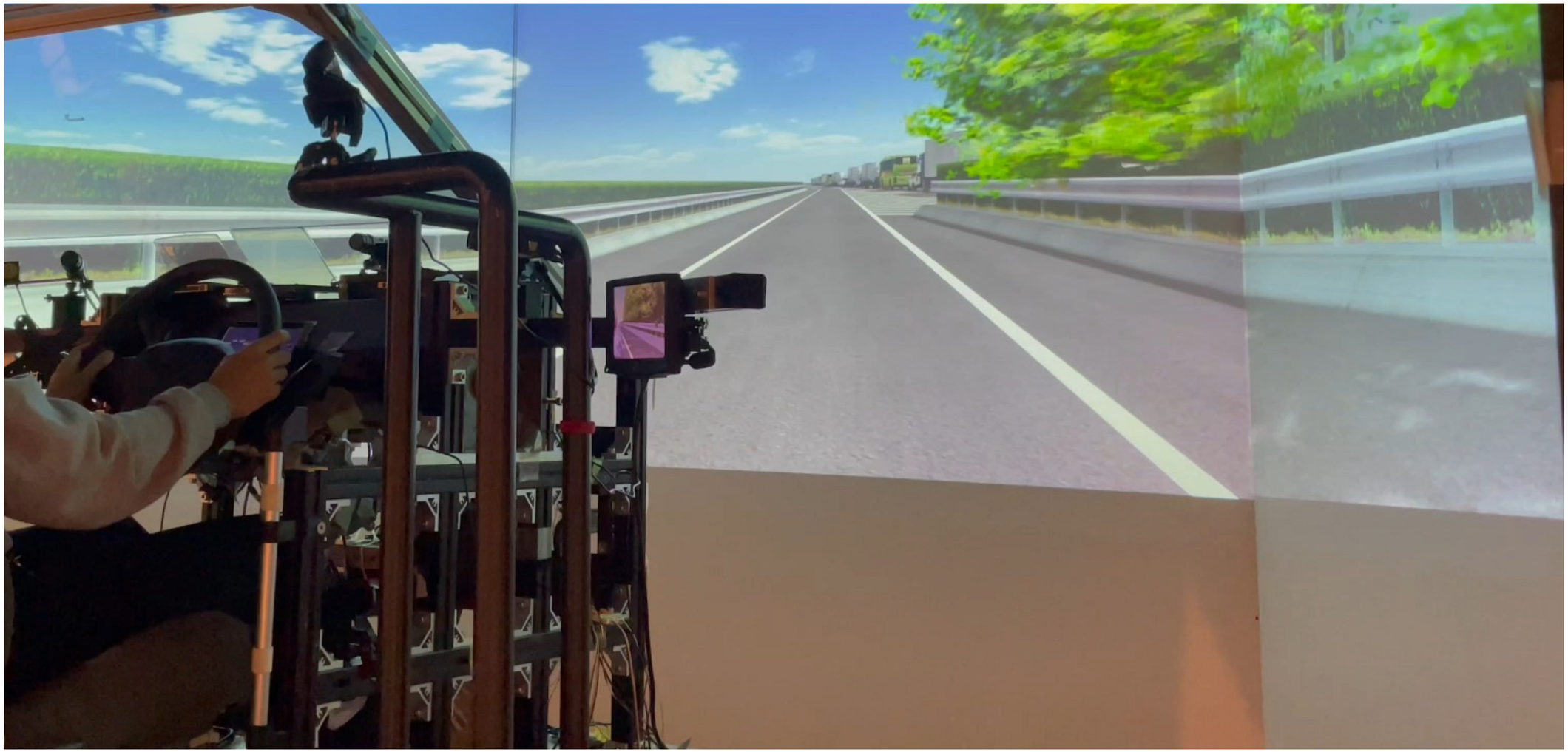


Level	Give way condition
1	2 s after indicator blinking
2	4 s after indicator blinking or close to 1.25 m from center line
3	8 s after indicator blinking or close to 1.05 m from center line
4	do not give way



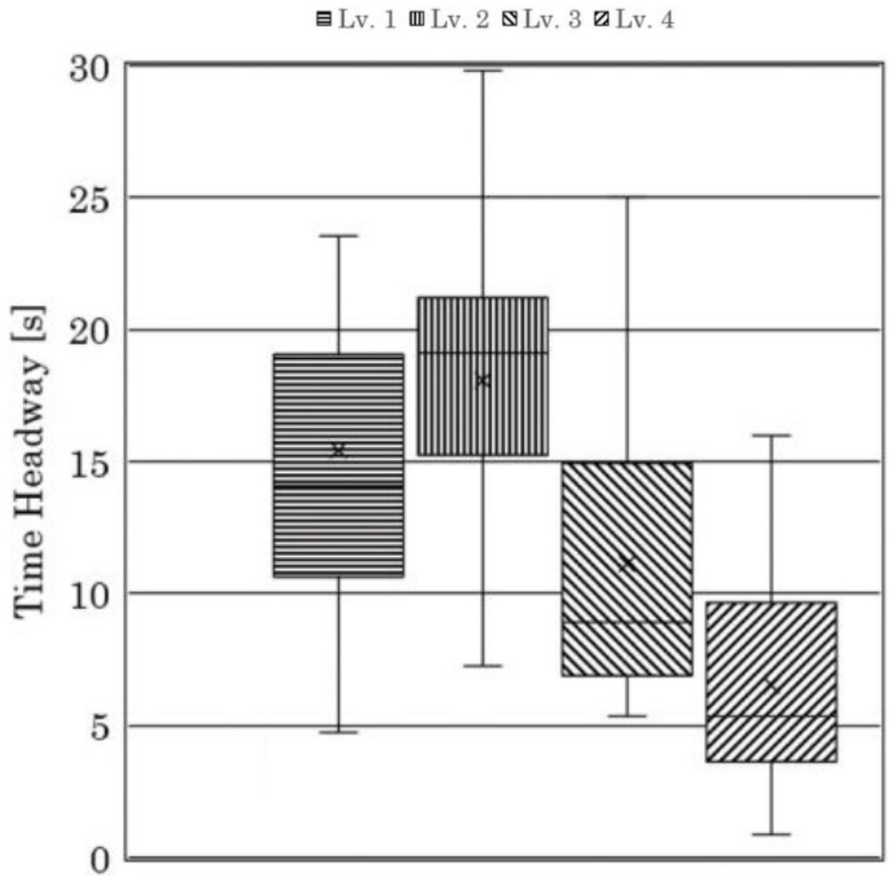
- Subjects were instructed to change lane at their discretionary timing
- 7 subjects were participated (Male, University students), 12 trials/subject

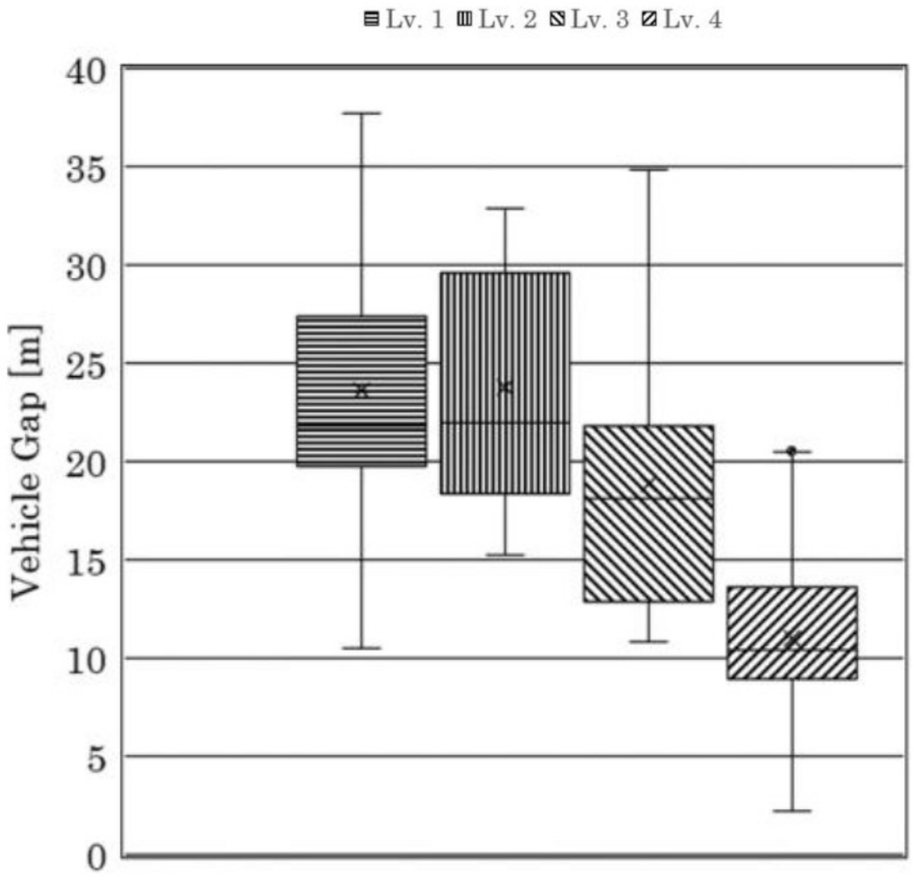
Example of DS Experiments



Results of DS Experiments

Data for 0.5 s before subject vehicle crossed center line were analyzed

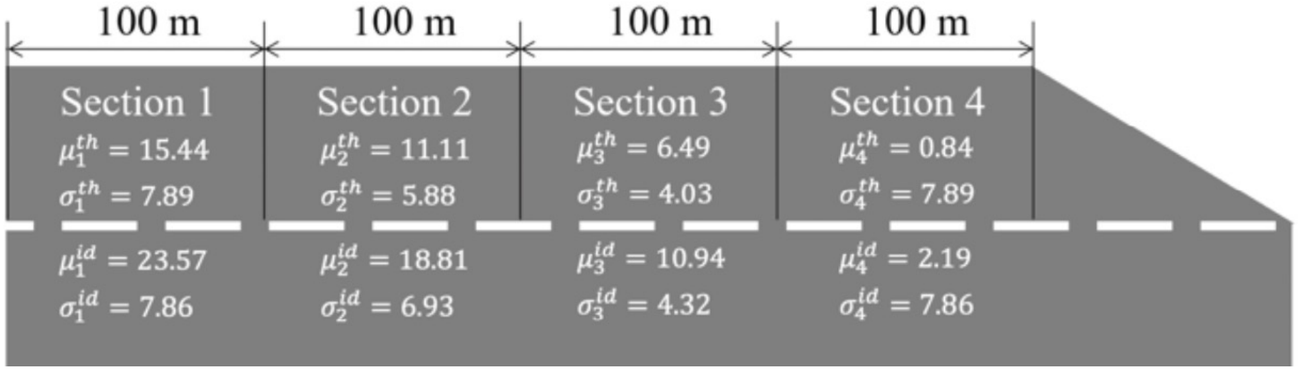




Lane-Changing Decision Module

- Only trials in which safe lane change was performed based on maximum deceleration
- Merging lane was divided into 4 sections, and distribution in each section was defined

DS results



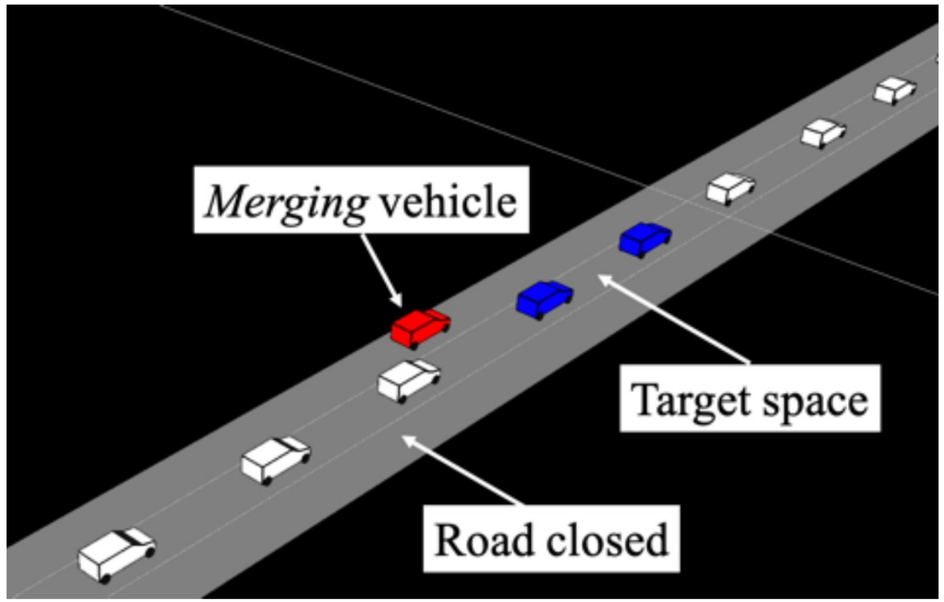
Through this approach,

host vehicle tries to change lanes more aggressively

as remaining distance of merging lane decreases

Evaluation

- Behaviors of vehicles in main lane were generated based on ACC
- Speed of vehicle at front of main lane was controled according to sine function
- **Driving characteristics of drivers in main lane were determined randomly**
- Total of 100 trials were conducted



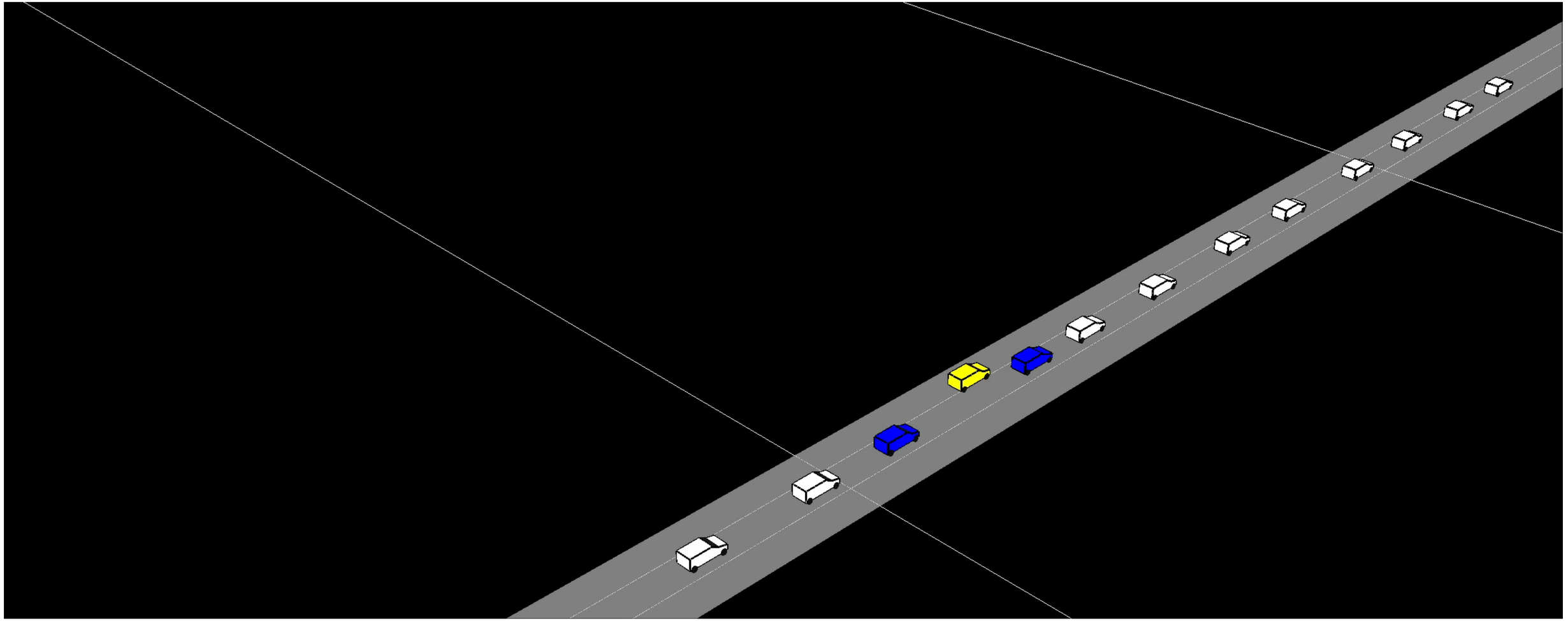
Driving characteristics of drivers in main lane

	k_1	k_2	t_{hw}
Min.	0.02	0.04	1.0
Max.	0.03	0.10	2.5

Give way time

Min.	1.0 s
Max.	4.0 s

Example of Evaluations



Evaluation Results

Data for 0.5 s before host vehicle crossed center line were analyzed.

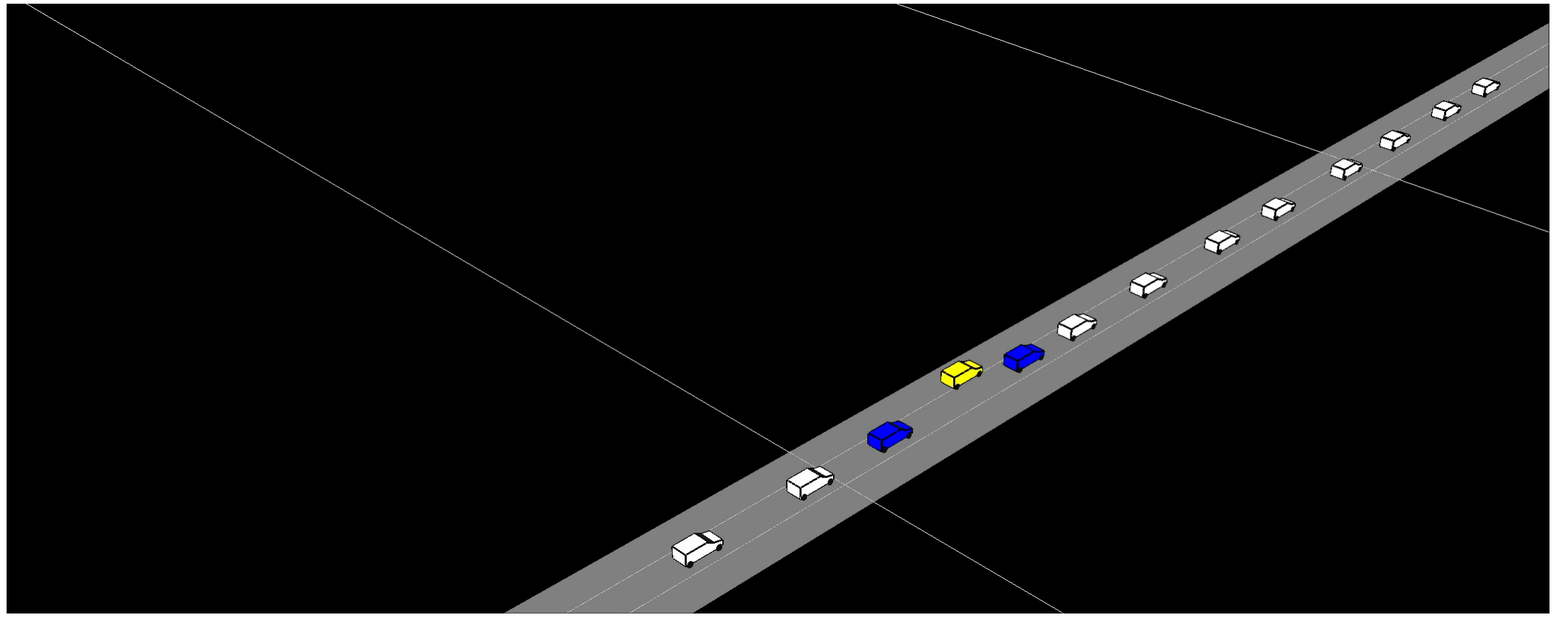
Margin-to-collision (MTC) was used as index to evaluate safety of lane change.

Larger value of MTC than 1 means that there is no collision risk.

Avg. of time headway	1.71 s
Min. of time headway	0.89 s
Avg. of inter-vehicle distance	8.86 m
Min. of inter-vehicle distance	4.51 m
Avg. of position performed LC	389.43 m
Avg. of MTC	7.92
Min. of MTC	5.03

Conclusions

- Autonomous lane-changing system at congested area was proposed
- Through DS experiments, operation data of human drivers were acquired
- Lane-changing decision module was constructed by imitating human drivers
- Through simulations, safety of proposed system was demonstrated



Thank you for your attention

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