23.11.08 FASTzero'23 (Testing & Validation Method)

Wed-PM2-C-2

SAKURA
Safety Assurance KUdos for Reliable Autonomous Vehicles

Driver Behavior Model to Define a Preventable Boundary for Scenario-based Safety Evaluation of Automated Driving

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1. Introduction

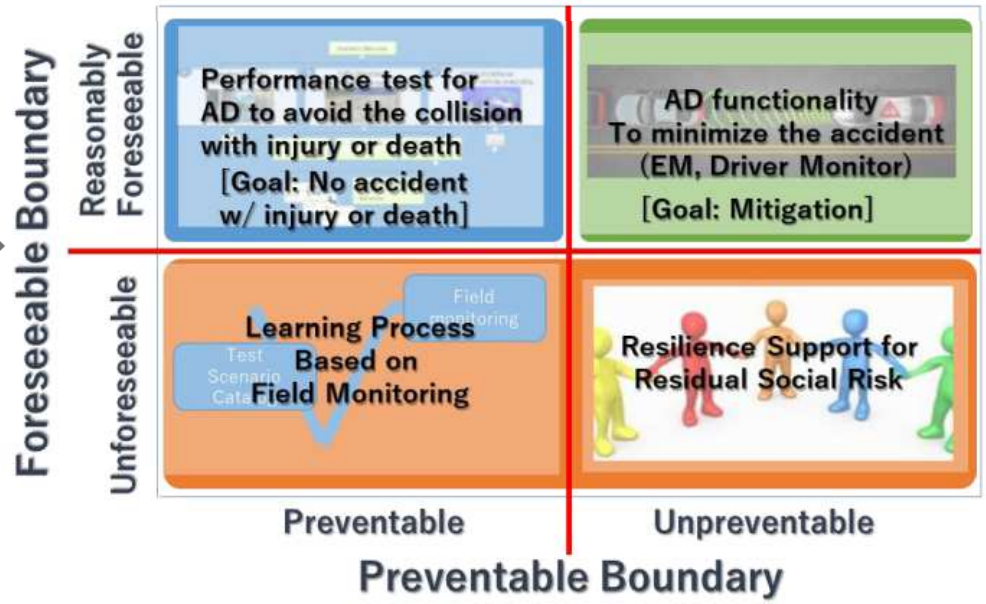
Scenario-based safety evaluation of ADSs

UN WP29 & MLIT

Automated Driving Systems, **under their automated mode**, shall not cause any traffic accidents resulting in injury or death that are **reasonably foreseeable** and **preventable**.

Foreseeability and preventability matrix

Nakamura et al. (2022)
Muslim et al. (2023)



JAMA (2022)

Boundaries : reasonably foreseeable and preventable scenario definition

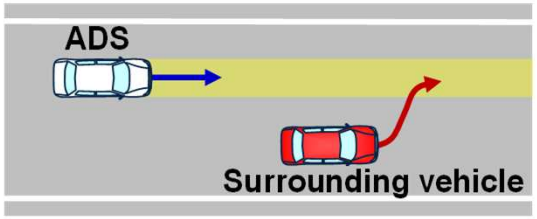
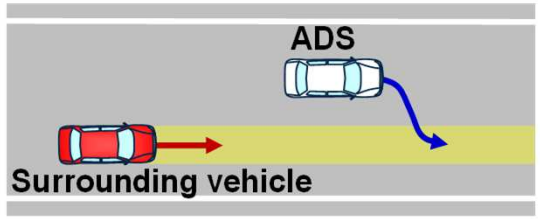
Purpose

- To propose a driver behavior modelling concept to define the preventability
- To apply this concept to specific models based on experimental data and real traffic data, corresponding to the respective roles required by ADS

2. Method

Approach to driver behavior modeling

- **Two aspects about preventability definition**

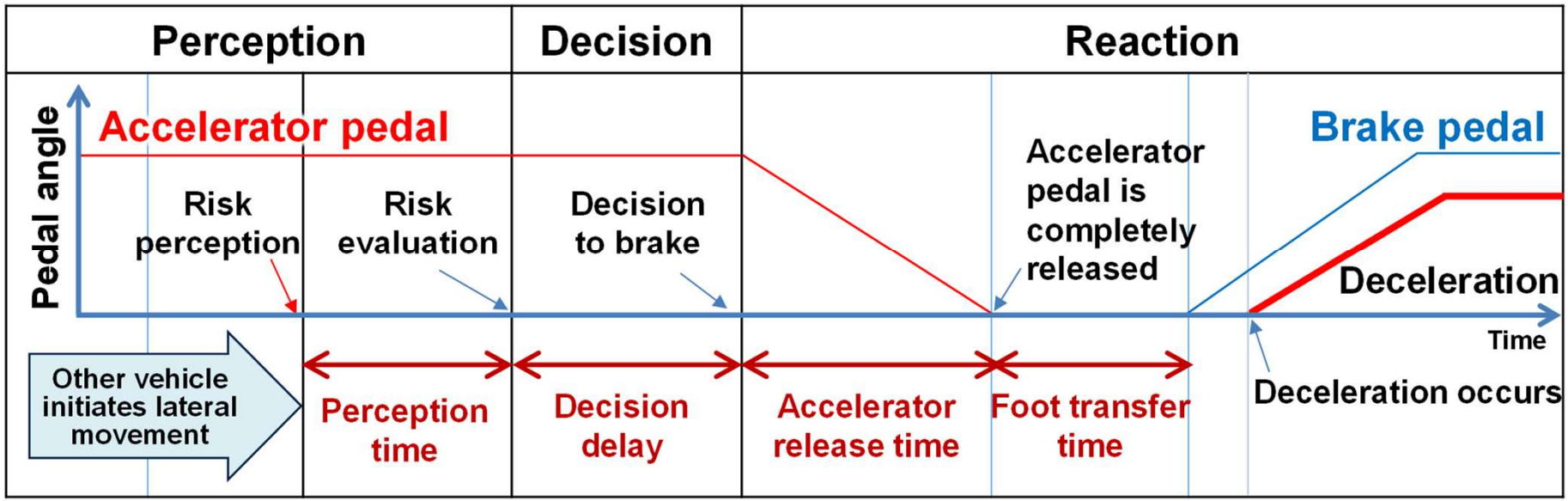
	Responder role ← Role inversion → Initiator role	
Scenario	**No.1** 	**No.7** 
Safety requirement	- Strive to achieve utmost effort for collision avoidance or damage mitigation while surpassing the performance of human driver	- To temporarily withhold lane change to prevent collisions and avoid obstructing the rear vehicle - To complete the lane change appropriately
Research subject	Quantification of **a competent and careful driver behavior**	Quantification about **the subjective experience of the rear vehicle driver's feelings**

Waymo (2023)

Different safety requirements : responder role / initiator role

Example of responder role

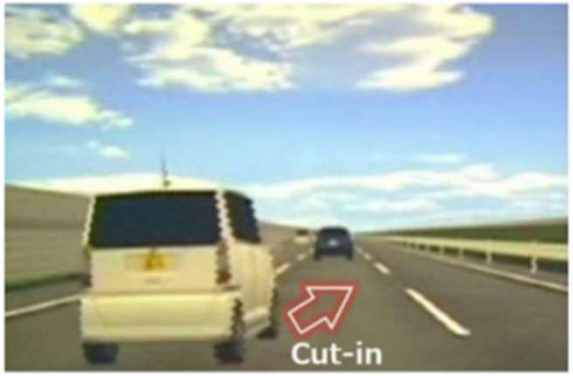
- **Driver's evasive behavior processes by a braking operation**



Requirement : to make its utmost effort to avoid a collision

Driving Simulator Experiment 1

- **Data acquisition to define a driver behavior model for responder role**
  - **11 ordinary drivers (average age 38.7 (25-49))**
  - **Data collection driver's utmost effort to avoid a collision**
  - **Quantification of required time for risk judgement by driver**

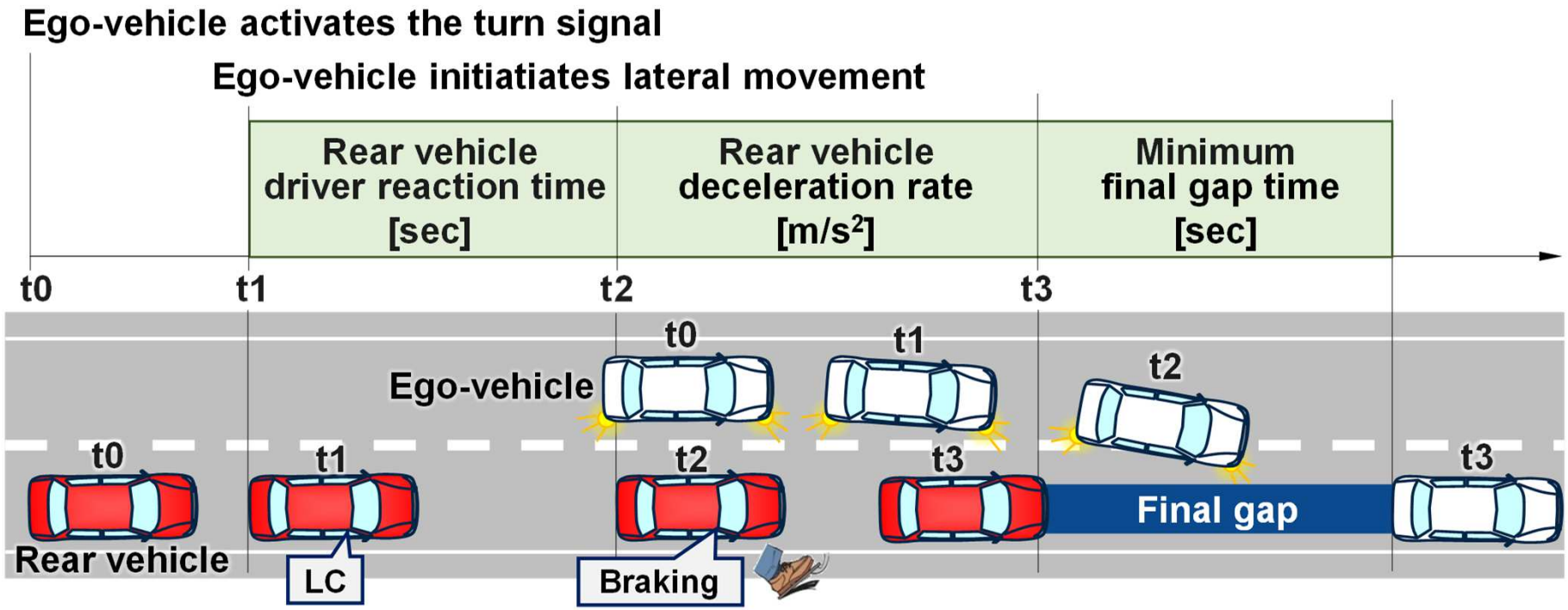


Parameter	Value
Ego-vehicle velocity	100 km/h
Traveling velocity in the adjacent lane	70 km/h
Lateral velocity of cut-in vehicle	1.8 m/s
Time to collision at the onset of the cut-in	3.0 sec

Quatification : driver's evasive operation by braking as utmost effort

Example of initiator role

- Human driver's behavior processes of a vehicle approaching from behind



Requirement : to behave to avoid not just collision but obstructing

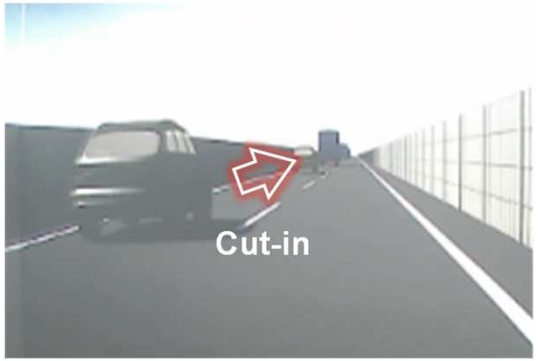
Driving Simulator Experiment 2

◆ **Data acquisition to define a driver behavior model for initiator role**

Obstructing progress [Japanese Road Traffic Act, 1960]

the act of initiating or sustaining movement in a manner that could potentially compel another vehicle **to abruptly alter its speed** or **direction to evade potential danger**

- 26 ordinary drivers (average age 42.2 (23-61))



Parameter	Value
Ego-vehicle velocity	120 km/h
Traveling velocity in the adjacent lane	60-110 km/h
Lateral velocity of cut-in vehicle	1.0 m/s
Time to collision at the onset of the cut-in	5.0 sec

Quatification : inferior driver's reaction to forward cut-in event

3. Results

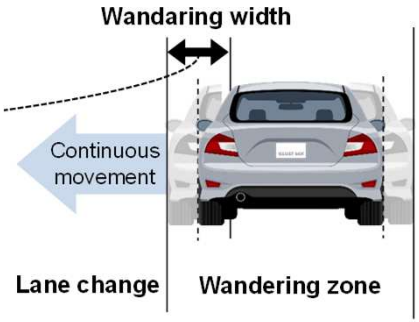
3.1 Driver Behavior Model for "Responder Role"

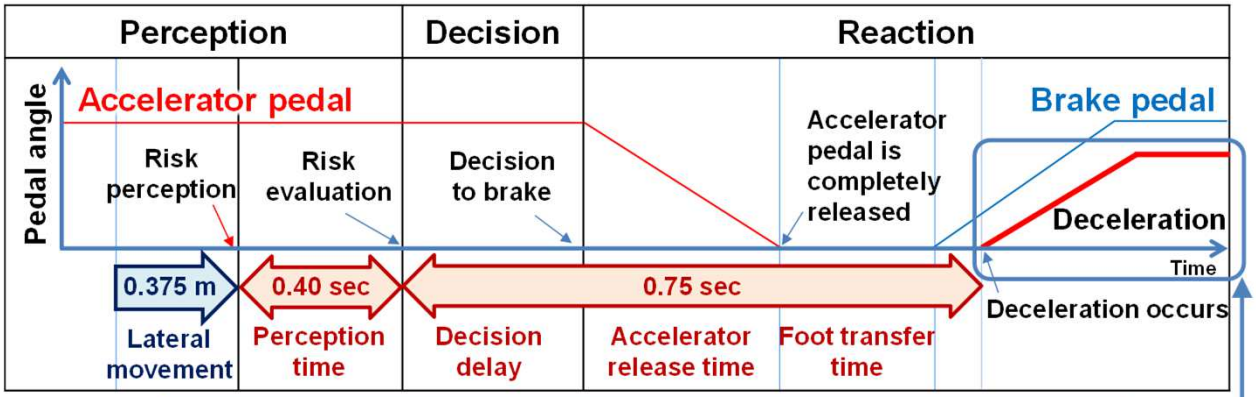
3.2 Driver Behavior Model for "Initiator Role"

Competent and careful driver model

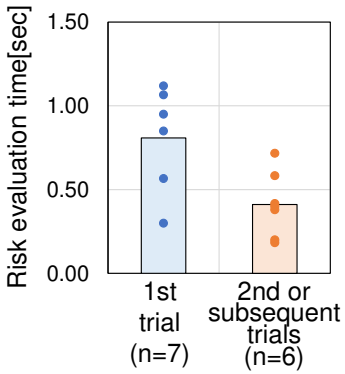
◆ Behavior model surrogating a superior driver performance (braking)

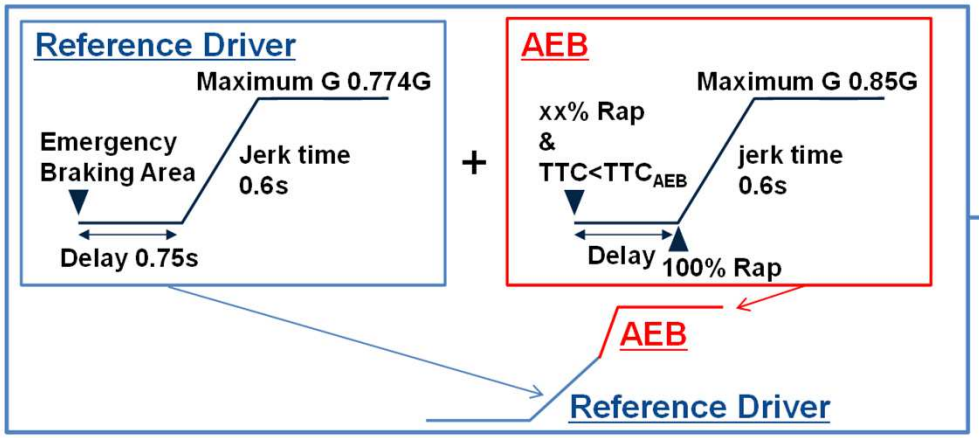
Real traffic data





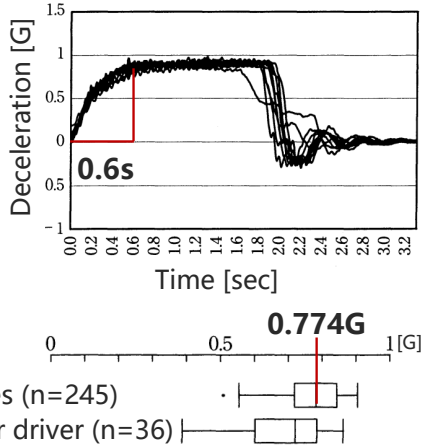
Experiment 1





Previous research

Trainees' brake operation profiles



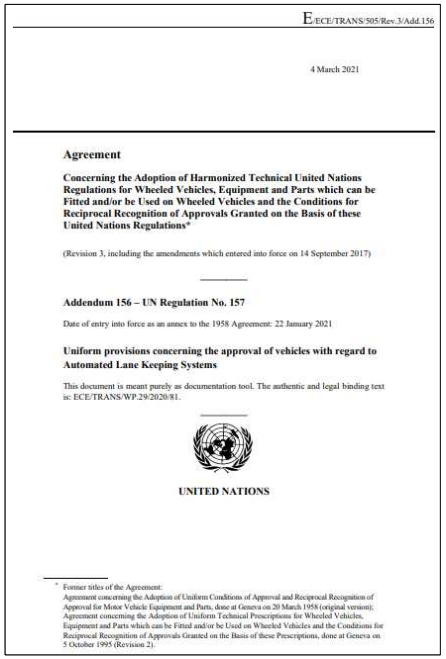
Makishita et al. (2001)

Specific parameters for competent and careful driver behavior

Provision of safety criteria for responder role

- **Reasonably foreseeable test scenarios with preventable boundary**

UN Regulation No.157



E/ECE/TRANS/505/Rev.3/Add.156

4 March 2021

Agreement

Concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations*

(Revision 3, including the amendments which entered into force on 14 September 2017)

Addendum 156 – UN Regulation No. 157

Date of entry into force as an annex to the 1958 Agreement: 22 January 2021

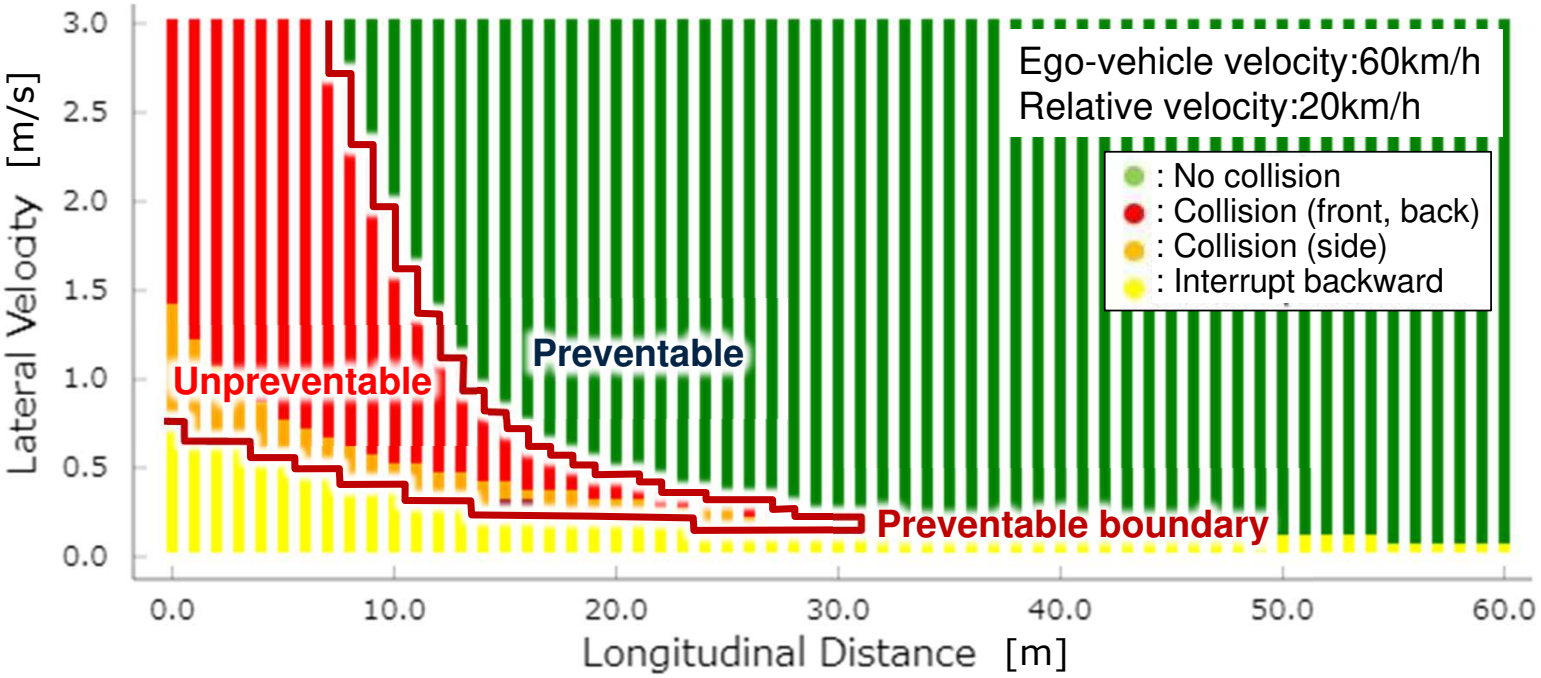
Uniform provisions concerning the approval of vehicles with regard to Automated Lane Keeping Systems

This document is meant purely as documentation tool. The authentic and legal binding text is: ECE/TRANS/WP.29/2020/81.

UNITED NATIONS

* Former titles of the Agreement:
Agreement concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, done at Geneva on 20 March 1958 (original version);
Agreement concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions, done at Geneva on 5 October 1995 (Revision 2).

Traffic disturbance critical scenarios for Automated Lane Keeping System



UN-ECE (2020)

Definite preventable boundary for responder role of ADSs

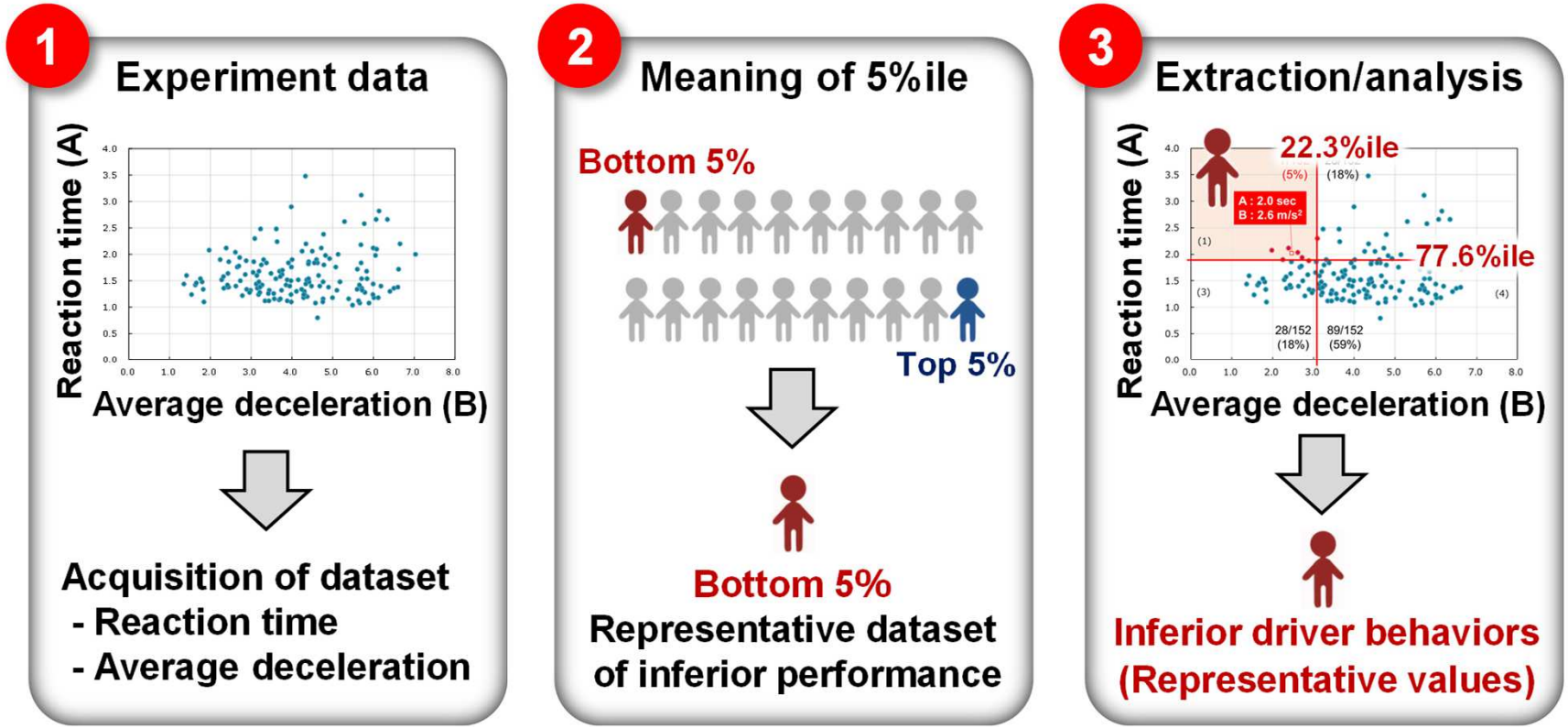
3. Results

3.1 Driver Behavior Model for "Responder Role"

3.2 Driver Behavior Model for "Initiator Role"

Concept to analyze experimental dataset

◆ **Processes to define a inferior human driver behavior**

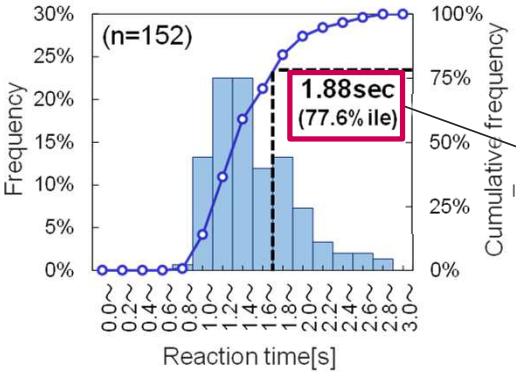


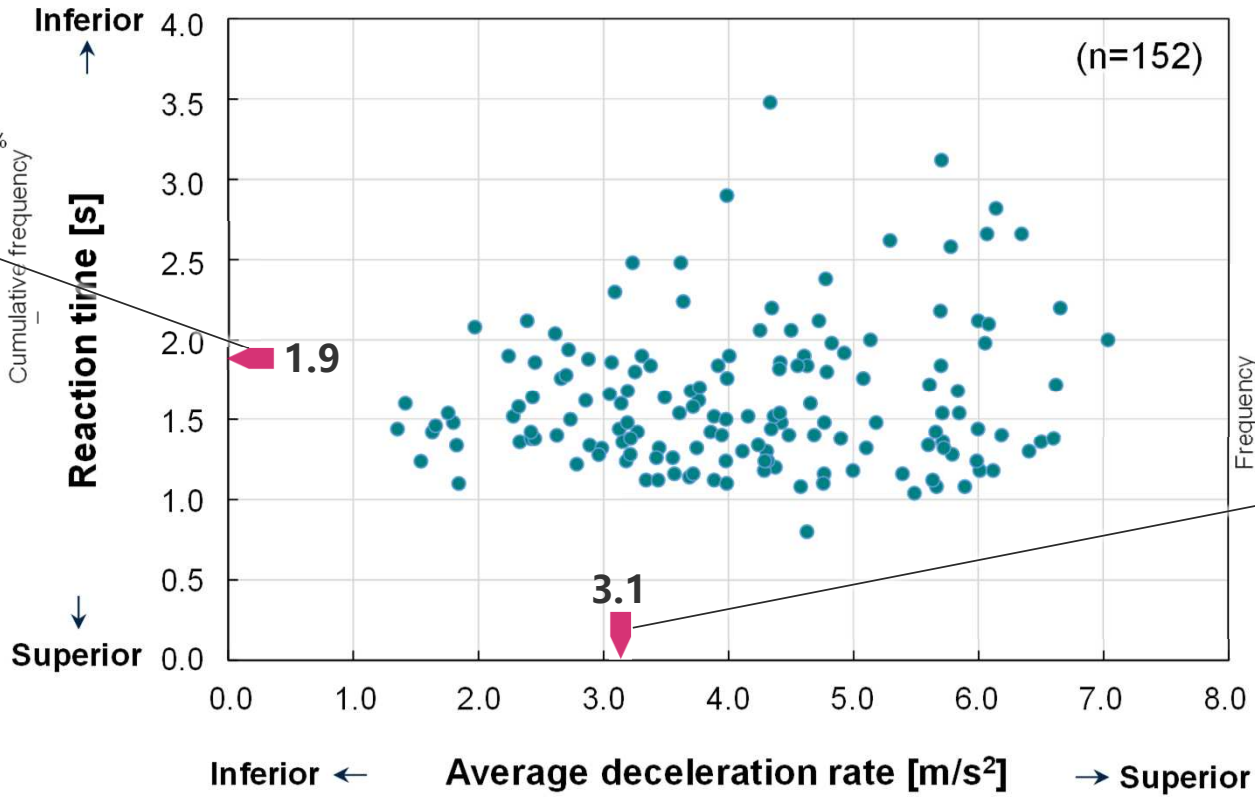
Quantification of obstructing progress coming from initiator's behavior

Extraction criteria for targeted dataset

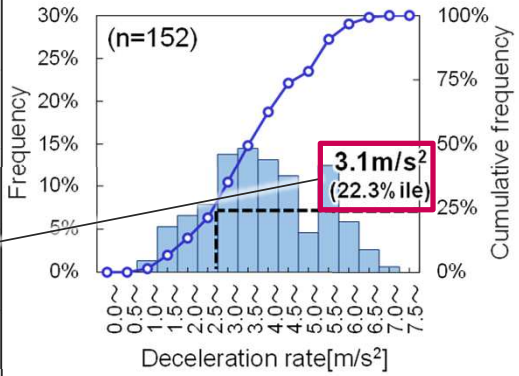
◆ **Relationship between driver reaction time and average deceleration rate**

Distribution of reaction time





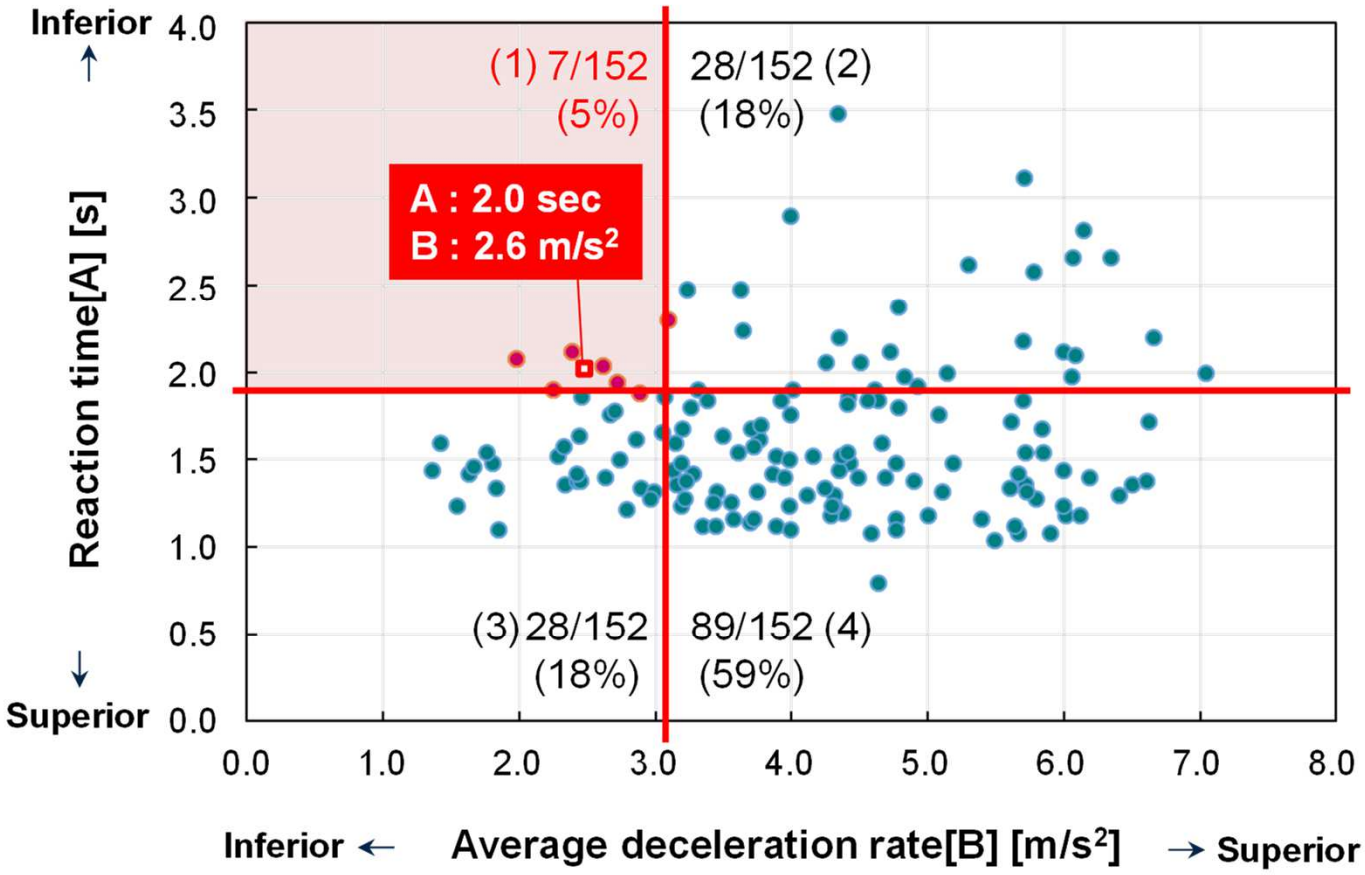
Distribution of deceleration rate



Extraction criteria reflecting inferior driver performance

Inferior driver performance data

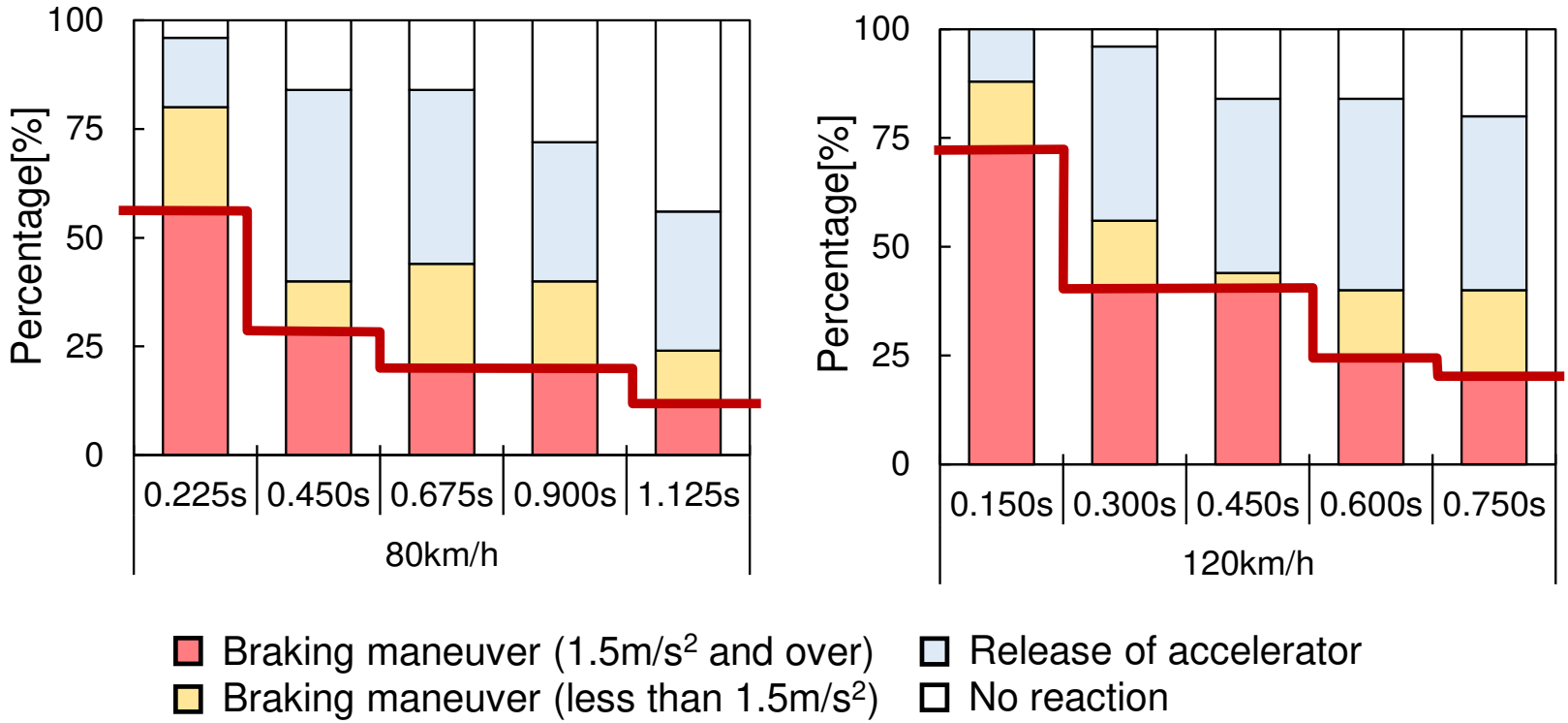
- **Classification result of 4 groups based on driver's performance**



Parameterization by extracting bottom 5%ile performance dataset

Minimum safety margin for rear vehicle driver

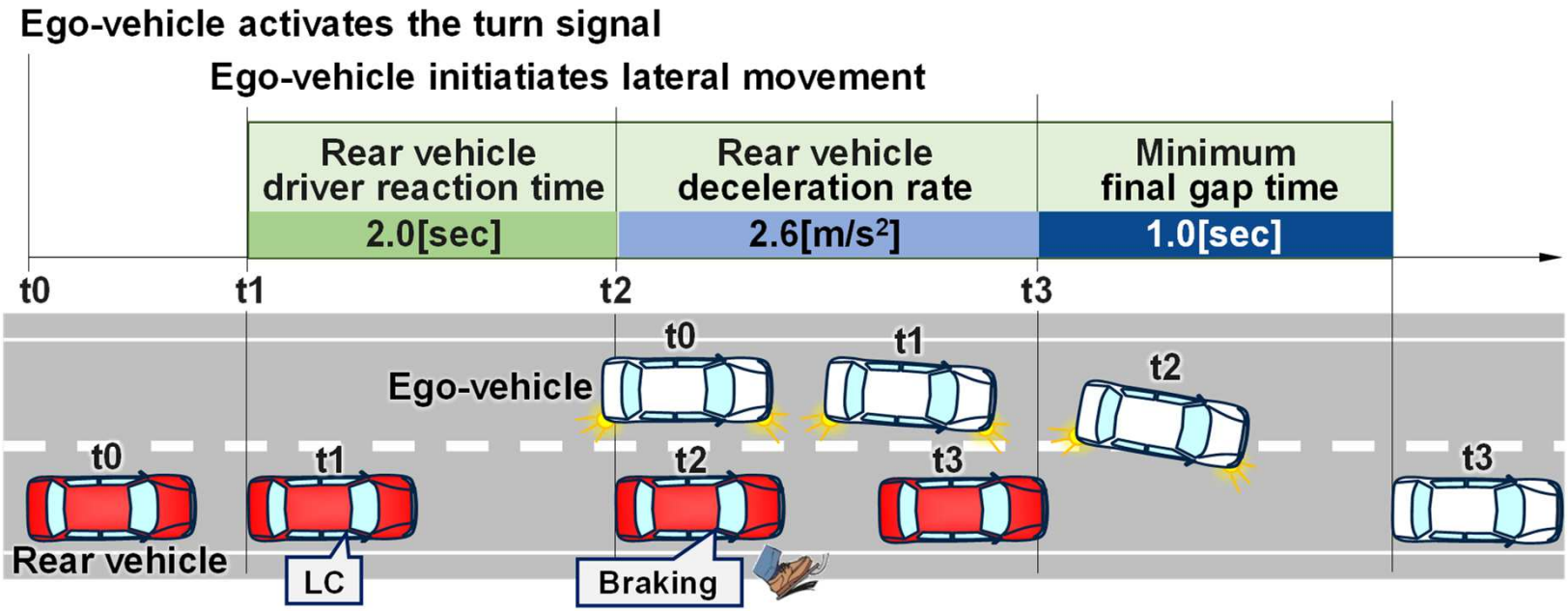
◆ **Component rate of driver reaction toward different time-headway values**



Rear driver's expectation : more than 1.0 time-headway

Provision of safety criteria for initiator role

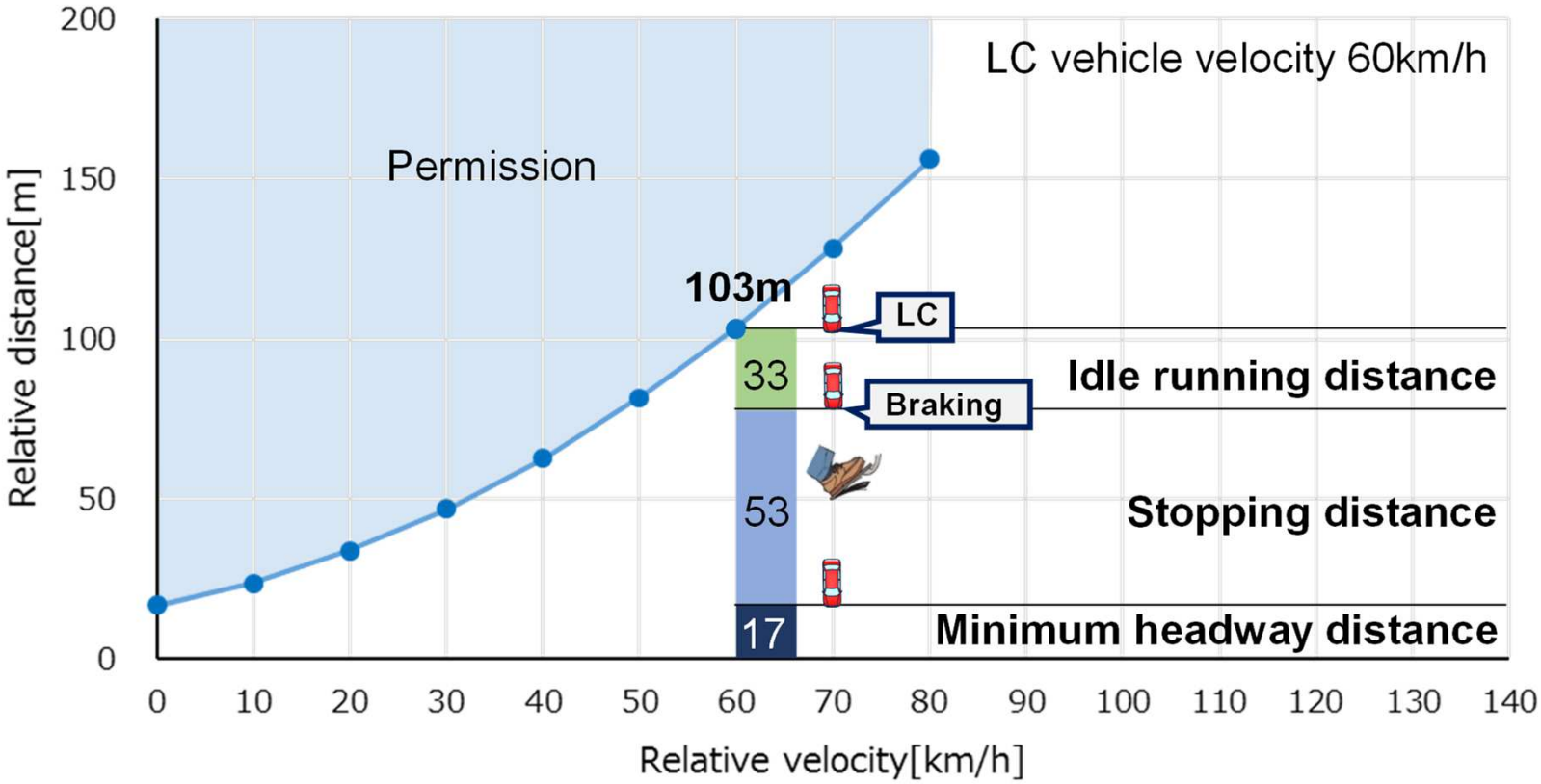
- **Parameters of driver behavior model of rear vehicle**



Specific parameters for inferior driver reaction to forward cut-in event

Required margin for safe lane changing

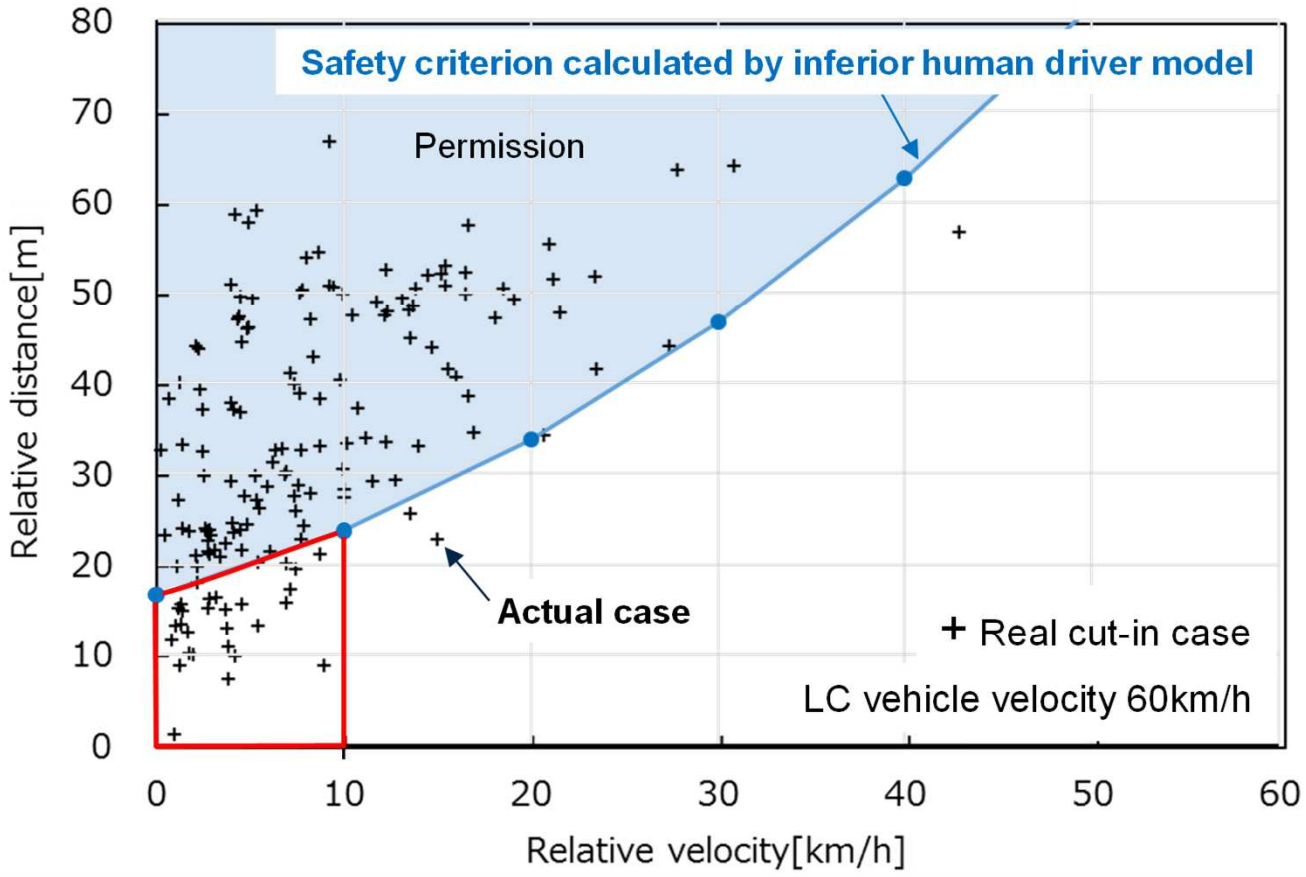
- **Example of calculated distance to assure sufficient margin for rear vehicle**



Safety requirement of initiator's behavior without obstructing progress

Suitability of proposed safety criteria

- **Comparison between the proposed safety criterion and actual lane changes**



Tolerant tendency to lane change with relative velocity below 10 [km/h]

4. Conclusion

Conclusion

- **A novel concept of driver behavior modelling**
  - -for defining a preventable boundary through a comparison with human driver behavior
  - -for derivation of a specific model by parameterizing based on relevant empirical evidences

- **Adaptable approach to define respective preventability to aspects of ADS (responder role/initiator role)**

Future work

- **Refinement of driver behavior modeling methodologies**
- **Applying preventability definition toward vulnerable road users**

Thank you for your kind attention

Jtown Specific Environment Area