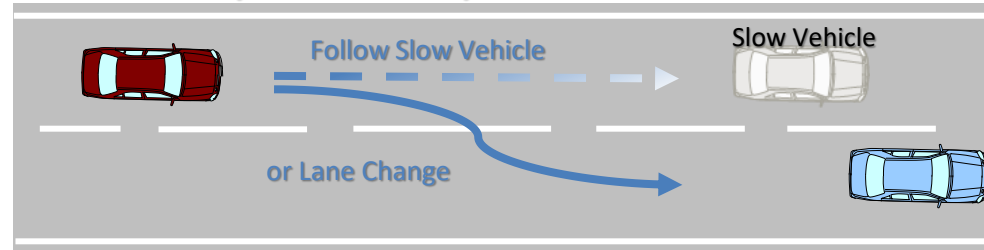# Criteria definition for Regular Lane Change

December 9-10, 2021

Japan

Definition of various Lane Changes

1) Regular LC: It is **not absolutely necessary** to LC.

2) Emergency LC: Have to LC to avoid danger.

The significant difference between RLC and Emergency LC

In the case of RLC, it is not absolutely necessary to LC.

It is possible to choose an option other than RLC. (ex. decelerate to keep in the lane, stop, etc.)

Basis of RLC concept

<u>NATM MD</u>

1.4   During the development of this work, the ToR outlines that VMAD should:

(a)...

(i)...

(ii)Validation for system safety: vehicle manufacturers should demonstrate a robust design and validation process based on a system-engineering approach with the goal of designing automated driving systems (ADS) free of unreasonable risks and ensuring compliance with road traffic regulation and the principles listed in this document.

...

<u>FRAV(Doc.5, FRAV21-05)</u>

4.   ADS Safety Requirements

4.1.   ADS performance of the DDT ...

4.1.5.   The ADS shall interact safely with other road users. ...

<u>ALKS (latest draft)</u>

5.2.6.7.1.   A LCP shall only be initiated if an-approaching vehicle in the target lane is not forced to unreasonably decelerate due to the lane change of the ALKS vehicle.

<u>Japanese Road Traffic Law 26-2 (Prohibition of Changing the Course)</u>

Paragraph 2

A vehicle shall not change the course if such change is likely to cause a sudden change in the speed or direction of a vehicle, etc. proceeding from behind on the same course as the changed course.

Difference between requirement to RLC and ELC

RLC: Do not cause the surrounding traffic participants (e.g. rear vehicle at lane change location) to be scared

ELC: LC performed as the best option to secure safety. It is acceptable to perform LC that does not cause danger (collision) to other vehicles as long as the surrounding traffic participants are acting/driving appropriately.

Objective
To quantitatively define the conditions under which RLC is acceptable based on the above concepts
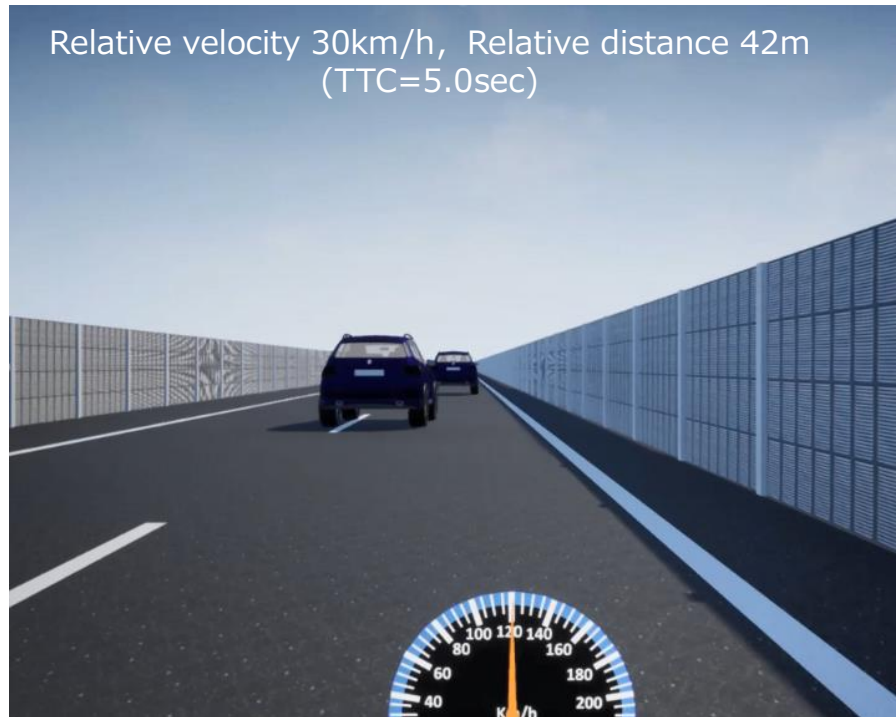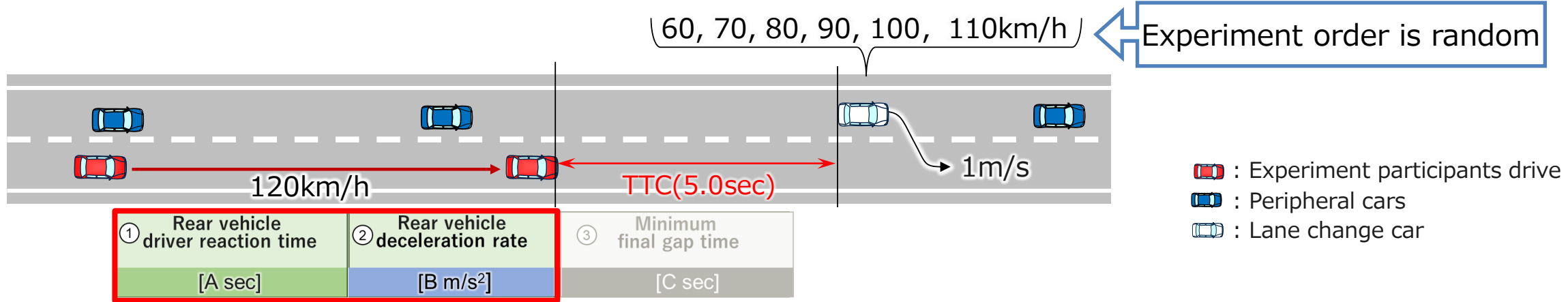
How to define Parameters
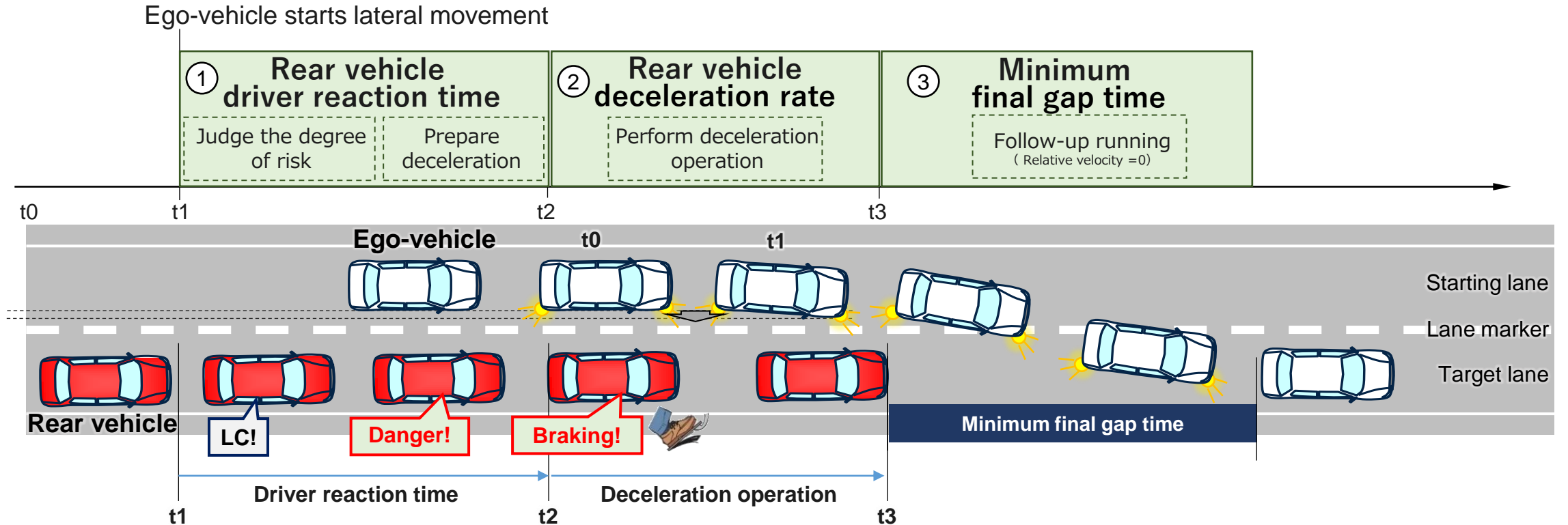
Three parameters are defined to satisfy the requirements for RLC.

RLC: Do not cause the surrounding traffic participants to be scared

Experiment Results

Experiment 1

**Experiment 1** | Measurement of driver reaction under various relative velocity conditions

60, 70, 80, 90, 100, 110km/h

Experiment order is random

120km/h

TTC(5.0sec)

1m/s

① Rear vehicle driver reaction time	② Rear vehicle deceleration rate	③ Minimum final gap time
[A sec]	[B m/s²]	[C sec]

: Experiment participants drive

: Peripheral cars

: Lane change car

Relative velocity 30km/h, Relative distance 42m
(TTC=5.0sec)

List of cut-in conditions (Experiment 1)

	Relative velocity [km/h]	Time to Collision [sec]	Lateral velocity [m/s]
1	10		
2	20		
3	30	5.0	1.0
4	40		
5	50		
6	60		

Experiment 2

Experiment 2 | Measurement of driver reaction under various time head-way conditions

Experiment order is random

80, 120km/h
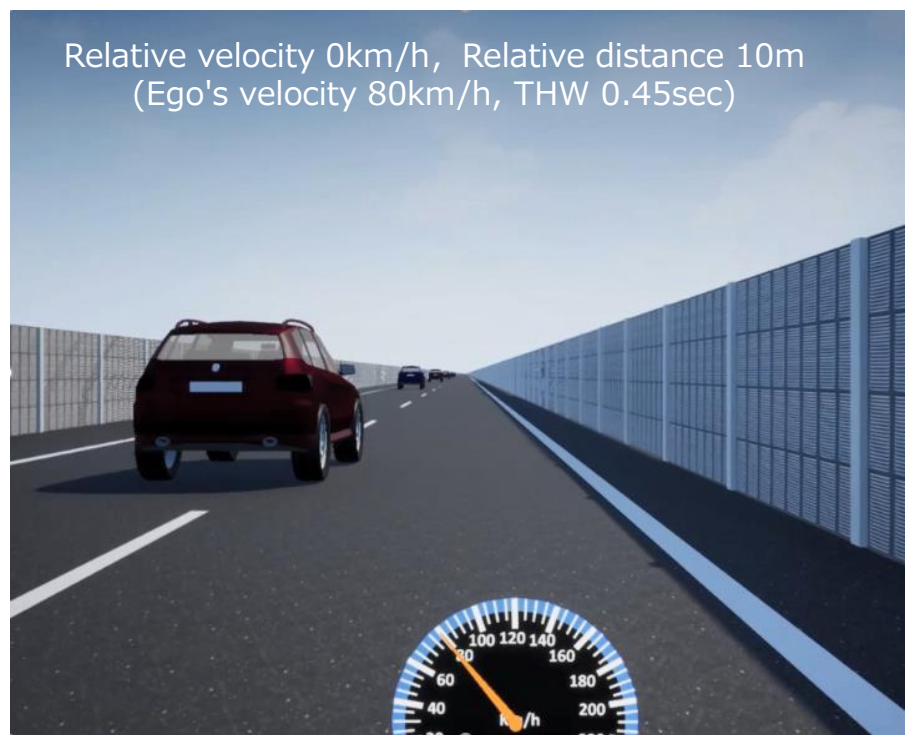
THW
(0.150~1.125sec)

1m/s

80, 120km/h
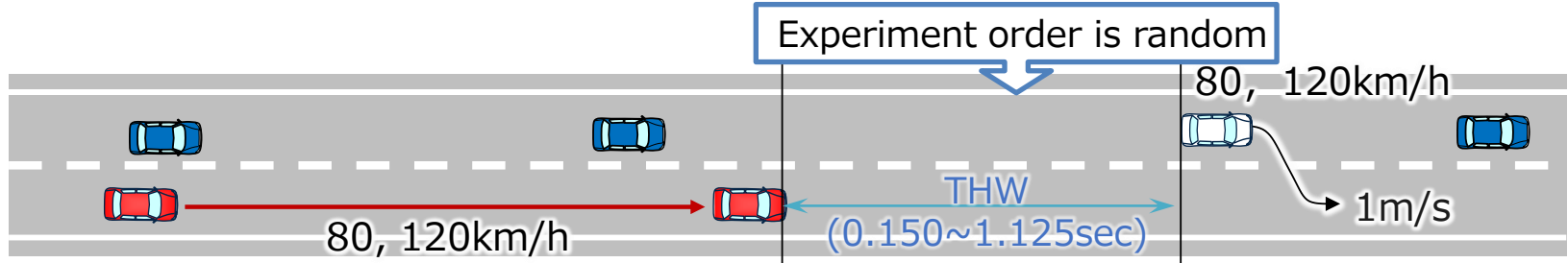
🚗 : Experiment participants drive
🚙 : Peripheral cars
🚘 : Lane change car

① Rear vehicle driver reaction time	② Rear vehicle deceleration rate	③ Minimum final gap time
[A sec]	[B m/s²]	[C sec]

Relative velocity 0km/h, Relative distance 10m
(Ego's velocity 80km/h, THW 0.45sec)

List of cut-in conditions (Experiment 2)

	Time Head-Way [sec]	Relative distance [m]	Ego vehicle's velocity [km/h]	Lateral velocity [m/s]	Relative velocity [km/h]
1	0.225	5	80	1.0	0
2	0.450	10			
3	0.675	15			
4	0.900	20			
5	1.125	25			
6	0.150	5	120		
7	0.300	10			
8	0.450	15			
9	0.600	20			
10	0.750	25			

Experiment participants

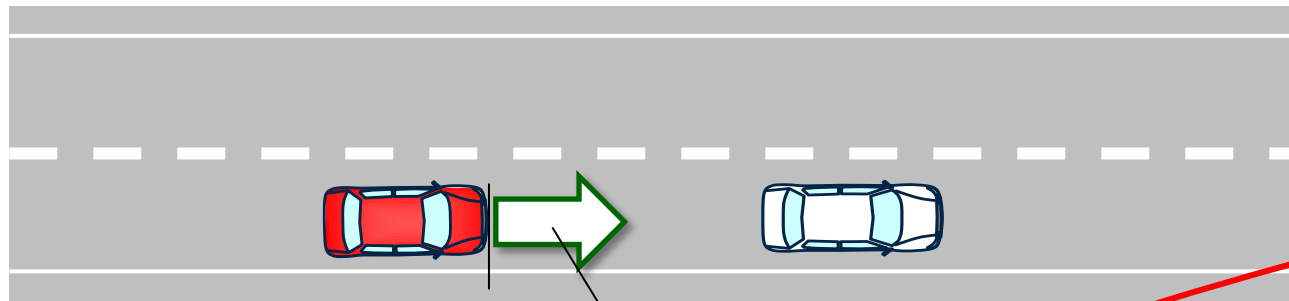| Attribute	Number of people	Characteristic	composition
General driver	26 people	◆Use the highway more than 6 times a year ◆Average years of driving experience: 19 years ◆Average annual mileage：About 13,000km	・Men:15/Women:11 ・Average age: 42.2
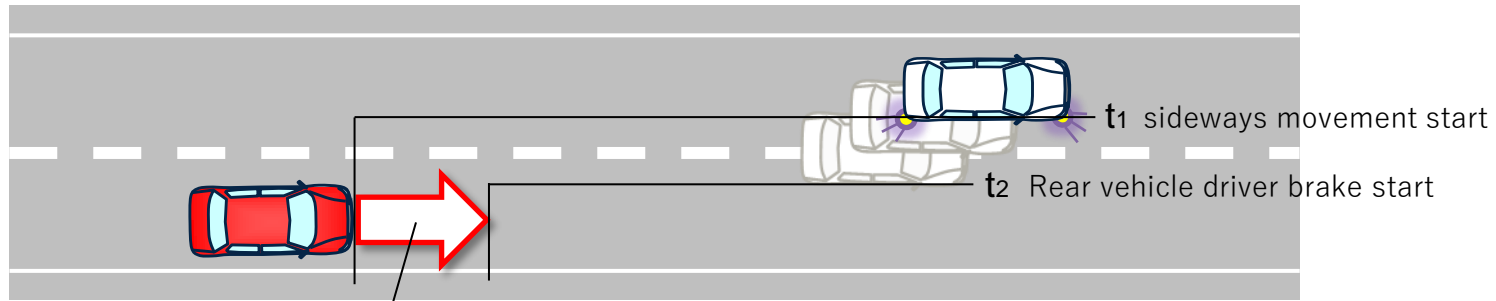
t_1 sideways movement start

t_2 Rear vehicle driver brake start

① Rear vehicle driver reaction time	② Rear vehicle deceleration rate	③ Minimum final gap time
[A sec]	[B m/s²]	[C sec]

① Rear vehicle driver reaction time	② Rear vehicle deceleration rate	③ Minimum final gap time
[A sec]	[B m/s²]	[C sec]

t_1 ： LC car sideways movement start
t_2 ： Rear vehicle driver brake start

Slope = D_{mean}
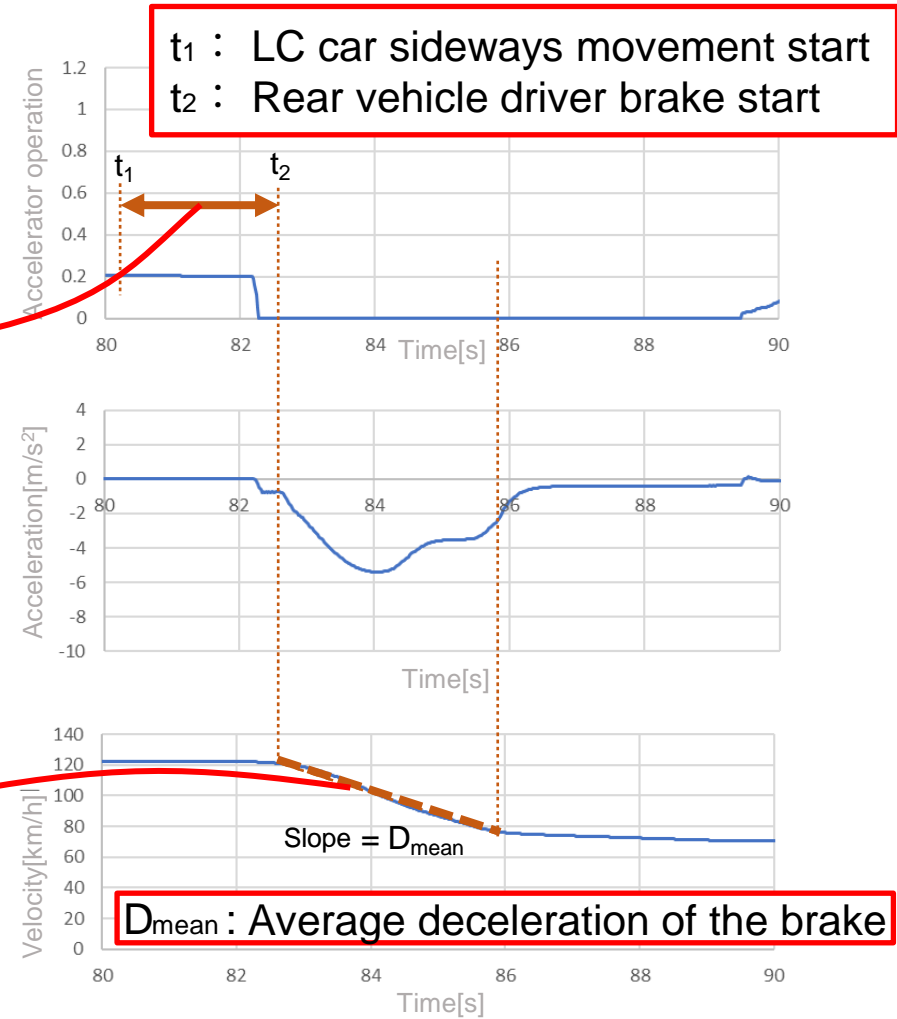
D_{mean} : Average deceleration of the brake

Define the average value by caress side driver as the Reaction delay of the model
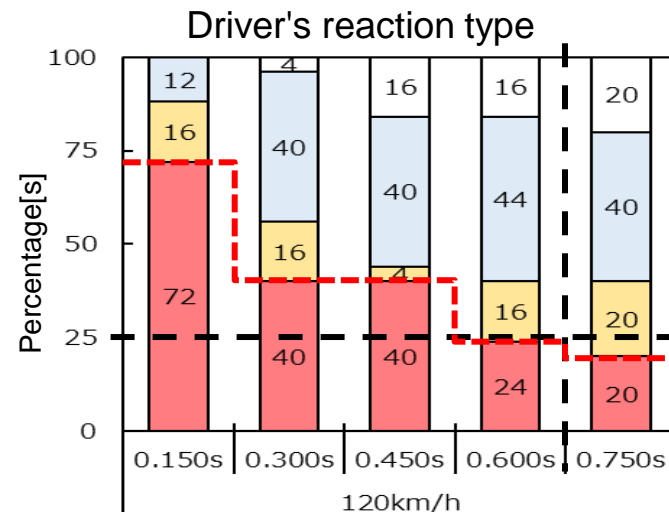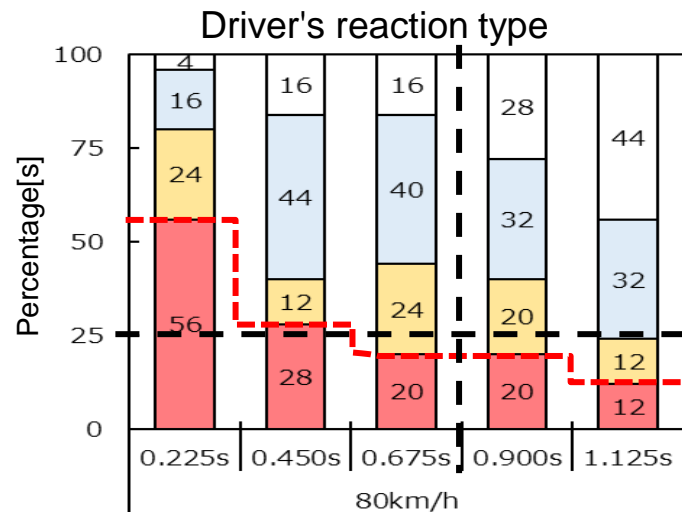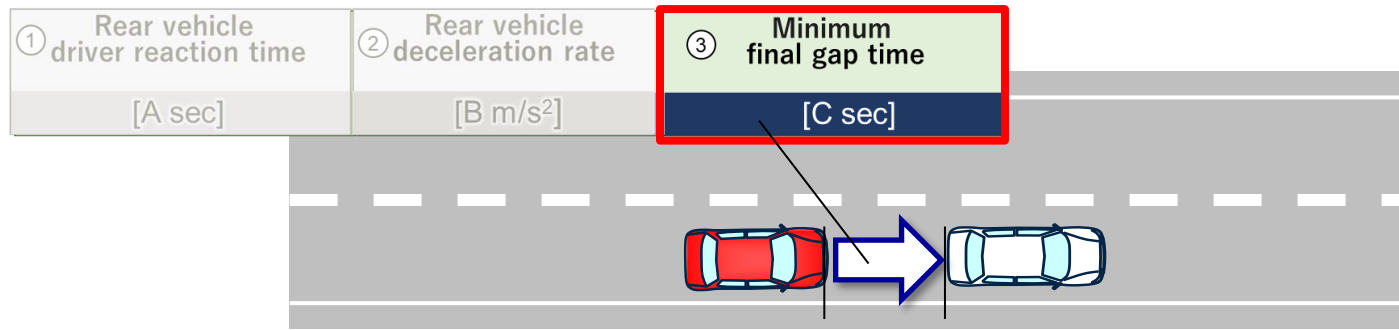
Under the conditions of this experiment, it was not possible to find out clearly what the deceleration rate would be if the rear driver did not feel threatened. It is defined as equal to the deceleration rate used for general speed control under normal traffic flow.

A : 2.0 sec
B : 1.5 m/s²

poor

↑ 4.0

3.5

3.0

Careless Dr.

2.5

2.0sec

Reaction time (A) [s]

1.5

Careful Dr.

1.0

0.5

↓ 0.0

fine

~2.6

0.0   1.0   2.0   3.0   4.0   5.0   6.0   7.0   8.0
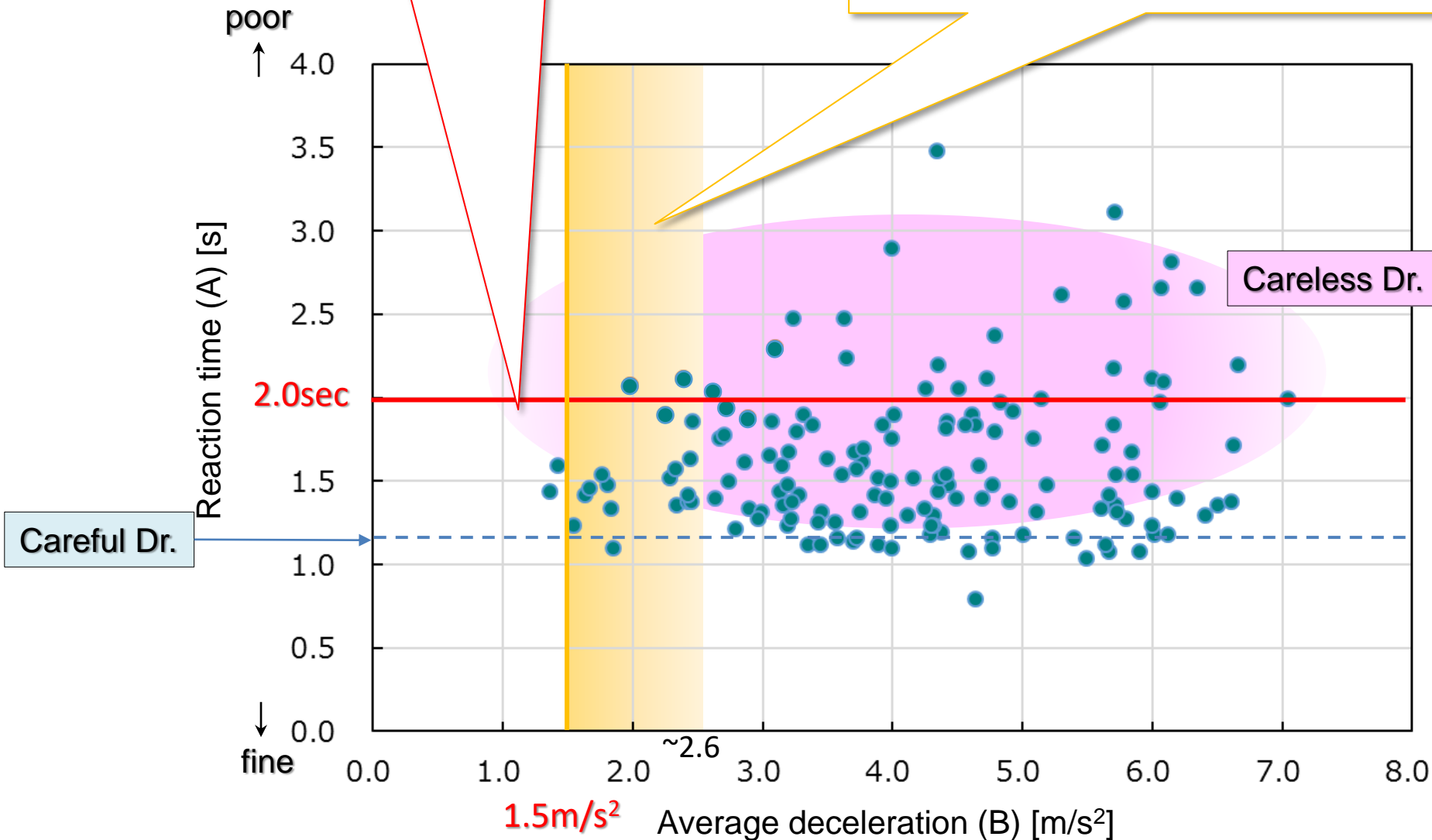
1.5m/s²   Average deceleration (B) [m/s²]
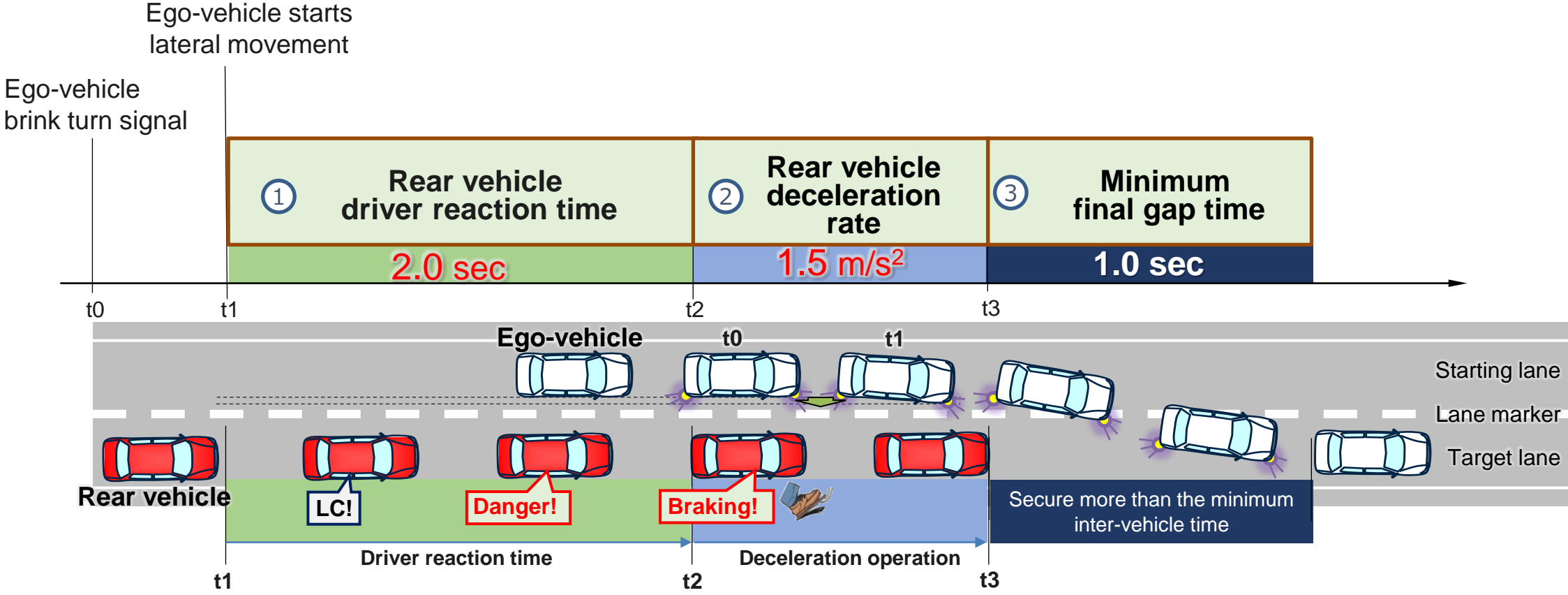
Minimum Final Gap Time

Setting the minimum final gap based on driver's reaction type and maximum deceleration
More than 80% of drivers respond with slow braking (0.15G or less) at THW 0.9sec at 80km/h and THW 0.75sec at 120km/h.

⇒The driver has driving characteristics that want to secure an inter-vehicle time Of about **1.0 sec**.

① Rear vehicle driver reaction time	② Rear vehicle deceleration rate	③ Minimum final gap time
[A sec]	[B m/s²]	[C sec]

Driver's reaction type — 80km/h

	0.225s	0.450s	0.675s	0.900s	1.125s
Accelerator release	4	16	16	28	44
	16	44	40	32	32
Brake (less than 0.15G)	24	12	24	20	12
Brake (0.15G and over)	56	28	20	20	12

Driver's reaction type — 120km/h

	0.150s	0.300s	0.450s	0.600s	0.750s
Accelerator release	12	4	16	16	20
	16	40	40	44	40
Brake (less than 0.15G)	72	16	4	16	20
Brake (0.15G and over)		40	40	24	20

- Brake operation (0.15G and over)
- Brake operation (less than 0.15G)
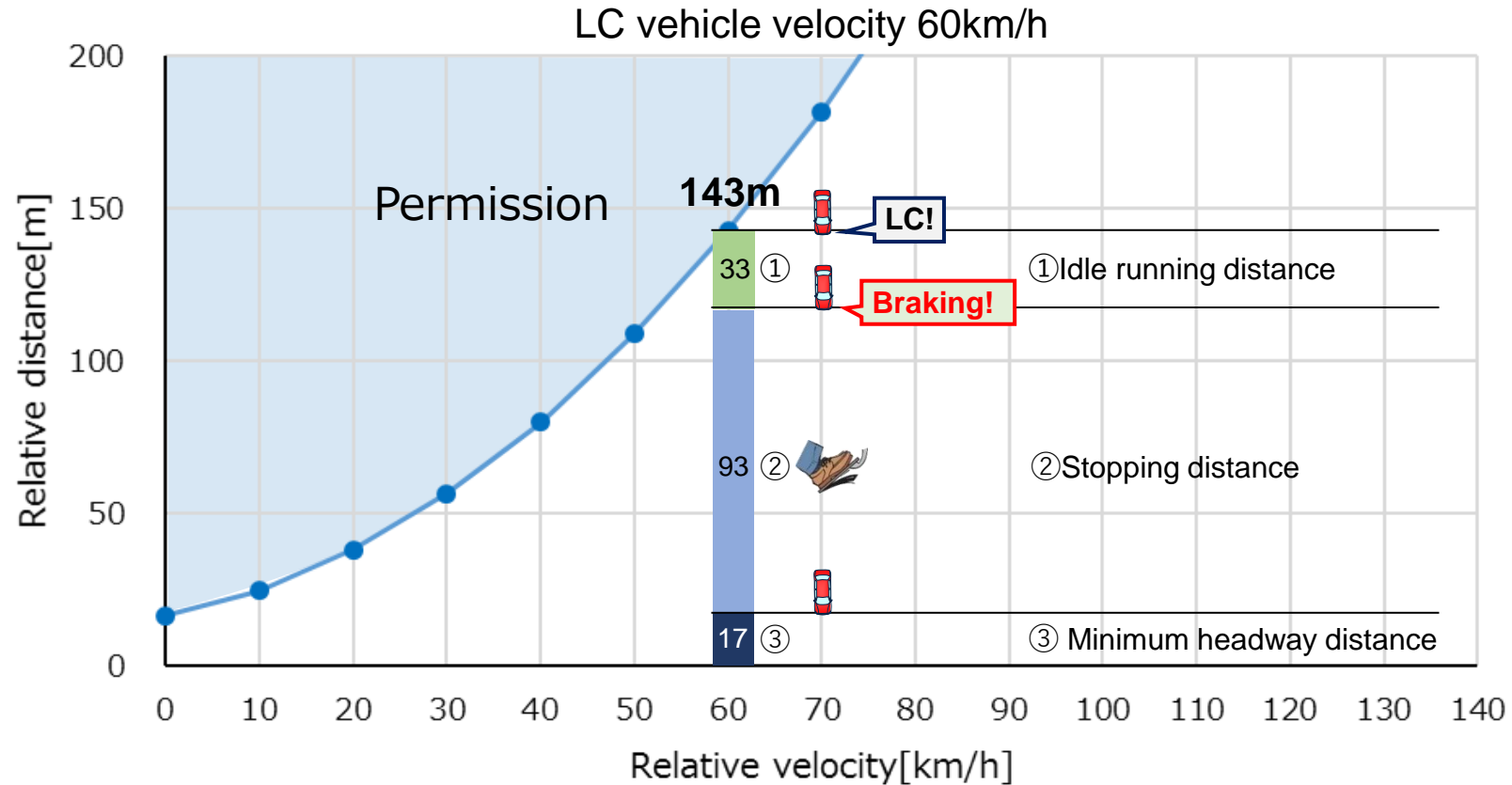- Acclerator release
- No reaction

12

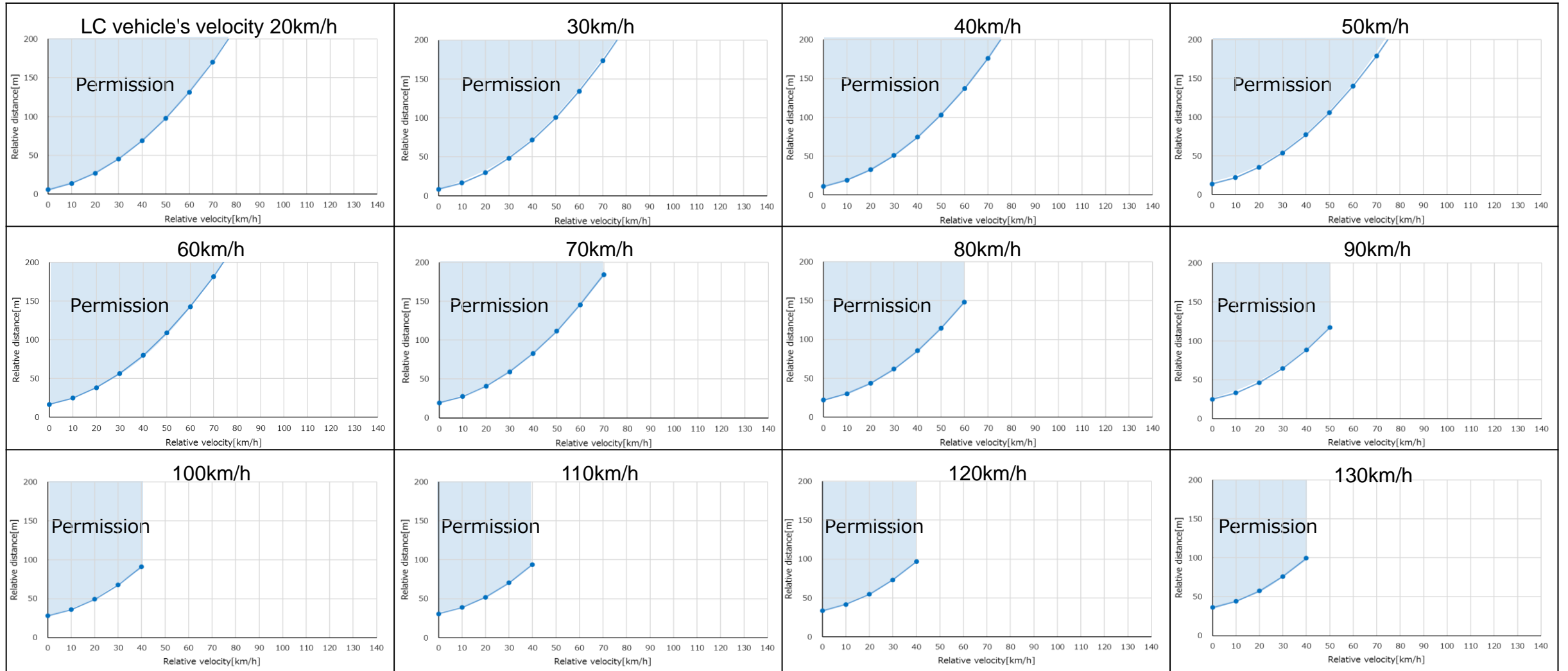# Proposal of parameters of Regular Lane Change

Safety criterion based on proposed parameters

Criteria values for regulation calculated by using proposed parameters .

①	Rear vehicle driver reaction time	②	Rear vehicle deceleration rate	③	Minimum final gap time
	2.0 sec		1.5 m/s²		1.0 sec

LC vehicle velocity 60km/h

Permission

143m

33 ①   LC!

①Idle running distance

Braking!

93 ②   ②Stopping distance

17 ③   ③ Minimum headway distance

Relative distance[m]

Relative velocity[km/h]

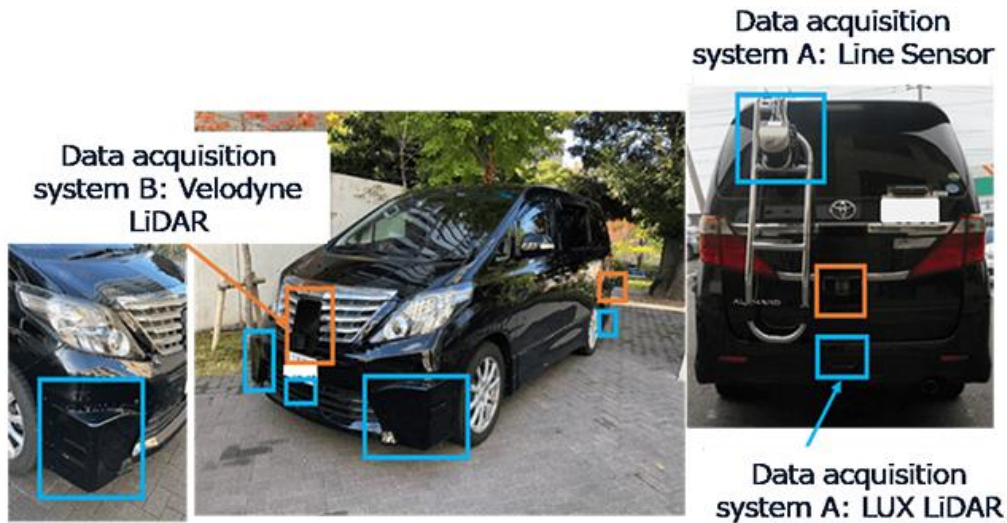# Safety criterion based on proposed parameters (other speed ranges)
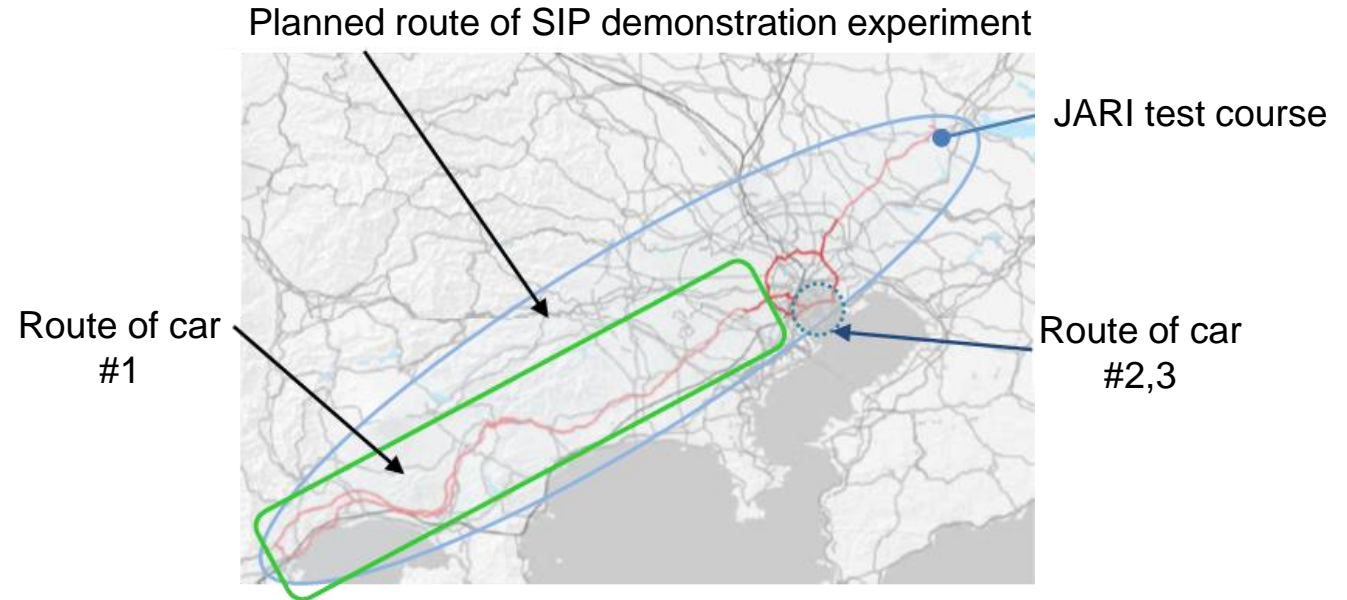
compare to Actual Traffic Flow Data

Measurement with test vehicle

Aim on measurement of naturalistic driving behavior

- Hide sensors and the exterior resembles to normal car

- Data acquisition system is developed in parallel

Data acquisition system A: Line Sensor

Data acquisition system B: Velodyne LiDAR

Data acquisition system A: LUX LiDAR

**Measurement test vehicle
（For Research and Development）**

Planned route of SIP demonstration experiment

JARI test course

Route of car #1

Route of car #2,3

Car #1   Driven on intercity highway
            Tomei-expressway (between Shimizu JCT and Tokyo JCT)
            Shin-Tomei-Expressway （between Shin-Shimizu JCT and Gotenba JCT）
Car #2,3   Driven on metropolitan highway(inner city)

Data amount : 2,968 hours / Approx. 165,000 km

Measurement with fixed cameras

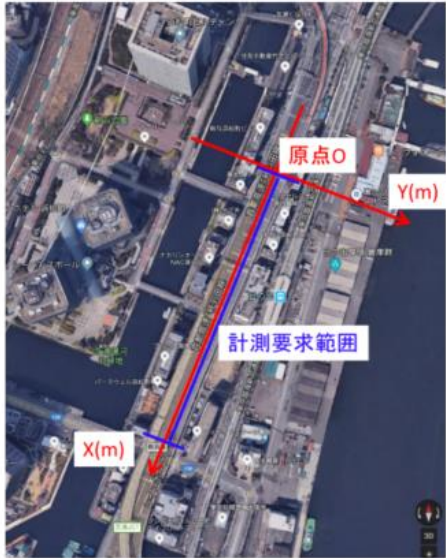- Installing high-quality cameras at measurement points (e.g. the rooftops of high-rise buildings)

Metropolitan expressway route 1 Main road (Hinode JCT)

Tomei highway entrance of merge (Yokohama-Machida IC)
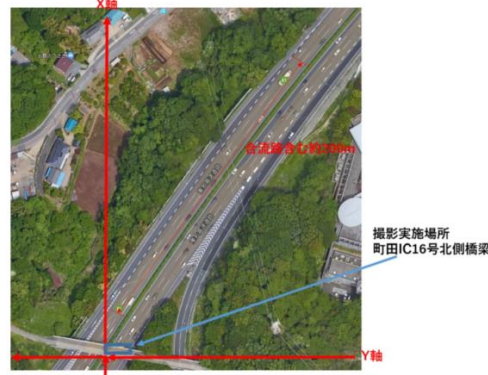
Tomei highway main road (Near Hachiouji crossing)

	Measurement location	Recorded time	Converted data length	Number of extracted trajectories
1	Metropolitan expressway route 1 (Hamazaki-bashi JCT-Shibaura JCT)	440 min.	320 min.	21,868
2	Metropolitan expressway route 4 (Sangu-bashi courner)	380 min.	40 min.	1,254
3	Tomei highway (Near Hachiouji crossing)	840 min.	220 min.	16,556
4	Tomei highway (Yokohama-Machida IC)	512 min.	70 min.	3,038
5	Daisan-heihin road (Near Orimto)	420 min.	165 min.	6,613
6	Metropolitan expressway route 5 (Hgashi-ikebukuro merge)	6,480 min.	600 min.	25,675
7	Tomei highway (Yokohama IC merge)	380 min.	380 min.	18,822
8	Tomei highway (Yokohama IC ramp)	380min.	80 min.	2,076

Data amount : 1,875 min. / Approx. 96,000 trajectories

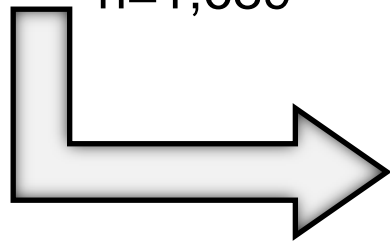# Comparison between proposal criteria and real traffic data

Suitability of the safety criterion is checked through comparison with real cut-in cases.
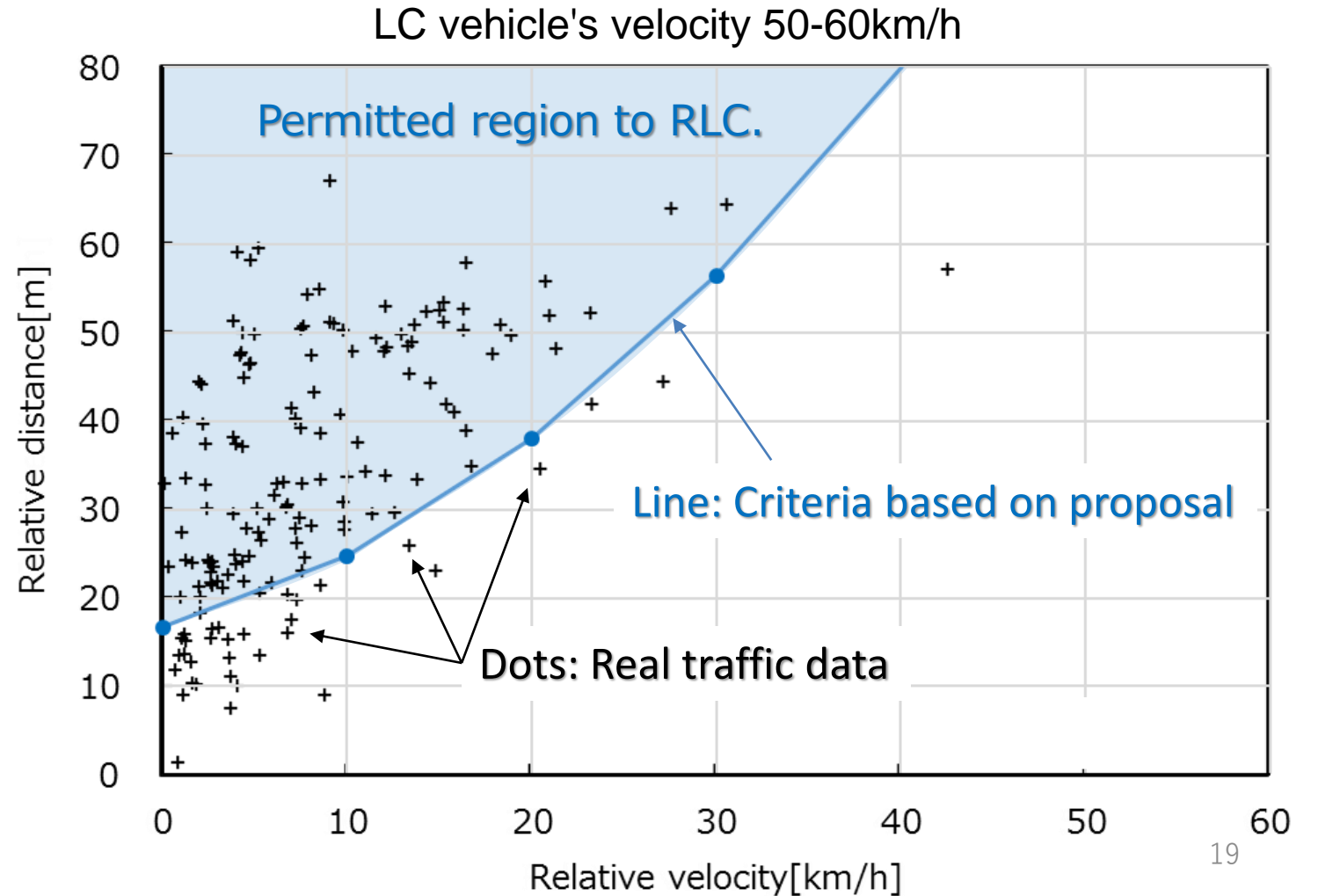
Analysis of real cut-in cases

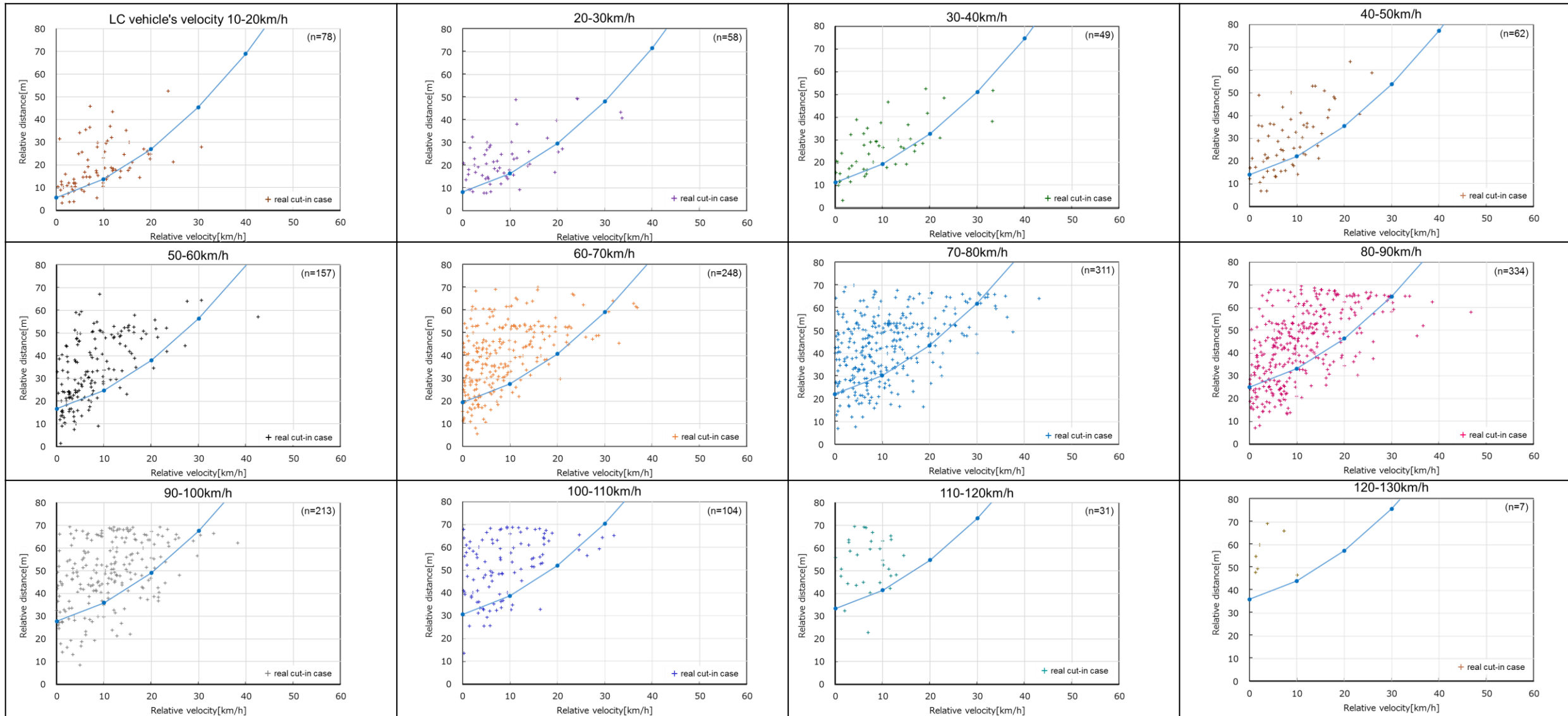・Ego vehicle velocity
・Relative distance
・Relative velocity

n=1,689

Comparison between safety criterion and real cut-in

LC vehicle's velocity 50-60km/h

Permitted region to RLC.

Line: Criteria based on proposal

Dots: Real traffic data

Relative distance[m]

Relative velocity[km/h]

Comparison between proposal criteria and real traffic data

Summary

1. Parameters for rear vehicle's driver behavior were proposed based on driving Simulator experimental data.

① Rear vehicle driver reaction time	② Rear vehicle deceleration rate	③ Minimum final gap time
2.0 sec	1.5 m/s^2	1.0 sec

2. Define a safety criterion for RLC based on the RLC concept.
   RLC: Do not cause the surrounding traffic participants (e.g. rear vehicle at lane change location) to be scared

3. As a result of comparison with actual traffic conditions, the compatibility of the criterion was confirmed.