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SAKURA
Safety Assurance KUdos for Reliable Autonomous Vehicles

Towards global AD safety assurance

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Aim of this presentation

To report on the development in Japan of an AD system safety assurance methodology.

(SAE Level 3+ in motorways)

Global trend for AV social acceptance

GUIDELINES ON THE EXEMPTION PROCEDURE FOR THE EU APPROVAL OF AUTOMATED VEHICLES

Safety requirements (pg.4)

When in the automated driving mode, the vehicle shall not cause any traffic accidents that are rationally foreseeable and preventable

Informal document **WP.29-177-19**
177th WP.29, 12-15 March 2019
Agenda items 2.3 and 17

Framework document on automated/autonomous vehicles

Safety vision (pg.1)

Automated vehicles shall not cause any non-tolerable risk, meaning that, under their operational domain, shall not cause any traffic accidents resulting in injury or death that are reasonably foreseeable and preventable

Comprehensive approach to safety

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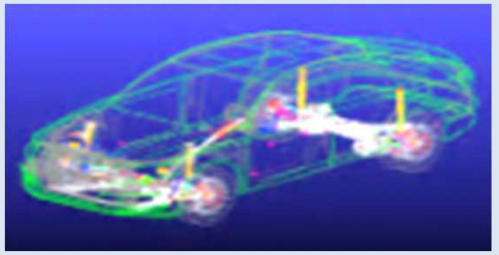
Scenario based approach

Scenario Structure

- Perception
  - Perception limitation

- Judgement
  - Traffic Disturbance

- Control
  - Vehicle Disturbance

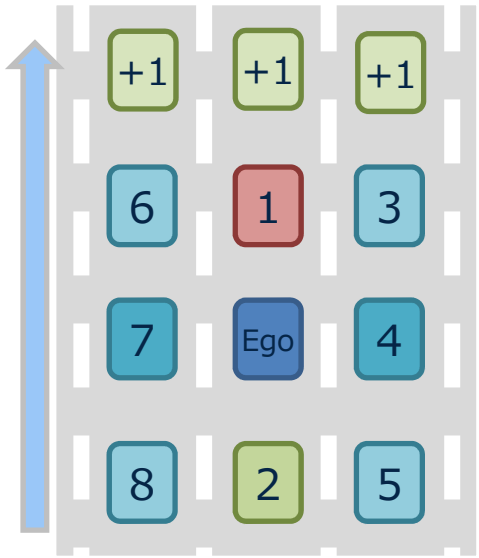


Safety testing driven by three scenario categories related to the physics of the AD system

Traffic disturbance scenario structure

Road geometry ✖ Ego-vehicle behavior ✖ Surrounding vehicles location ✖ Surrounding vehicles motion

		Ego-vehicle behavior	
		Lane keep	Lane change
Road geometry	Main	Free Driving Following	Lane changing Overtaking
	Merge lane	Being Merged	Merging
	Departure lane	---	Departing
	Ramp	Free Driving Following	Lane changing Overtaking



Veh. loc.	Cut in	Cut out	Acc.	Dec.	Sync
1		✓		✓	
2			✓		
3	✓			✓	
4	✓				✓
Ego					
5	✓		✓		
6	✓			✓	
7	✓				✓
8	✓		✓		

✓ May affect AD judgement

Scenario Structure based on road geometry, ego-vehicle behavior, and surrounding vehicles location and motion

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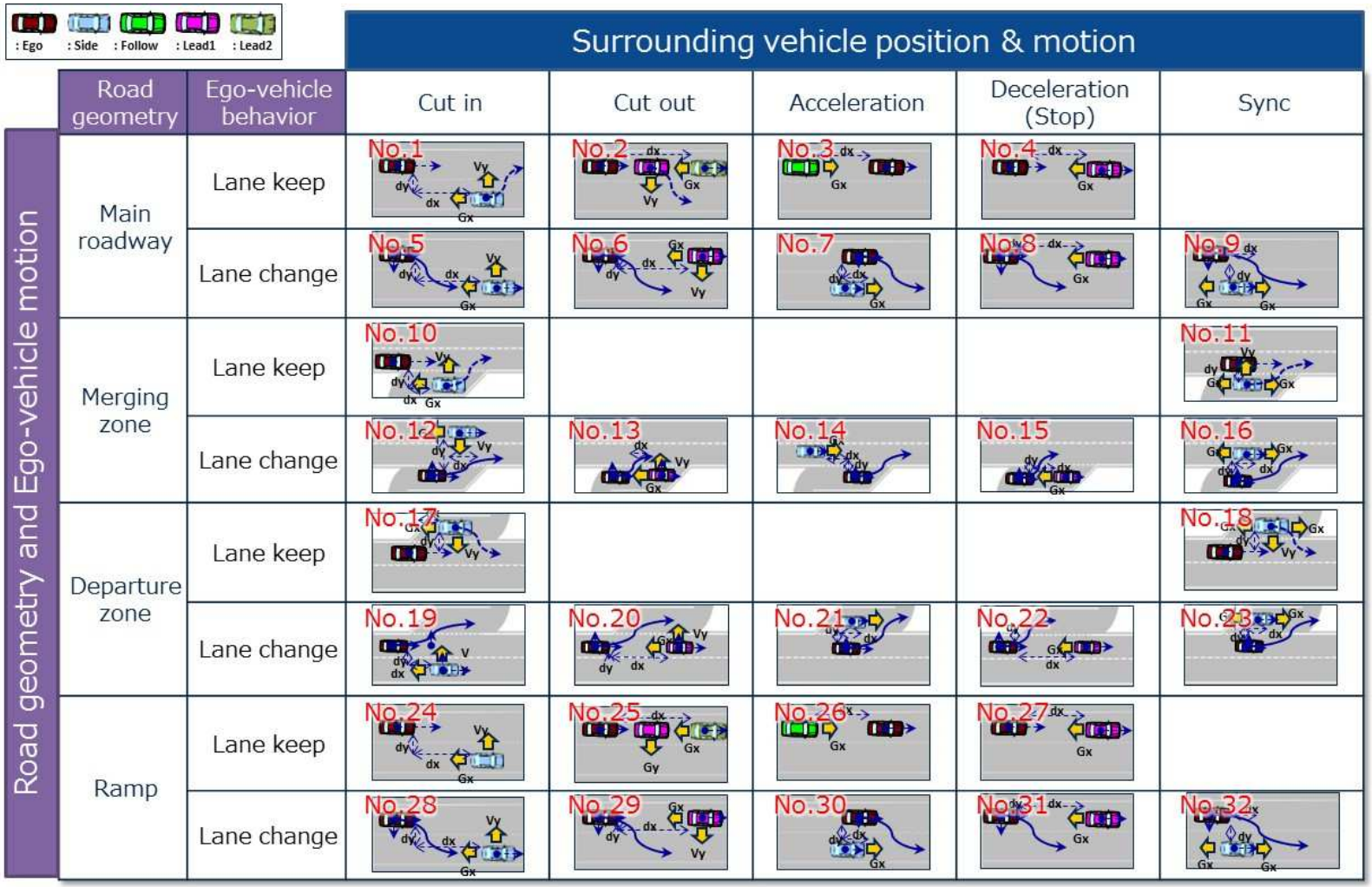
Traffic disturbance scenarios



32 well organized functional scenarios out from the proposed structure

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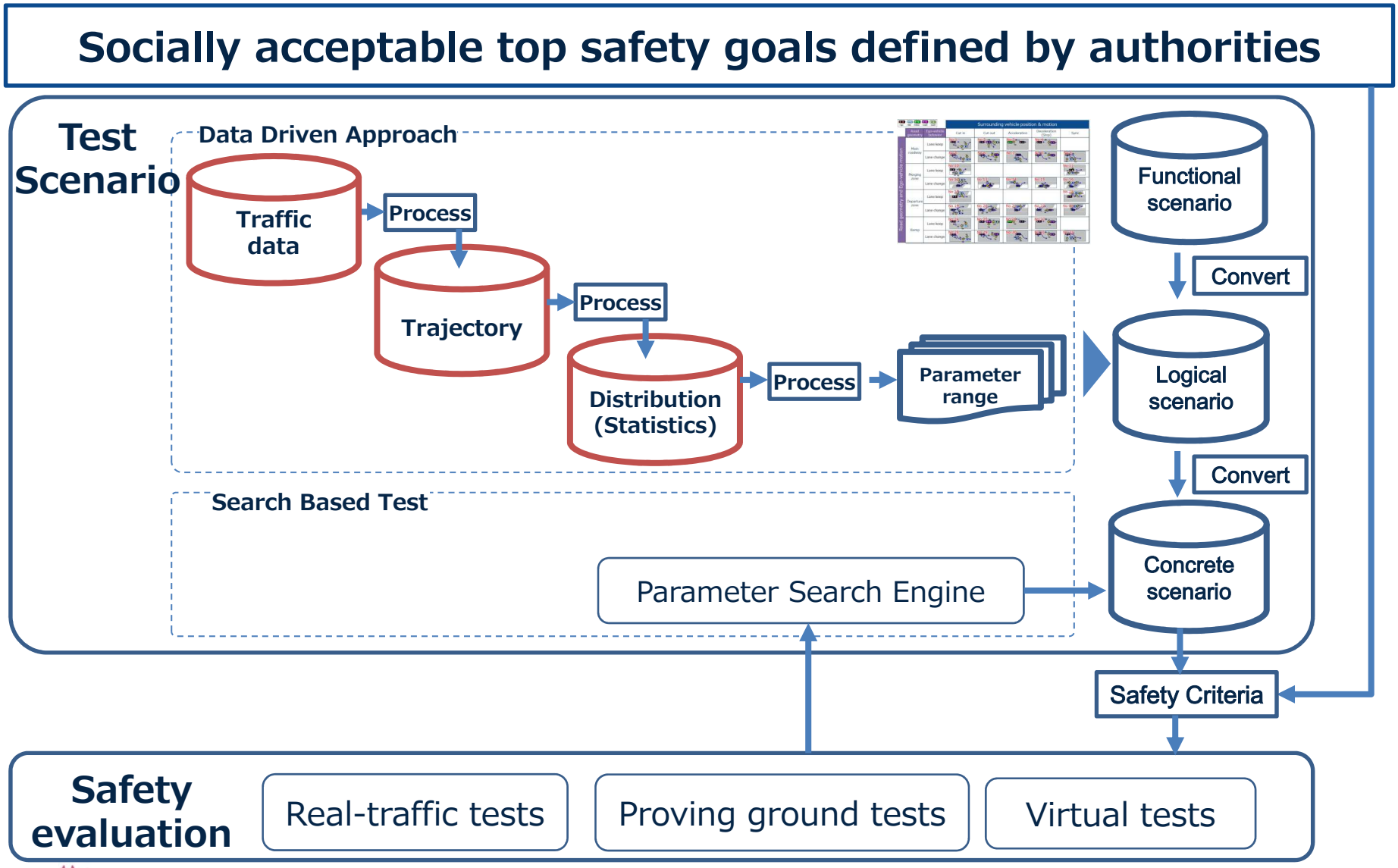
Safety assurance engineering approach



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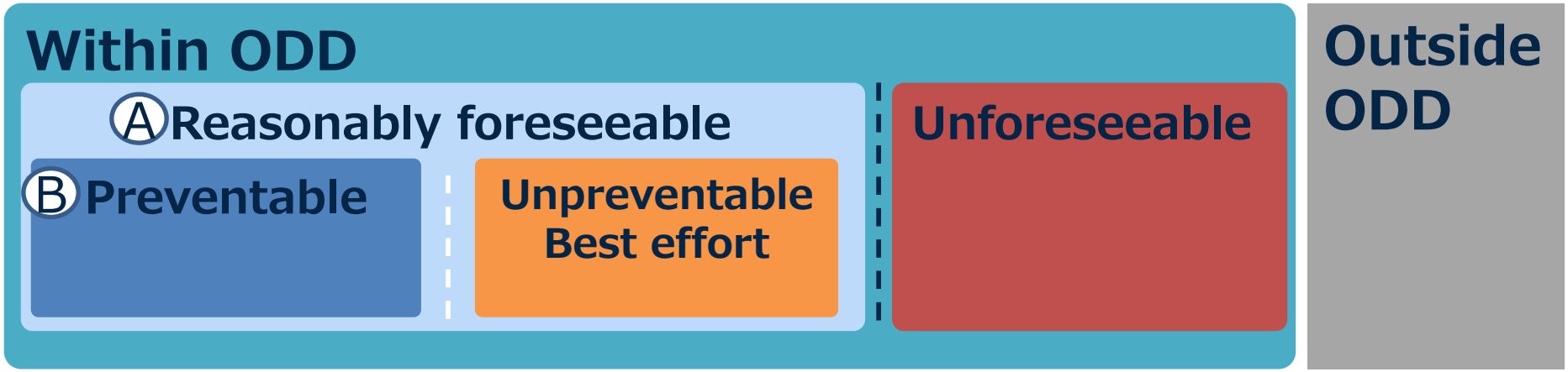
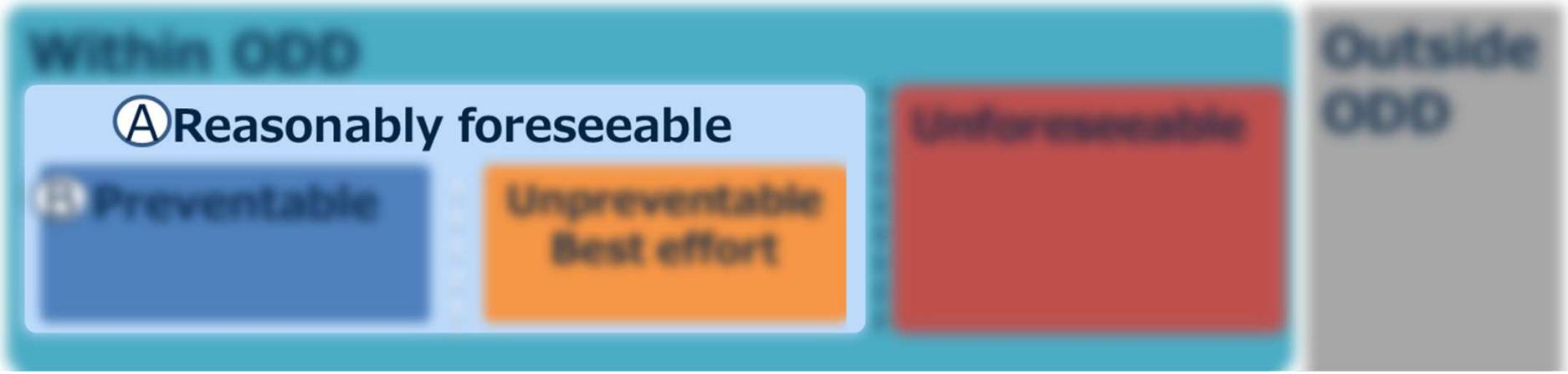
Safety requirement schematic structure



Reasonably foreseeable scenarios

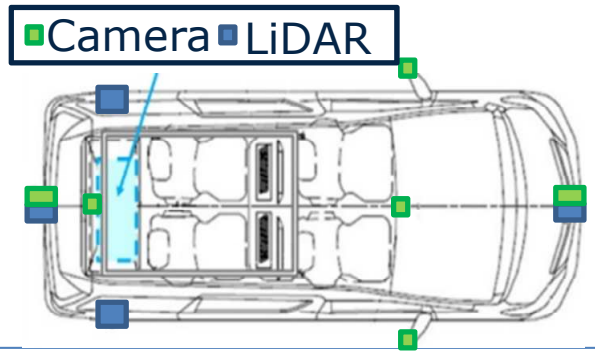


Traffic data collection in Japan

Ongoing

Data Source	TUAT Driving Recorder (~2018~)	JAMA Driving Recorder (2008)	Driving Database (2017)	On road Recognition Database (2017)	Instrumented Vehicles (2018~)	Fixed Camera (2018~)
◎ / ◎ Parameter available ○ Video only △ visible ✕ Not recorded	Ego	Ego	Ego	Ego	Ego	Ego

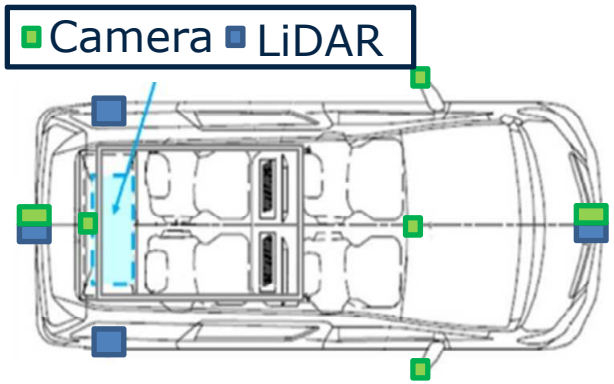
Instrumented vehicles

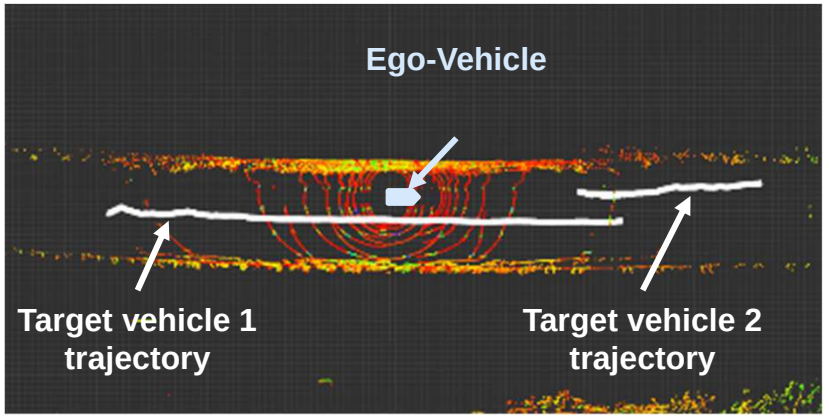


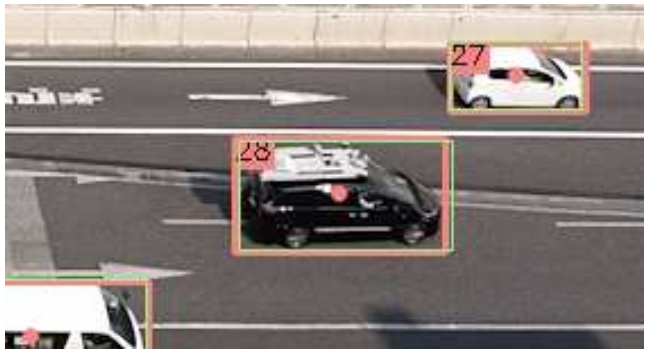
Fixed cameras

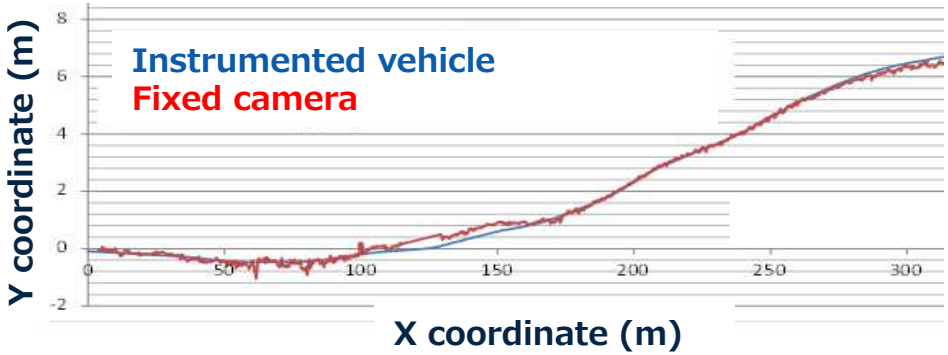
Ongoing data acquisition with instrumented vehicles and fixed cameras over motorways

Trajectory data extraction and accuracy evaluation









Vehicle trajectory extraction from both instrumented vehicles and fixed cameras, including data accuracy verification

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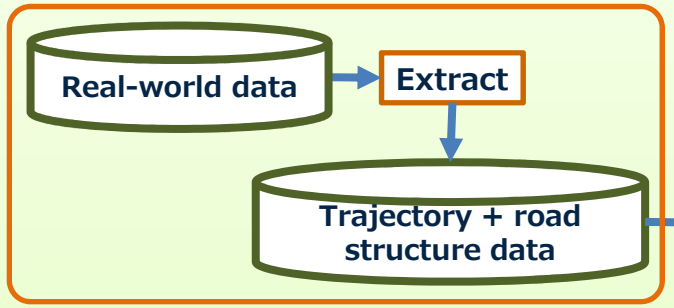
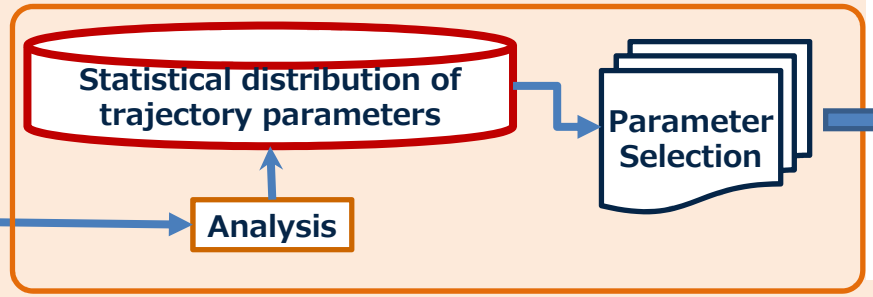
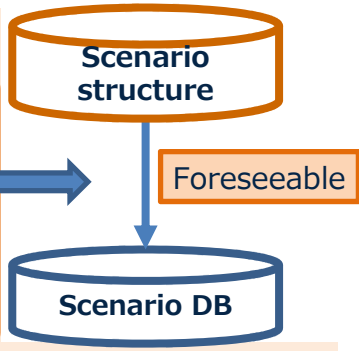
Derivation process of foreseeable scenarios

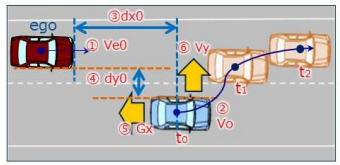
Driving data processing



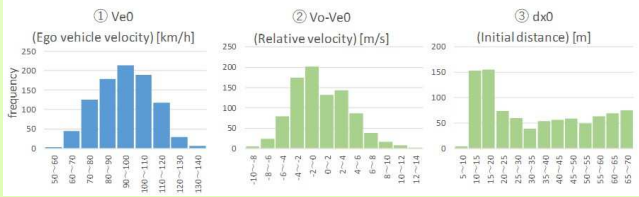
Analysis and parameter selection

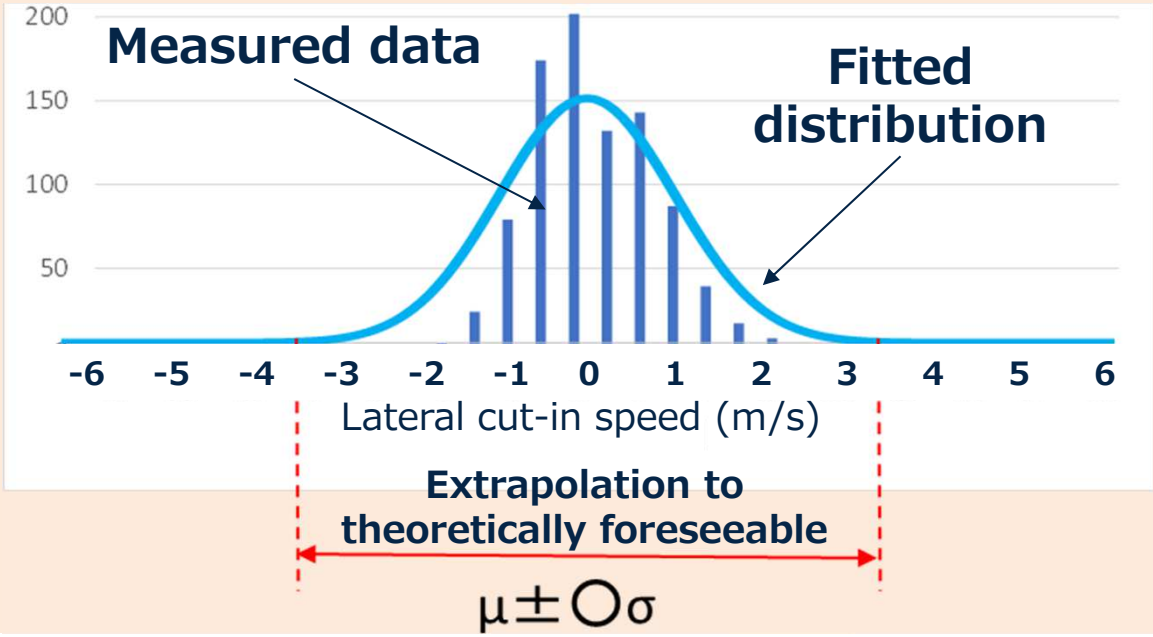






Scenario dependent parameter definition and automatic extraction





Consensus based rules to process and analyze real-world data, as well as to define corresponding foreseeable parameter ranges

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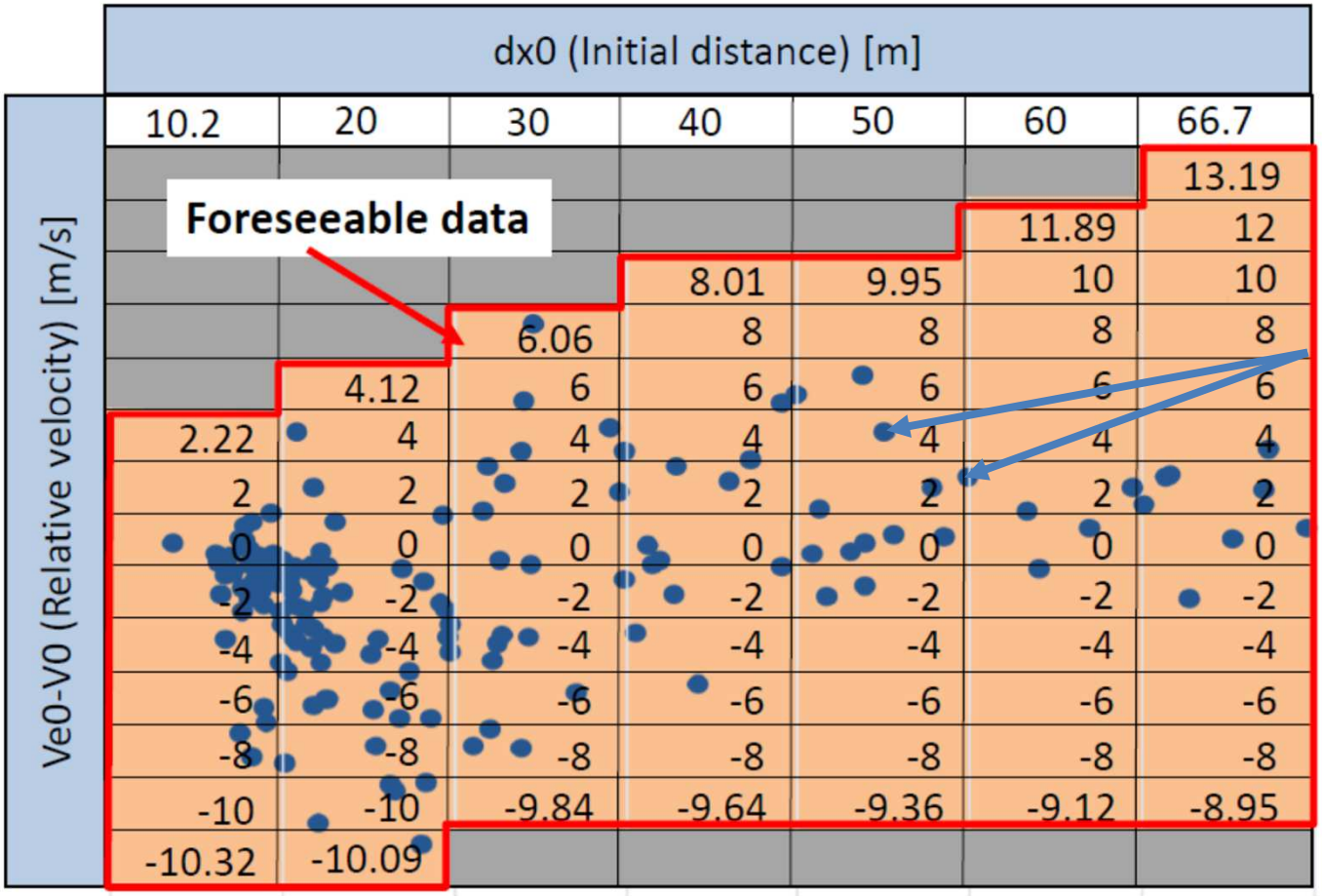
Foreseeable parameters from measured parameters

Precondition data :Ve0=80kph, Vy=1.72m/s



Ranges for foreseeable scenarios derived from measured data

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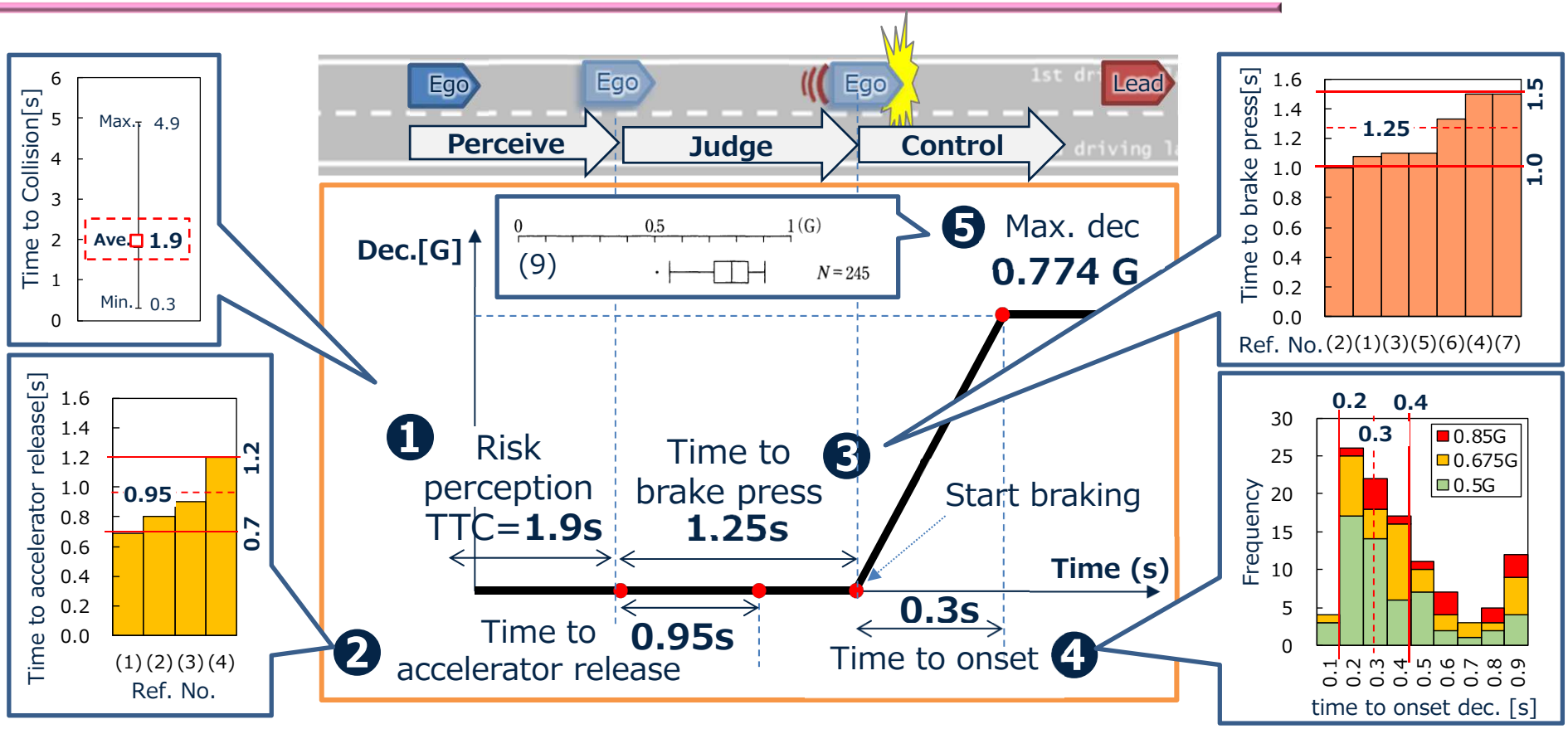
Preventable scenarios

Experienced driver braking model



(1) Olson et al. 1986, (2) Lechner et al. 1991, (3) McGehee et al.2000, (4) Mazzae et al. 2003, (5) Barrett et al.1968, (6) Broen et al.1996, (7) Lerner 1993, (8) McLaughlin et al. 2009 (NHTSA), (9) Makishita et al. 2001

Experienced driver functions constructed based on experimental and naturalistic driving data studies

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Virtual test results

Simulation Results (Ve0=80kph, Vy=1.72m/s)

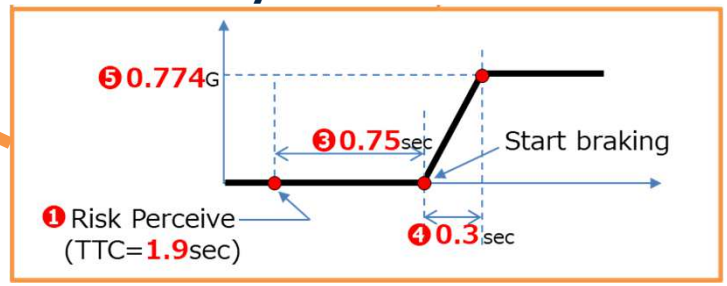
dx0(Initial Distance) [m]

Ve0-V0(Relative Velocity)[m/s]

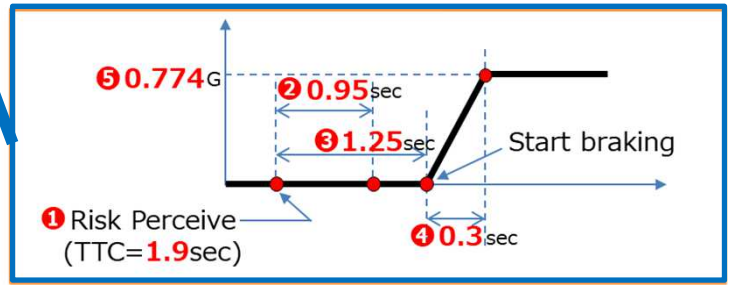
10.2	20	30	40	50	60	66.7
						✘ ✔13.19
					✘ ✔11.89	✘ ✔ 12
			✘ ✔ 8.01	✘ ✔ 9.95	✘ ✔ 10	✘ ✔ 10
		✔ ✔ 6.06	✘ ✔ 8	✘ ✔ 8	✘ ✔ 8	✘ ✔ 8
	✔ ✔ 4.12	✔ ✔ 6	✔ ✔ 6	✔ ✔ 6	✔ ✔ 6	✔ ✔ 6
✘ ✘ 2.22	✔ ✔ 4	✔ ✔ 4	✔ ✔ 4	✔ ✔ 4	✔ ✔ 4	✔ ✔ 4
✘ ✘ 2	✔ ✔ 2	✔ ✔ 2	✔ ✔ 2	✔ ✔ 2	✔ ✔ 2	✔ ✔ 2
✔ ✔ 0	✔ ✔ 0	✔ ✔ 0	✔ ✔ 0	✔ ✔ 0	✔ ✔ 0	✔ ✔ 0
✔ ✔ −2	✔ ✔ −2	✔ ✔ −2	✔ ✔ −2	✔ ✔ −2	✔ ✔ −2	✔ ✔ −2
✔ ✔ −4	✔ ✔ −4	✔ ✔ −4	✔ ✔ −4	✔ ✔ −4	✔ ✔ −4	✔ ✔ −4
✔ ✔ −6	✔ ✔ −6	✔ ✔ −6	✔ ✔ −6	✔ ✔ −6	✔ ✔ −6	✔ ✔ −6
✔ ✔ −8	✔ ✔ −8	✔ ✔ −8	✔ ✔ −8	✔ ✔ −8	✔ ✔ −8	✔ ✔ −8
✔ ✔ −10	✔ ✔ −10	✔ ✔ −9.84	✔ ✔ −9.60	✔ ✔ −9.36	✔ ✔ −9.12	✔ ✔ −8.95
✔ ✔ 10.32	✔ ✔ 10.09					

✔ : Non−crash, ✘ : Crash

AD system function



Experienced human driver



By running virtual tests of all foreseeable scenario conditions with either experienced human driver or AD vehicle functions, technically feasible preventable levels can be defined.

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Test scenario catalogue database application

Test Scenario Catalog database

Scenario XML

```
<?xml version="1.0" encoding="UTF-8"?>
-<SimScenario Name="LS-G1-2-E1-10-00B-3030">
<Description>Lane keeping(Steady running) Ego vehicle
constant speed、Side vehicle(Pr-s) changes the lane(Cut in:
(right -> left)</Description>
<Road ID="2"/>
-<Object Name="Ego vehicle" Category="EgoVehicle">
<VehicleInit Speed="40" Abscissa="0" Ordinate="0"
Lane="1stDrivingLane"/>
</Object>
-<Object Name="Side vehicle(Pr-s)" Category="OtherVehicle">
<VehicleInit Speed="40" Abscissa="0" Ordinate="100"
Lane="2ndDrivingLane"/>
<VehicleScene Speed="40" Abscissa="0"
Lane="2ndDrivingLane" Time="3"/>
<VehicleScene Speed="20" Abscissa="0" Lane="1stDrivingLane"
Time="1.5"/>
```

Road geometry XML

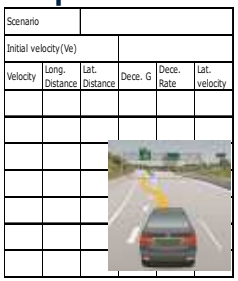
```
<OpenDRIVE>
<header revMajor="1" revMinor="1" name="" version="1.00"
date="2018/10/18 0:00:00"
north="0.0000000000000000e+00"
south="0.0000000000000000e+00"
east="0.0000000000000000e+00"
west="0.0000000000000000e+00"
vendor="TOYOTA"></header>
<road name="Mainroad_1Line" length="3000" id="1"
junction="-1">
<link>
</lane>
<lane id="2" type="border" level="0">
<width sOffset="0.0000000000000000e+00"
a="2.5000000000000000e+00"
b="0.0000000000000000e+00"
c="0.0000000000000000e+00"
d="0.0000000000000000e+00" />
</road>
</OpenDRIVE>
```

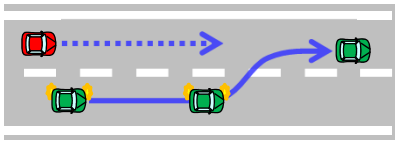
Test data

Real-traffic tests

Proving ground tests

Test procedure





Audit (Virtual tests)

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Summary

- A complete AD safety assurance methodology has been developed in Japan.
- The methodology can be applied to continue developing the systems and to evaluate their safety.

Need for international consensus:

1) Definitions of 'foreseeable' and 'preventable'
2) Qualification of real-world traffic data
3) Approach to social acceptance
4) Applicability to different countries/regions
5) Common database

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