SAKURA
Safety Assurance KUdos for
Reliable Autonomous Vehicles

# A Study on Safety Requirement for Automated Right-turn Function Considering Oncoming Driver's Interference

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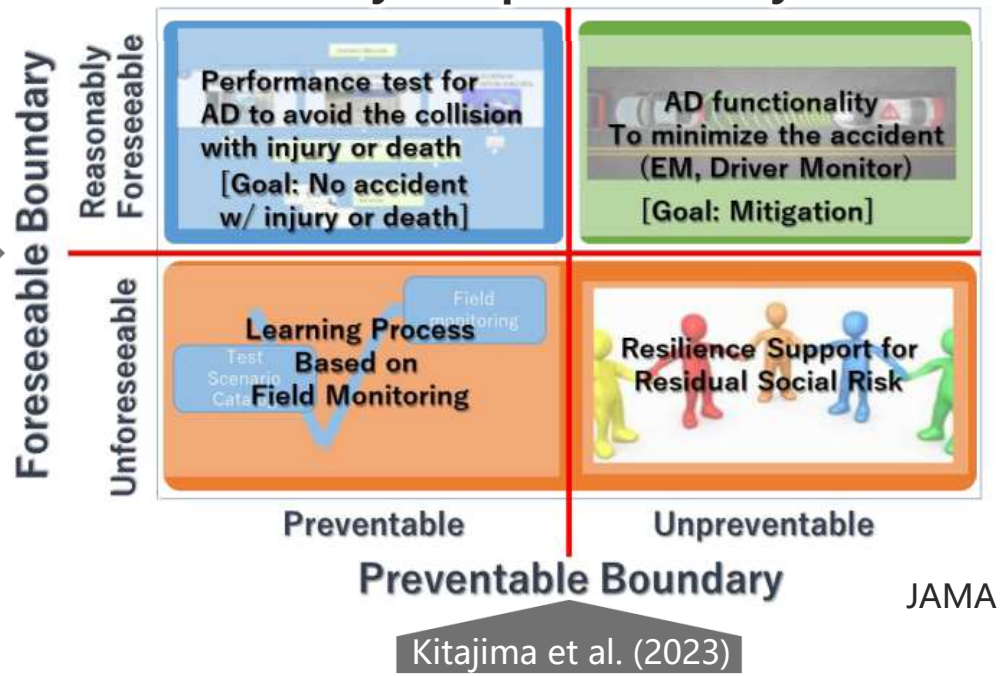
# 1. Introduction

# Scenario-based safety evaluation of ADSs

## UN WP29 & MLIT

Automated Driving Systems (ADSs), **while engaged**, shall not cause any traffic accidents that are **reasonably foreseeable** and **preventable**.

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



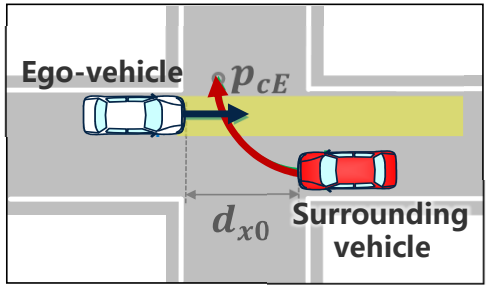
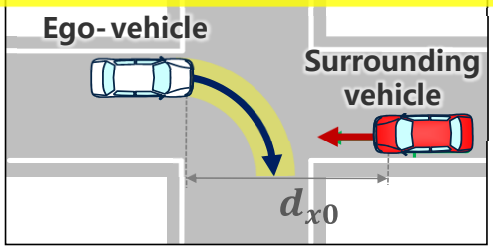

JAMA (2022)

Kitajima et al. (2023)

**Boundaries : reasonably foreseeable and preventable scenario definition**

# Driver behavior modeling approach

## ◆ Two aspects for defining preventability

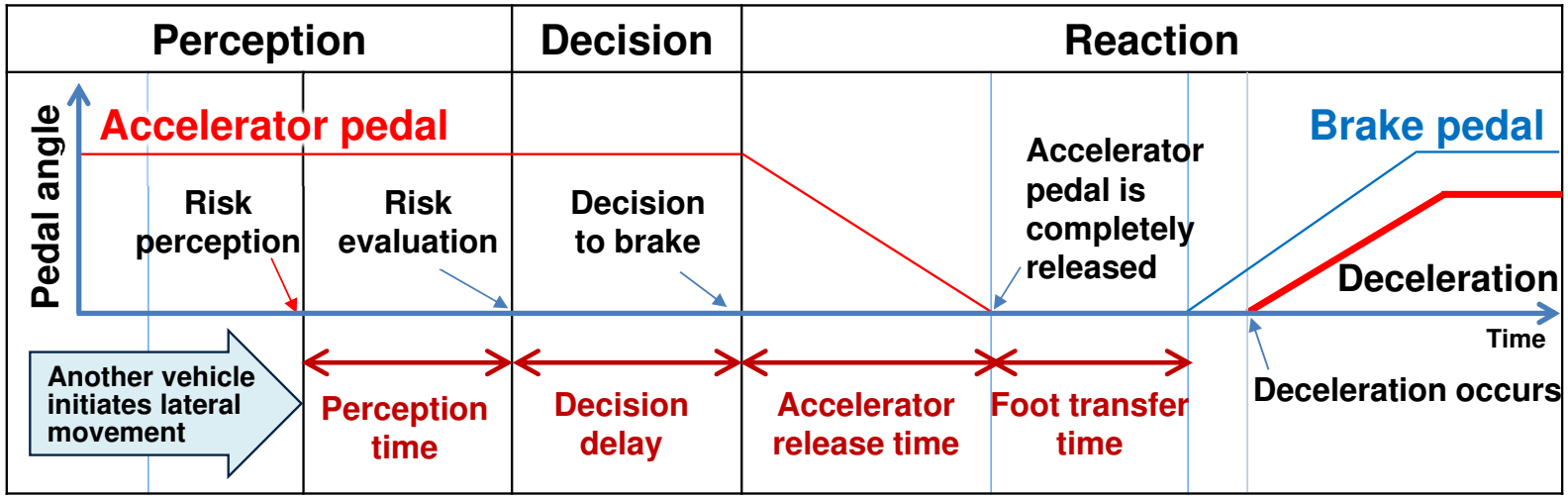
| Role | Responder Role | Initiator Role |
|---|---|---|
| **Example scenario** |  | **Current study**<br>  |
| **Role-based ADS safety requirements** | To achieve the best collision avoidance or damage mitigation while outperforming human drivers | To avoid colliding or obstructing with another vehicle by temporarily withholding the specific maneuver until it can be completed appropriately |
| **Research objectives** | To quantify the behavior of C&C (Competent & Careful) drivers | To quantify behavior and subjective experience of the oncoming vehicle driver |

Waymo (2023)
Kitajima et. al (2023)

**Different safety requirements : responder role / initiator role**

# Example of responder role

- **Driver's evasive behavior processes by a braking operation when responding to a cut-in by another vehicle**

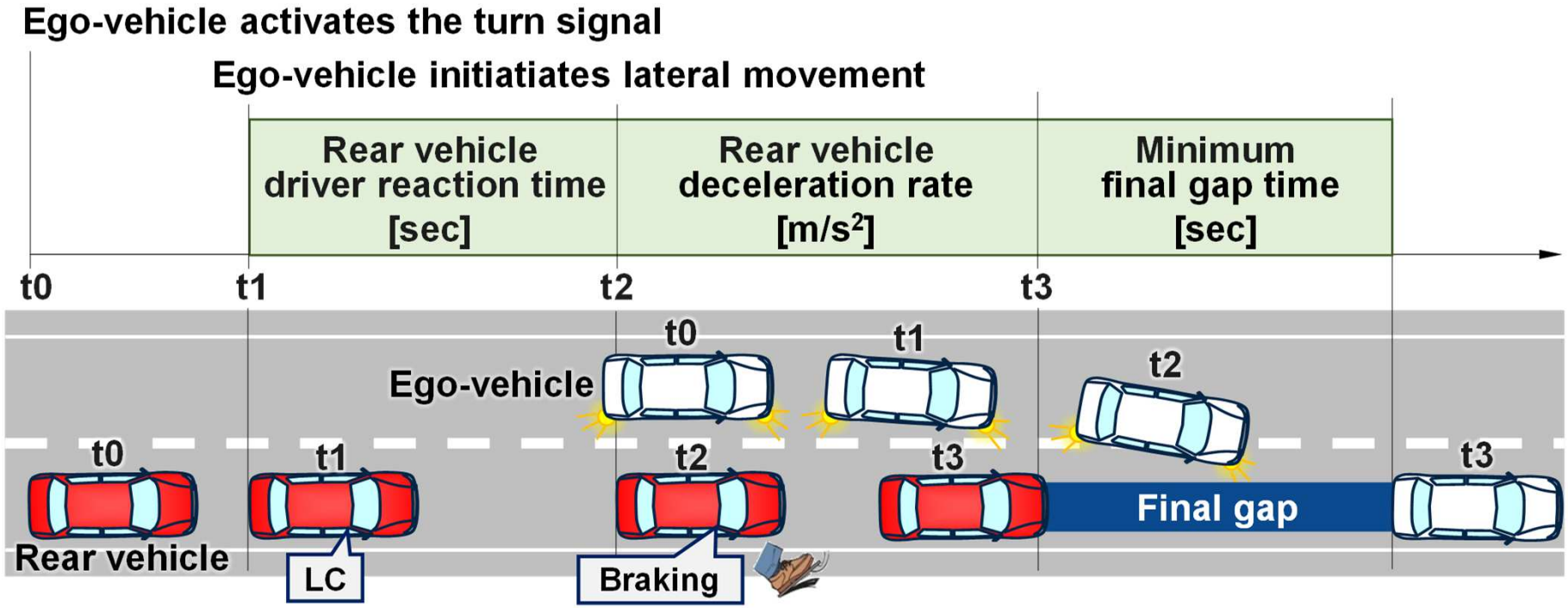



JAMA (2020)
UN ECE (2020)

**Requirement : to make its utmost effort to avoid a collision**

# Example of initiator role

- **Driver´s ordinary response and desired final gap after initiating a cut-in**



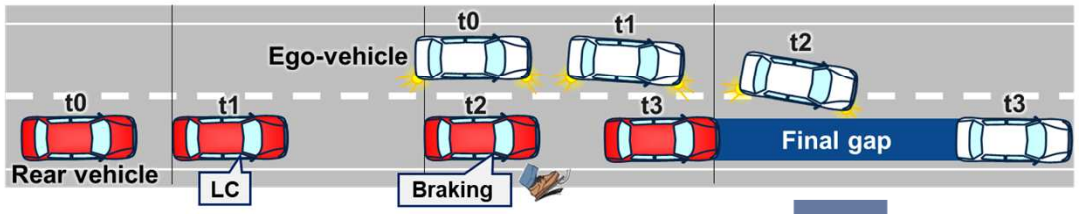

Kitajima et. al (2023)

**Requirement : to avoid not only collision but also obstructing**

# Required final gap for surrounding vehicle

- Surrogate safety indicator of drivers´ subjective feeling

## Cut-in at non-intersection

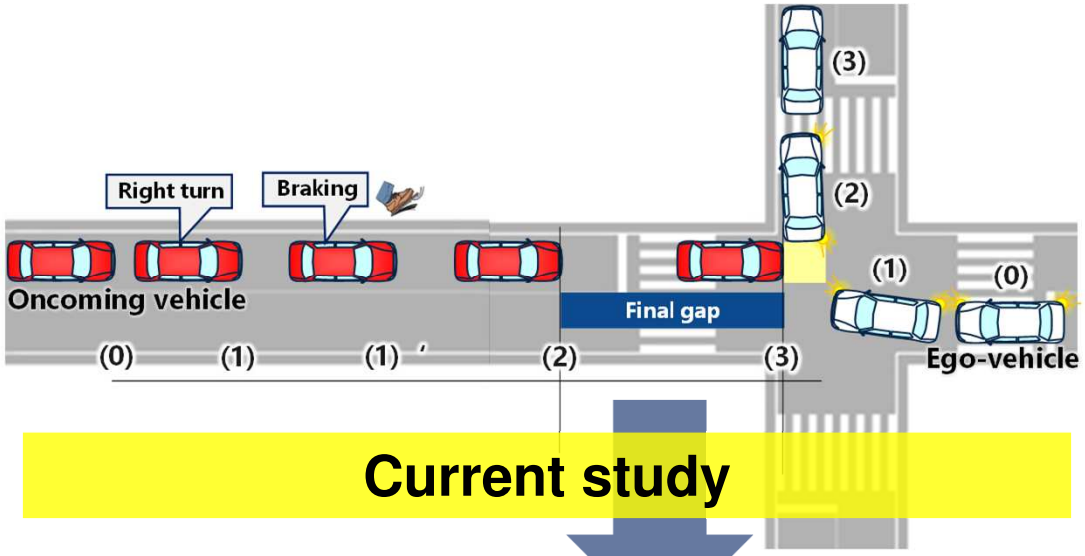



**Addressed by Kitajima et. al 2023**

**Time Head-Way (THW) [s]**

Evans (1991)

## Right-turn at intersection




**Current study**

**Post Encroachment Time (PET) [s]**

Allen (1978)

# Aims

**This study aims to:**

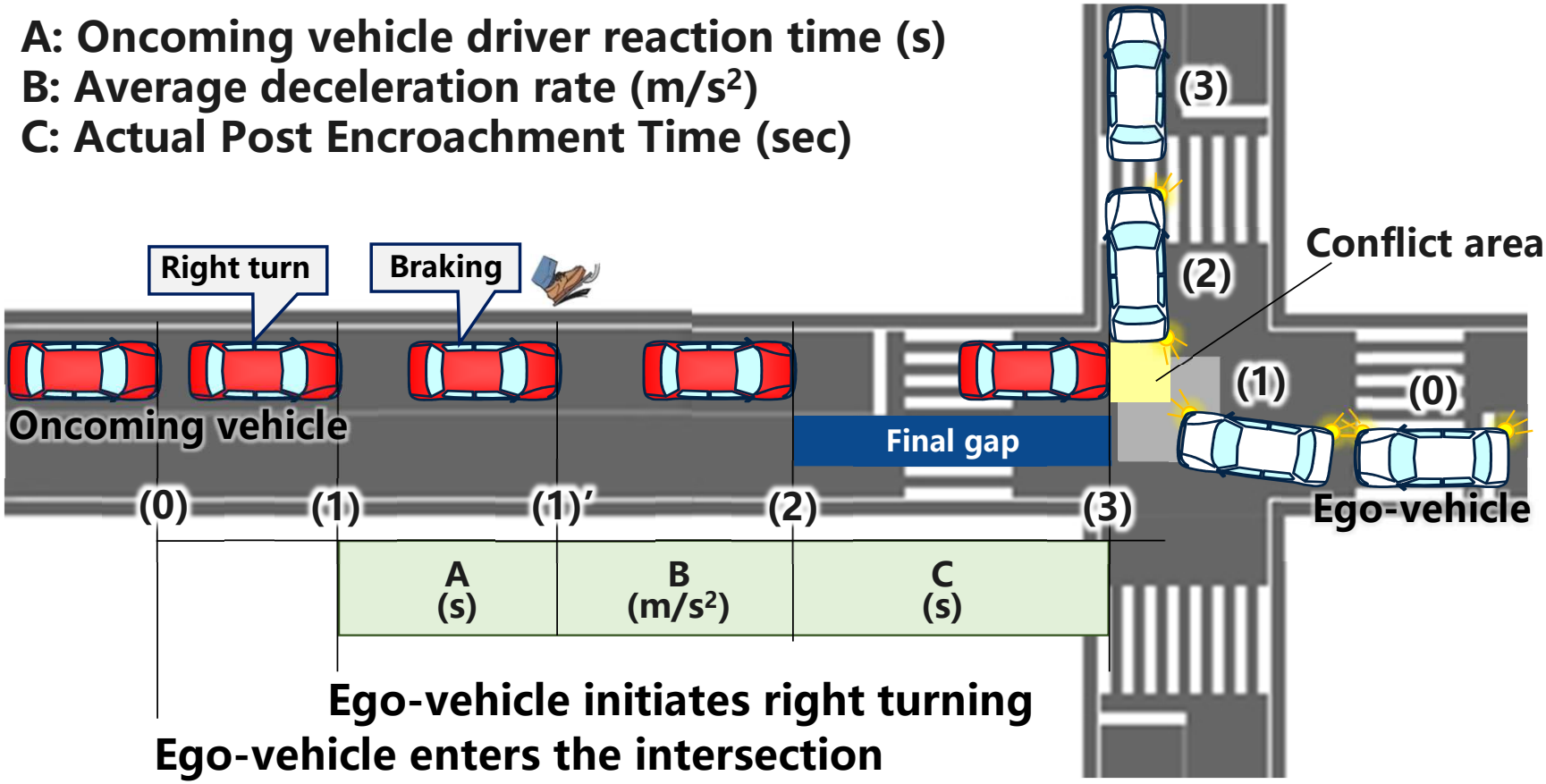
- **establish specific safety requirements for ADS right-turn functions by proposing a human driver behavior model as a benchmark for system evaluation,**

- **derive a framework that aligns with legal expectations, human behavior, and regulatory guidelines for ADS safety evaluations in complex urban environments.**

# 2. Method

# Requirement for right-turning function

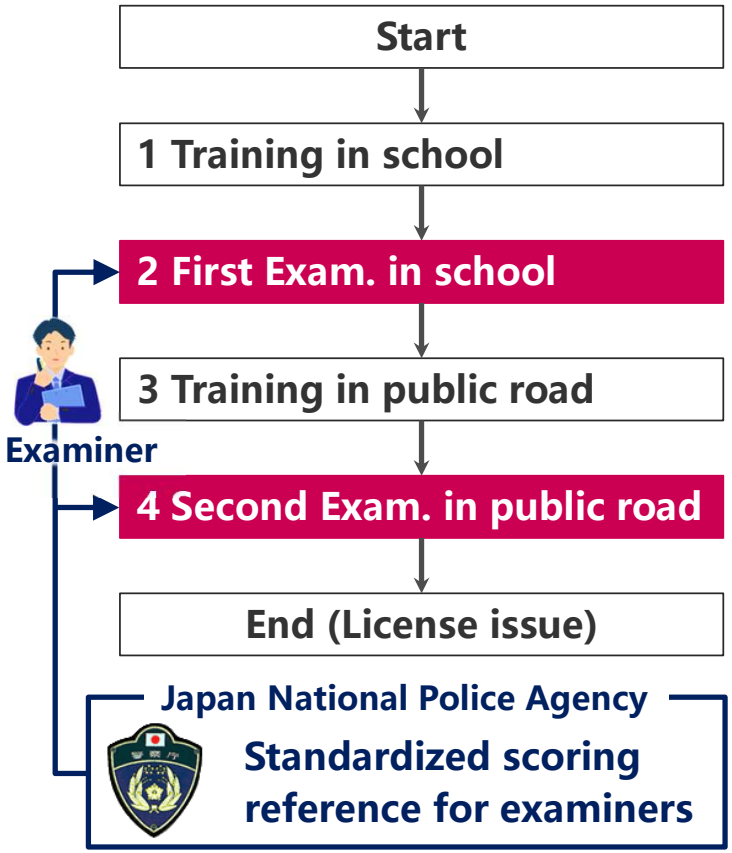
A: Oncoming vehicle driver reaction time (s)
B: Average deceleration rate (m/s²)
C: Actual Post Encroachment Time (sec)




**Requirement : to avoid colliding with & obstructing progress of priority vehicles**

# How to interpret obstructing progress

## Driving license issue flow in Japan (Driving skill aspect)




## Extracted deducting conditions about right-turning

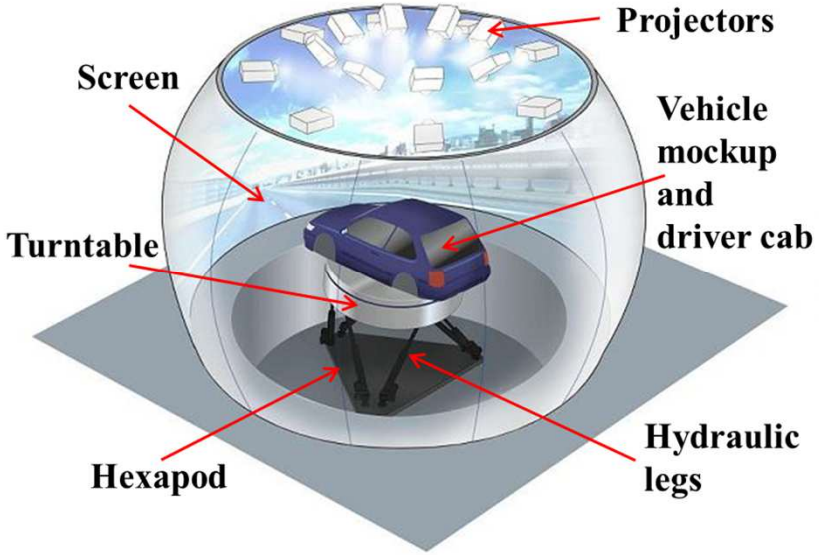
| Evaluation item | Explanation | Grade |
|---|---|---|
| Ignoring a traffic signal | Driver overruns a designated stop line while the front signal is red | Danger |
| **Obstructing progress** | Driver conducts a right turning maneuver **disregarding the oncoming traffic** | Danger |
| Prohibited entry behavior | Driver stops at the crossing zone for pedestrian, bicyclist, or vehicles even though there is no margin to stop after changing yellow signal | 20 |
| Speed violation | Driver does not reduce speed during right turning | 20 |
| Omitting safety confirmation | Driver fails to confirm the oncoming traffic or crossing vulnerable road users | 10 |
| **Priority misjudgment** | Driver fails to yield to straight-crossing vehicles during a right-turn maneuver **forcing them to decelerate or change direction** slightly | 10 |
| Abrupt steering operation | Driver performs an abrupt steering operation more than 0.3 G laterally | 10 |
| Abrupt brake operation | Driver performs an abrupt brake operation, except for collision avoidance, more than 0.4 G longitudinally. | 10 |
| Blinker misuse | Driver does not turn blinker on before turning right or turn blinker off before completing the right turning | 5 |

Japan National Police Agency (2025)

**Quantitative definition : obstructing progress for oncoming vehicle**

# Driving simulator experiment

- Omnidirectional moving-based Driving Simulator at Japan Automobile Research Institute
- 20 drivers (24-59 years old)
- Instructions: to drive straight-crossing an intersection while encountering a right-turning vehicle with various initial PET




Driving Simulator at JARI

# Experimental conditions



| Time gap (s) | Right-turn velocity | Initial PET (s) |
|---|---|---|
| 3.5 | Slow | -1.0 |
| | Fast | 0.5 |
| 4.0 | Slow | -0.5 |
| | Fast | 1.0 |
| 4.5 | Slow | 0.0 |
| | Fast | 1.5 |
| 5.0 | Slow | 0.5 |
| | Fast | 2.0 |

**Subjective feeling scale**

1. Absolutely
2. Highly exist
3. Rather exist
4. Rather not exist
5. Highly not exist
6. Not at all

**Instruction for drivers**
To score assuming the boundary for obstructing progress exists between **3** & **4**

**Measurement : driver´s response and subjective feeling**

# 3. Results

1) Oncoming drivers´ behavior analysis

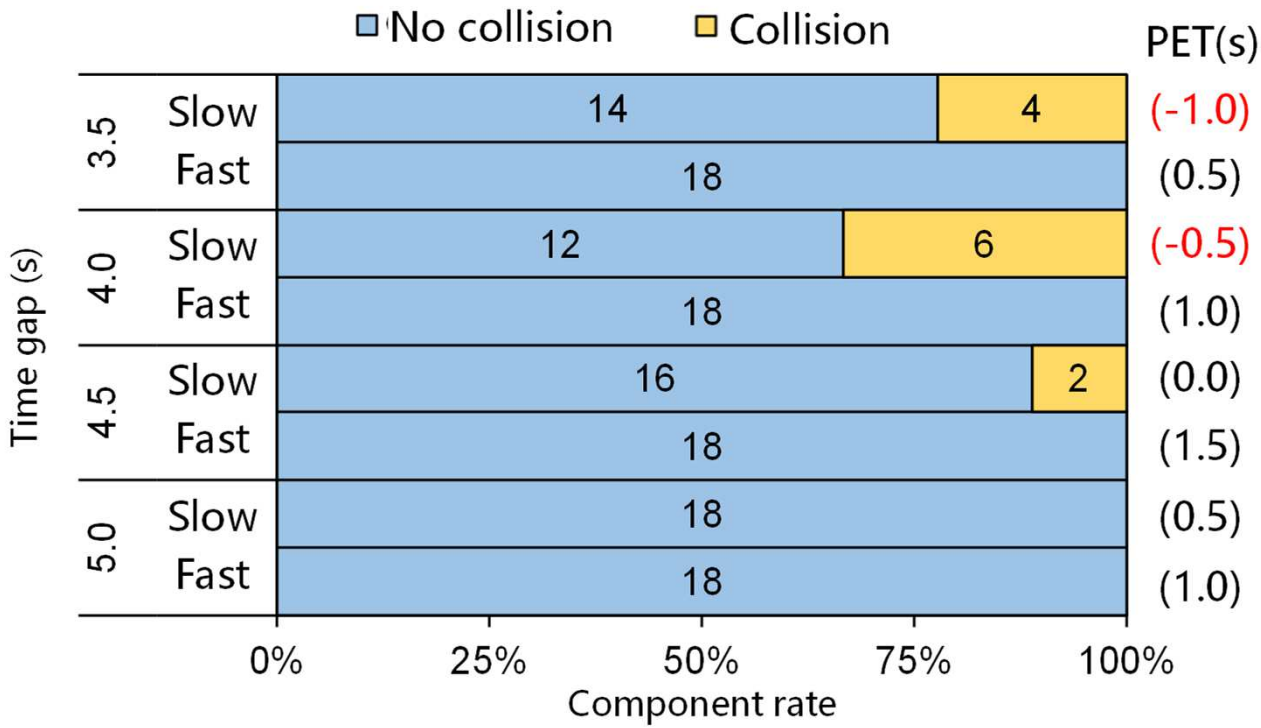
2) Desired PET

3) Subjective analyses

4) Price Sensitivity Meter (PSM) analysis

# 1) Oncoming drivers´ behavior analysis

◆ **Number of trials classified by collision/no collision events (n=144)**

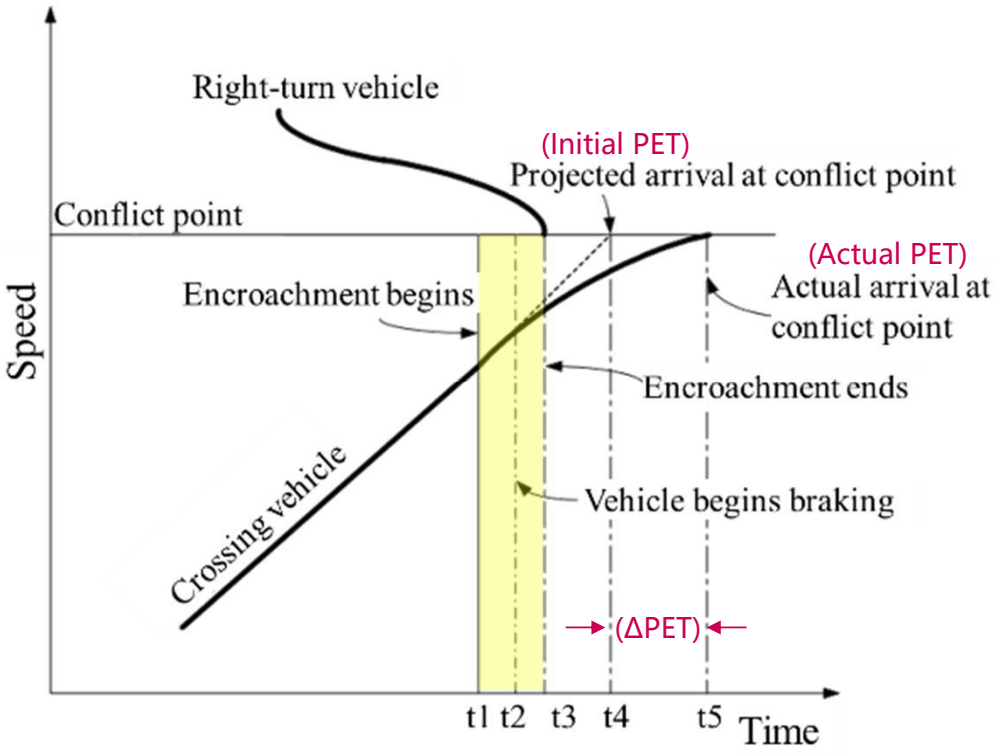



*Note: 2 participants out of 20 withdrew due to motion sickness.

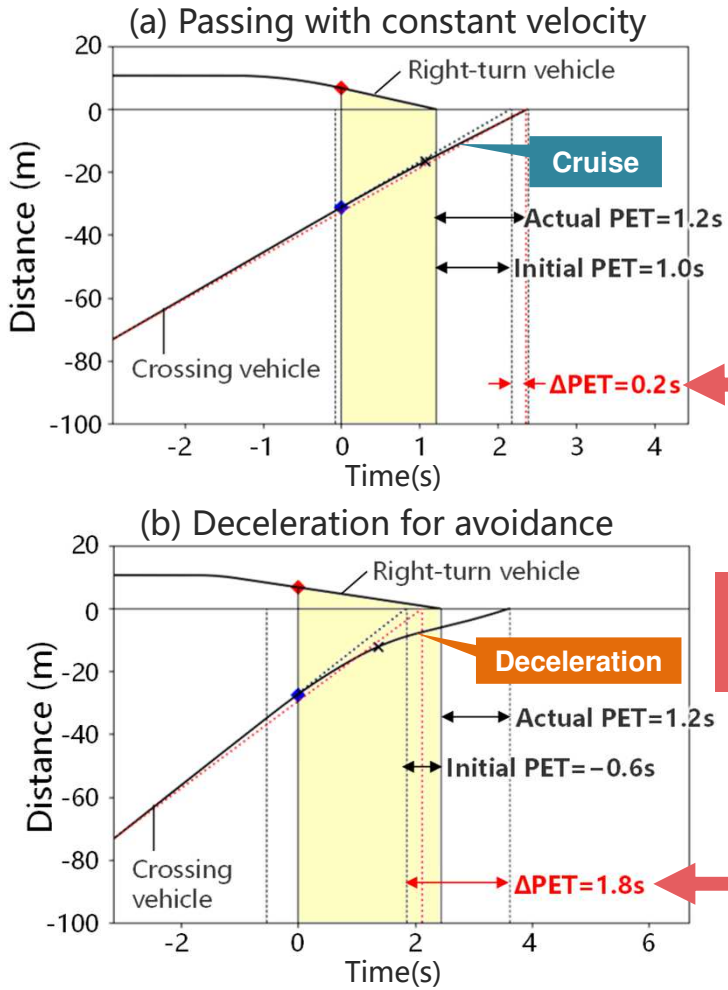
**132 trials : dataset to define drivers´ obstructing progress**

# 1) Oncoming drivers´ behavior analysis

## Analysis diagram to relative relation




US DOT (Department of Transportation) (2001)

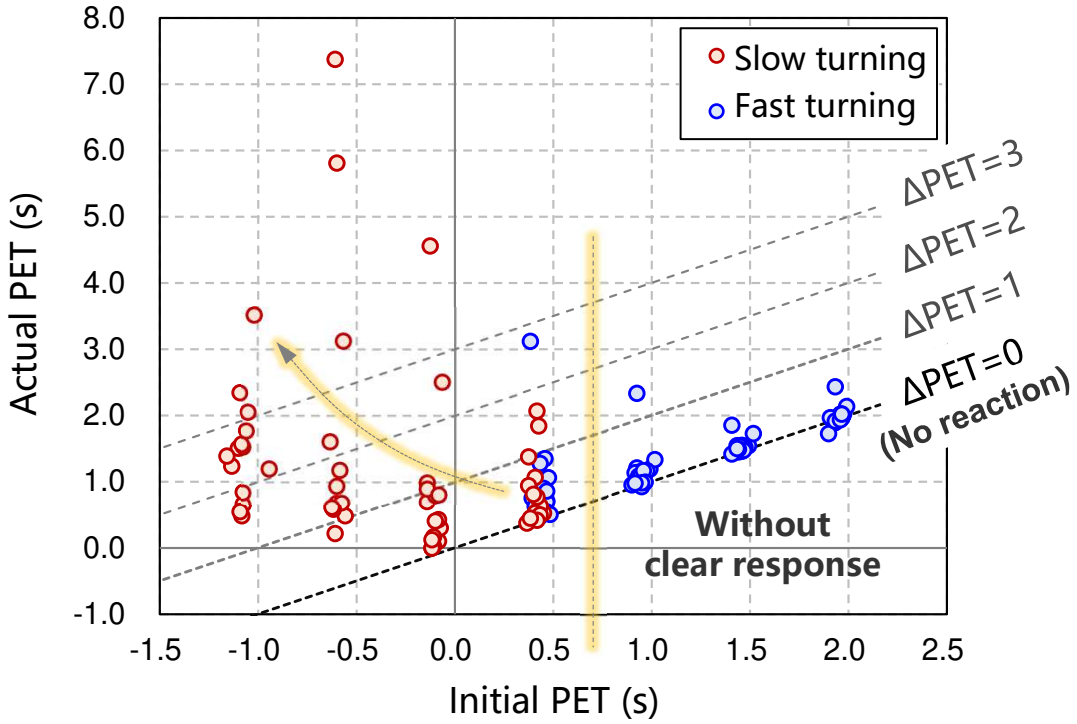



**Significant difference**

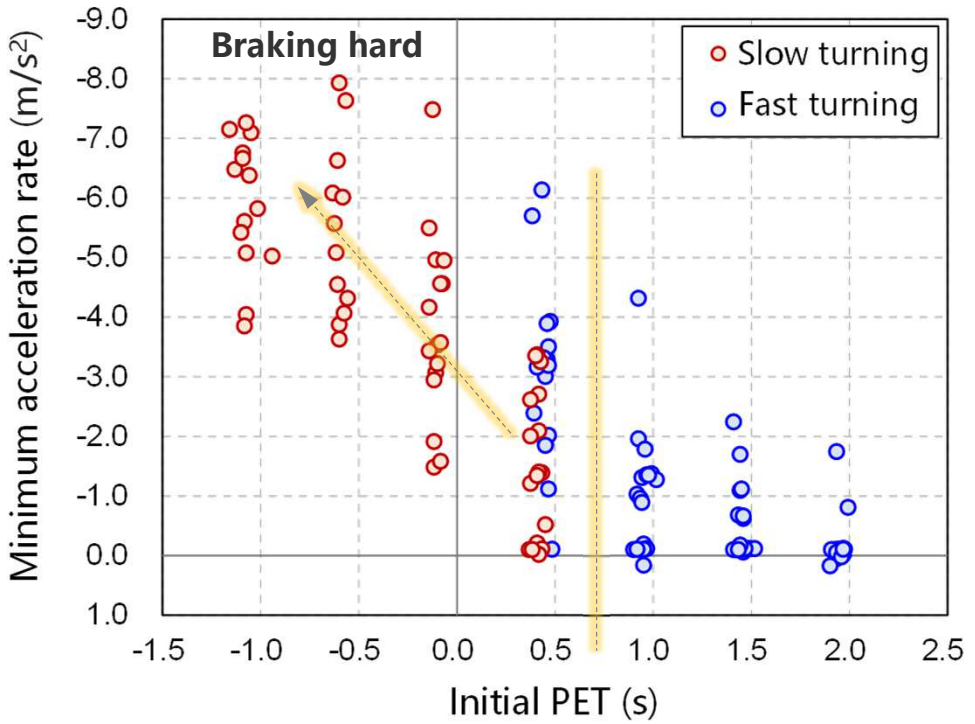
**ΔPET : useful value for driver´s obstructing progress evaluation**

# 2) Desired PET

## ◆ Relationship between the initial and actual PET



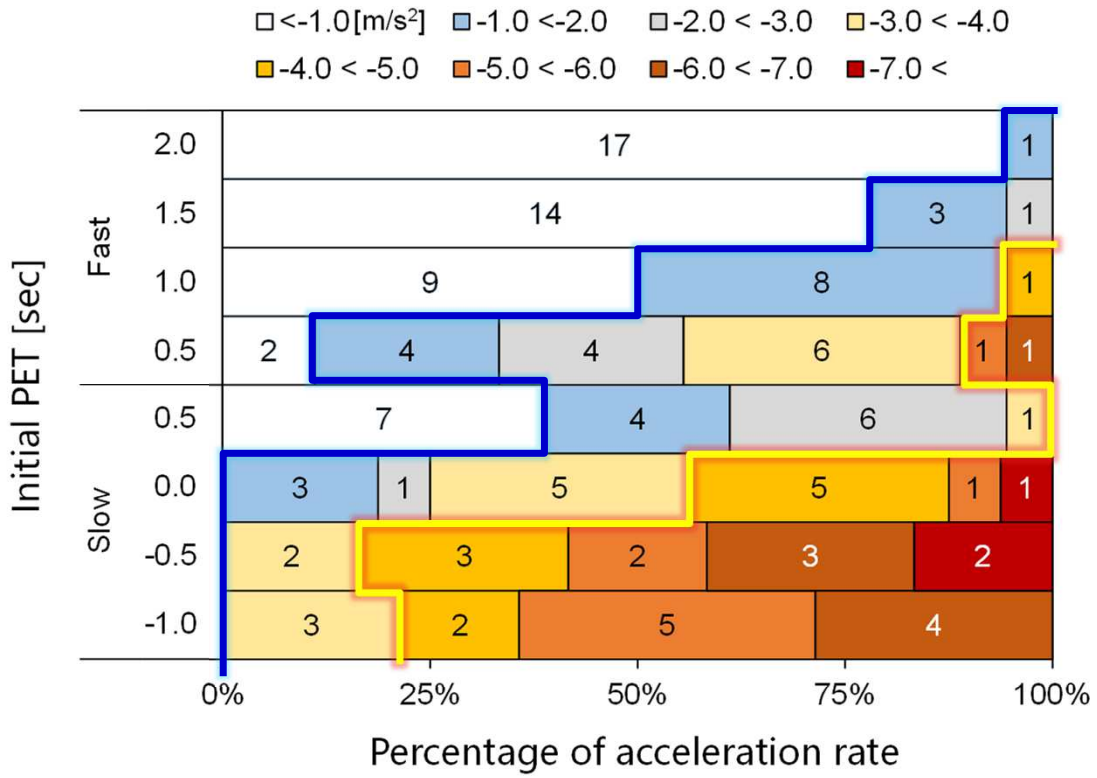

## ◆ Relationship between initial PET and minimum acceleration rate




**Drivers´ reactions indicate low tolerance when initial PET is less than 0.5**

# 2) Desired PET

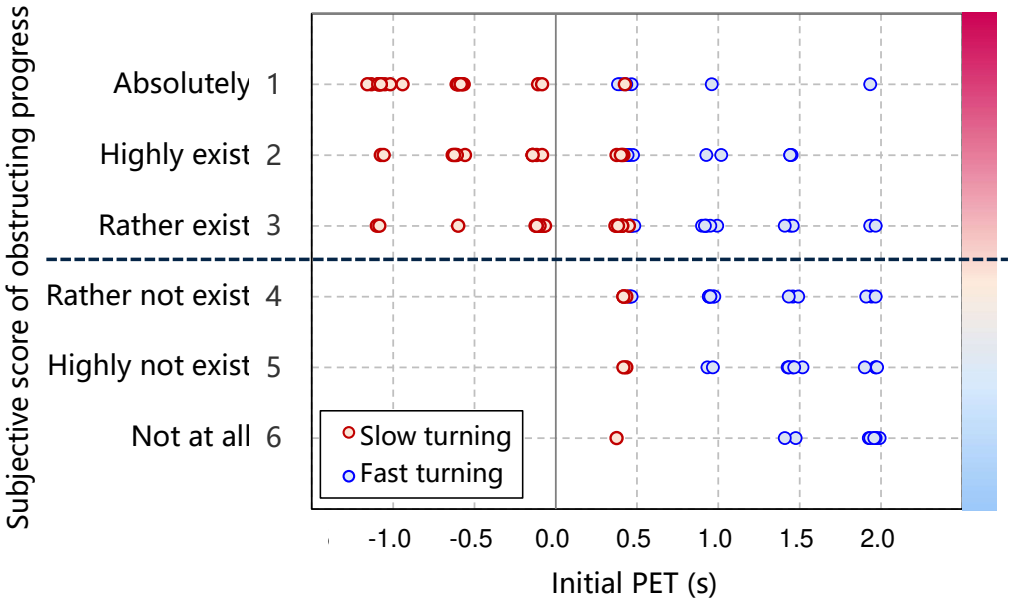
- **Classification of driver brake operation based on initial PET**



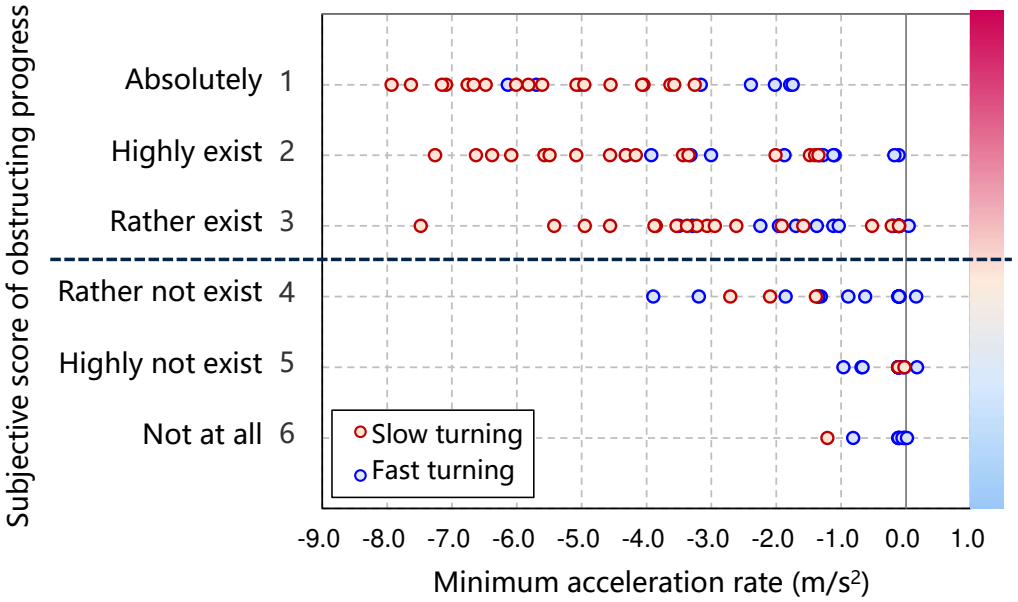

**Initial PET < 1.0 : applying brake operation for 40-100 % of drivers**
**Initial PET < 0.5 : frequent abrupt deceleration exceeding -4m/s²**

# 3) Subjective analyses

## ◆ Driver´s subjective feeling as a function of initial PET



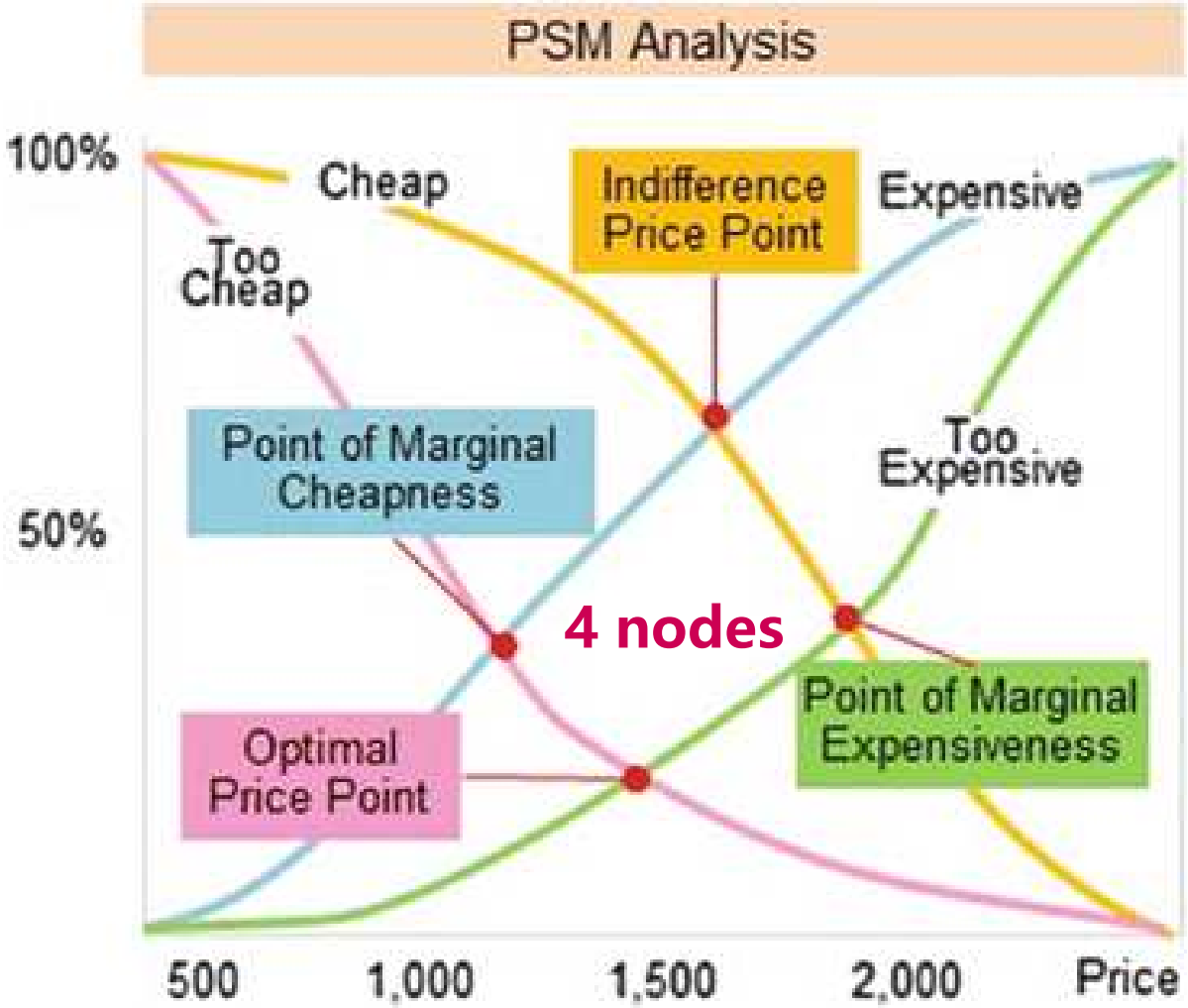

## ◆ Driver´s subjective feeling as a function of minimum deceleration rate




*Note: Drivers were instructed to answer each score, assuming the threshold for obstructing progress exists between 3 and 4.

**Difficult to specify an explainable & sole criterion for all drivers' subjective feelings**

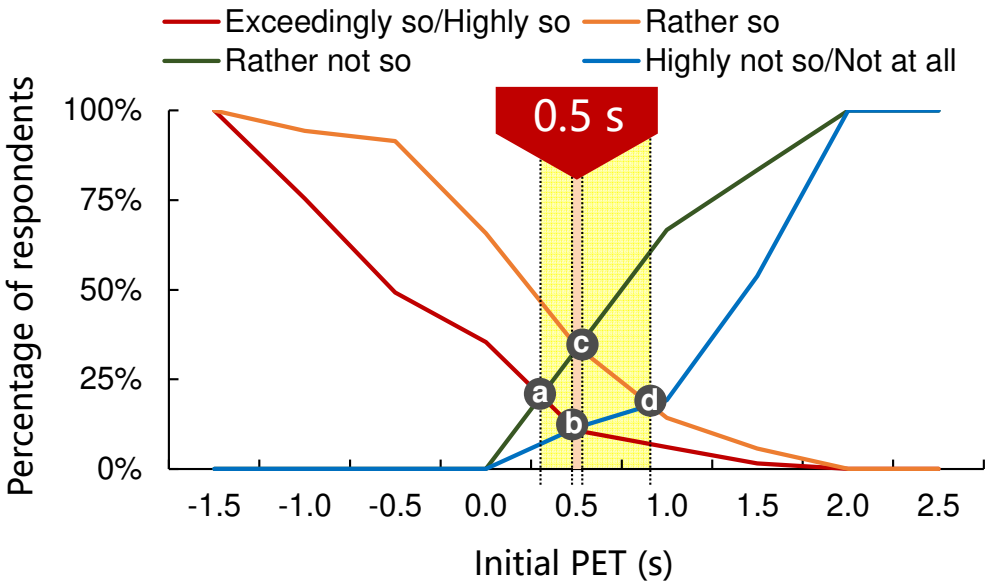
# 4) Price Sensitivity Meter (PSM) analysis



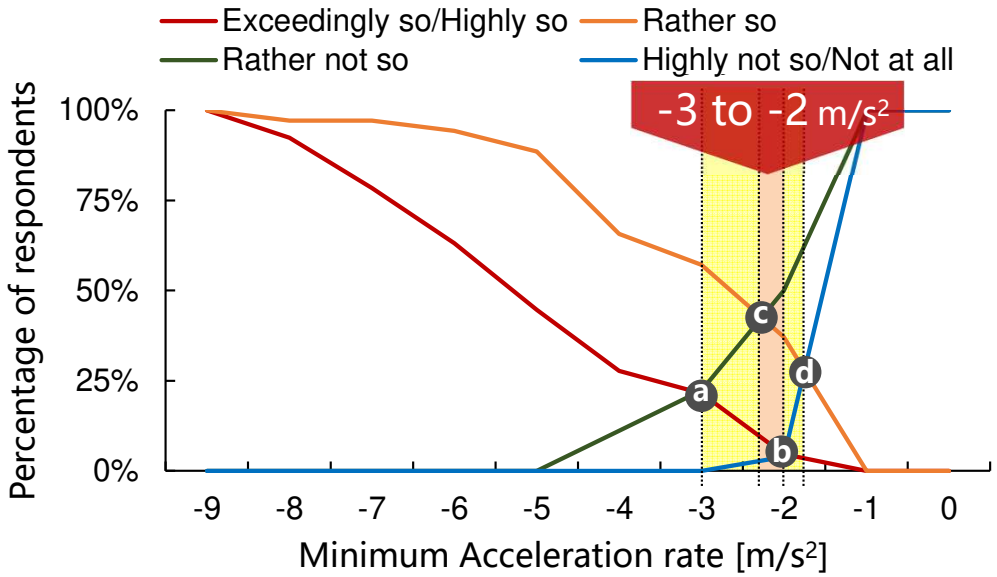

Chhabra(2015)

# 4) Price Sensitivity Meter (PSM) Analysis

- **Sensitivity analyses of subjective rating as a function of initial PET**




- **Sensitivity analyses of subjective rating as a function of minimum acceleration rate**




**Applying behavioral economics methodology : effective way to address the complex issue due to diversity-related individual differences**

# 4. Conclusion

# Conclusion

## ◆To specify safety requirements for ADS right-turn functions

- ✓ Integrating behavioral data with subjective feeling data
  - Initial PET : **at least 0.5 s** assuming right-turn completion
  - Minimum acceleration rate : **-3 to -2 m/s²**
- ✓ Proposal : to quantify qualitative statement of obstructing progress

## ◆To derive a framework for safety evaluations in urban domains

- ✓ Derivation : **quantitative requirement for initiator role** of ADS
- ✓ PSM analysis : one idea to find more plausible human acceptance bounds
- ✓ Approach : to bridge subjective human sensitivity & regulatory expectation

**Future work**

**- Refinement of driver behavior modeling methodologies**

**- Applying preventability definition for vulnerable road users**

# *Thank you for your kind attention*

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**Acknowledgement**
**The Ministry of Economy, Trade, and Industry of Japan funded this research through the SAKURA project.**


**Jtown Specific Environmental Chamber**


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