Cross-ministerial Strategic Innovation Promotion Program

「Cross-ministerial Strategic Innovation Promotion Program (SIP)/ Automated Driving for Universal Services/ HMI and User Education」

FY 2019 Report

Keio University
AIST
University of Tsukuba
Tokyoto Business Services

March, 2020

Task A

Communication method between AV and traffic participants
Education, knowledge on such communication

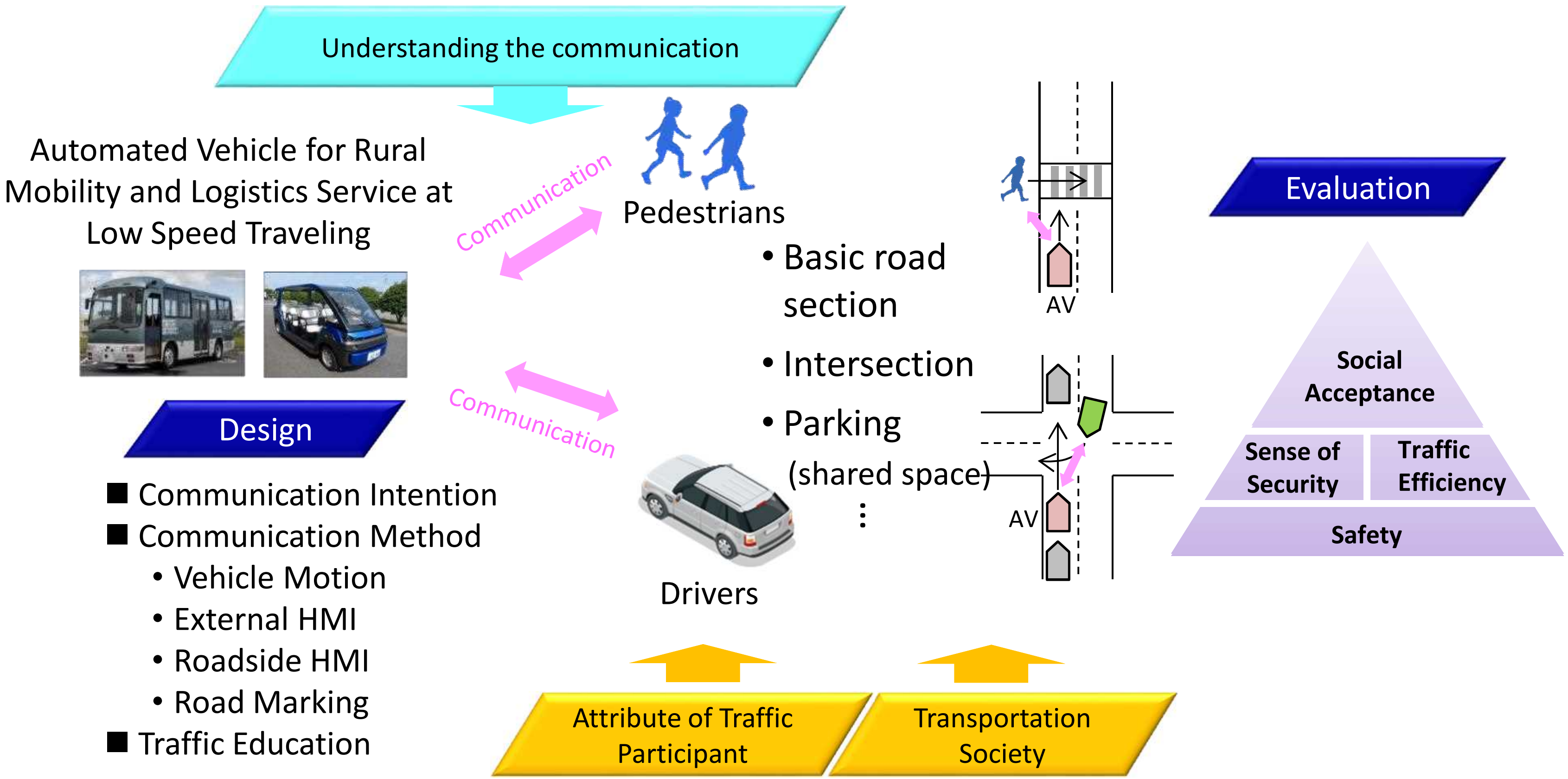
Keio University

Overview

Task A

Communication method between AV and traffic participants
Education, knowledge on such communication

Safe, secure and efficient communication between AVs and traffic participants



Research Flow of Task A

1. Understanding current communication between AV and traffic participants

Rural mobility and logistic services at low speed traveling, effects of driverless car, road traffic conditions, etc.

2. Research on negative effect of communication between AV and traffic participants

Communication with one participant, multiple participants, effect of vehicle motion, eHMI, road traffic conditions,

3. Research and proposal of communication method, knowledge necessary for communication

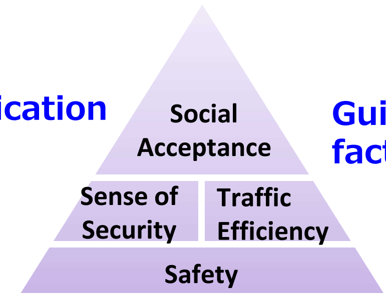
Vehicle motion, eHMI, roadside HMI, road marking, etc.
Knowledge necessary for AV, communication, limitation, etc.
(based on critical use-cases of communication)

- VR/DS, Test-Track
- Questionnaire (Web, etc.)

4. Verification of communication method and education for communication between AV and traffic participants

(In field operational tests or field observations)

Critical use-cases of communication
Guidance of design factors on communication



Guidance of educational factors on communication

<u>Safe, secure and efficient communication between AVs and traffic participants</u>

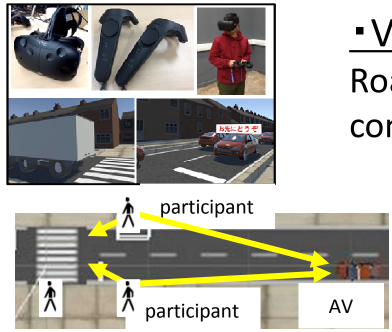
Current activity of Task A

1. Understanding current communication between AV and traffic participants

・Analysis of video data observed in FOTs

Extraction of features of interaction/communication between AV and surrounding traffic participants

2. Research on negative effect of communication between AV and traffic participants



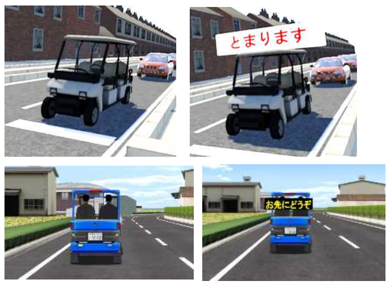
・VR/DS Experiments

Road environment, traffic condition, vehicle motion, eHMI, …

・Traffic participants

・Use-cases of communication

Preliminary experiment of communication between AV (rural mobility at low speed traveling) and traffic participants by using



・VR/DS experiment

pedestrian, following driver

・Communication method

vehicle motion, eHMI, …

Preparation of test-course experiment (Production of experimental vehicle)

Same vehicle as FOTs promoted by MLIT

・vehicle motion

・eHMI, road marking,

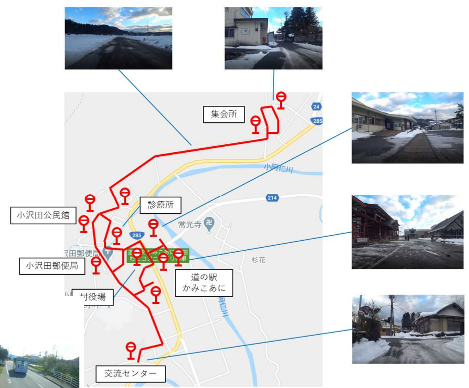
・knowledge, education

Understanding Current Communication between low-speed Automated vehicles and surrounding road users

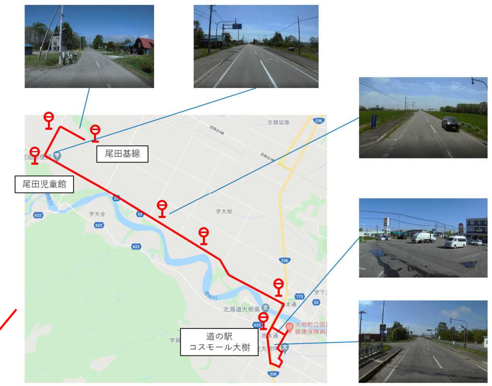
Analyzing Method

- Categorizing and defining interaction between automated vehicle and surrounding road users based on features as follows: approaching (AV approaches target participant within 1m) and avoiding, crossing (AV and target participant are crossing), overtaking (target participant or AV overtakes another)
- Observed interactions were categorized to several predetermined interaction-types based on road environment, AV's status (AV type, vehicle status, intention, direction and position of interaction, etc.), traffic participant-type, and their frequencies were extracted and calculated.
- Based on the observed data and results, discussing safety of communication and its traffic efficiency, communication design between AV and traffic participants

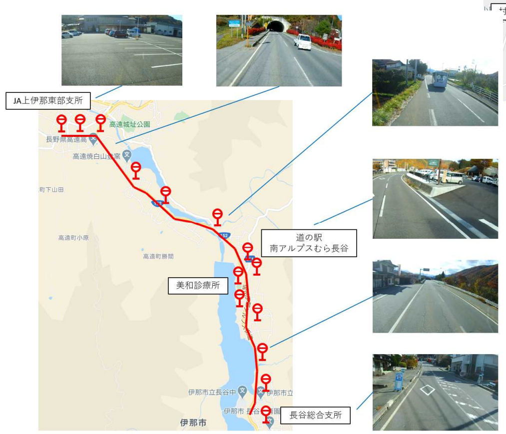
Target areas for Automated Vehicle (AV) FOT by MLIT, Type of AV



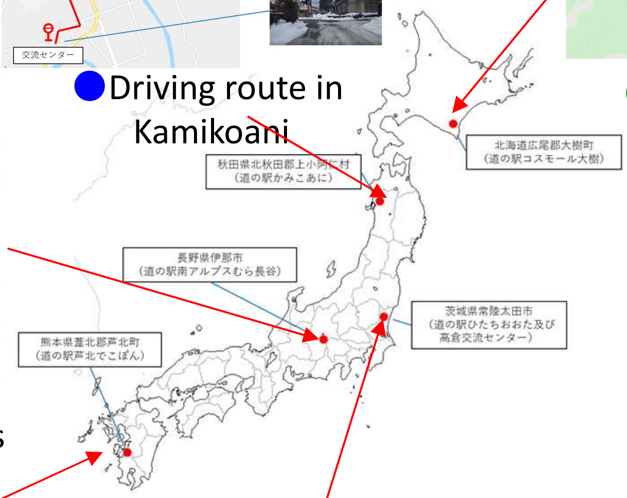
●Driving route in Kamikoani

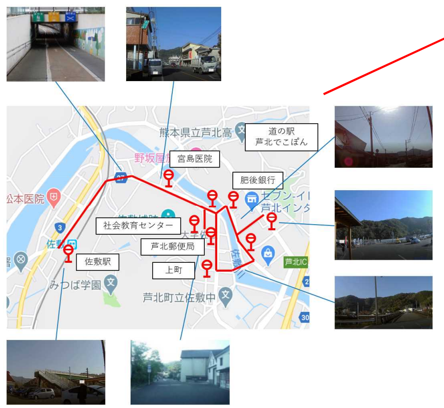


●Driving route in Taiki

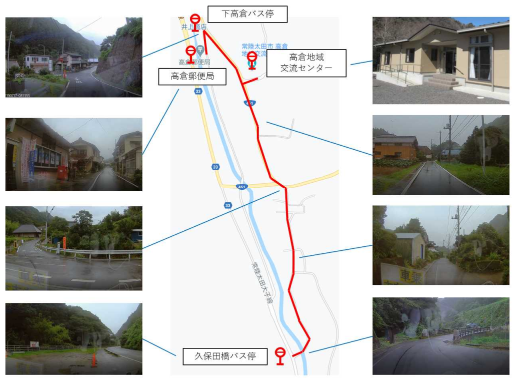


●Driving route in Minami-Alps





●Driving route in Ashikita



●Driving route in Hitachi-Ota

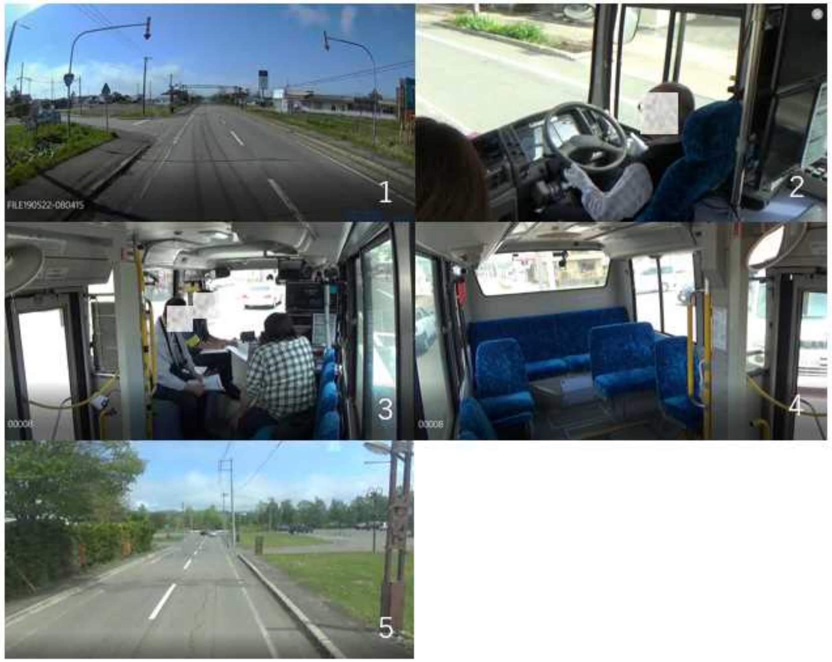
●Golf-Cart type AV

●Bus type AV

Dashcam data of each AV

●Bus type AV

●Golf Cart type AV

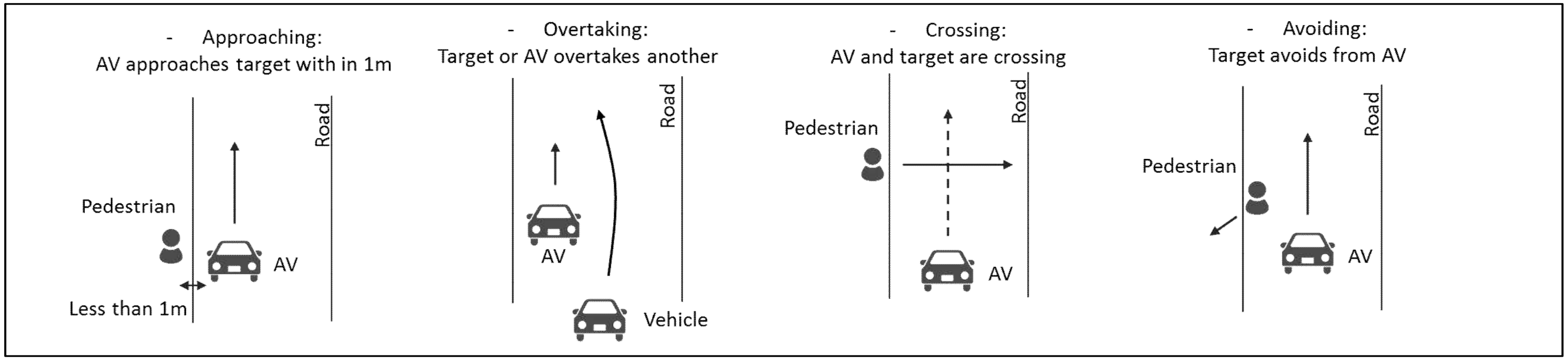


Examples for dashcam data measured in Taiki
1: Front-view 2: Driver
3: Passengers in front area 4: Passengers in rear area
5: Rear-view

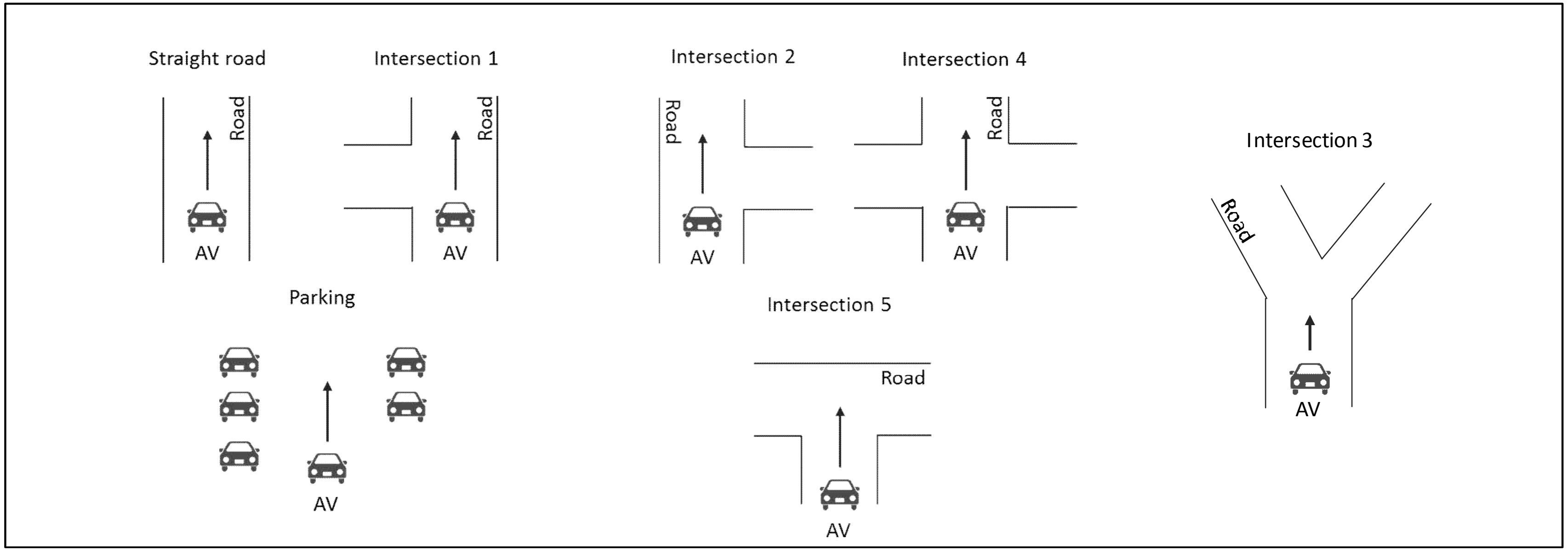
Examples for dashcam data measured in Kamikoani
1: Front-view 2: Driver
3: Passenger 4:Rear-view

Definition of interaction between AV and surrounding road users, devinition of road environment

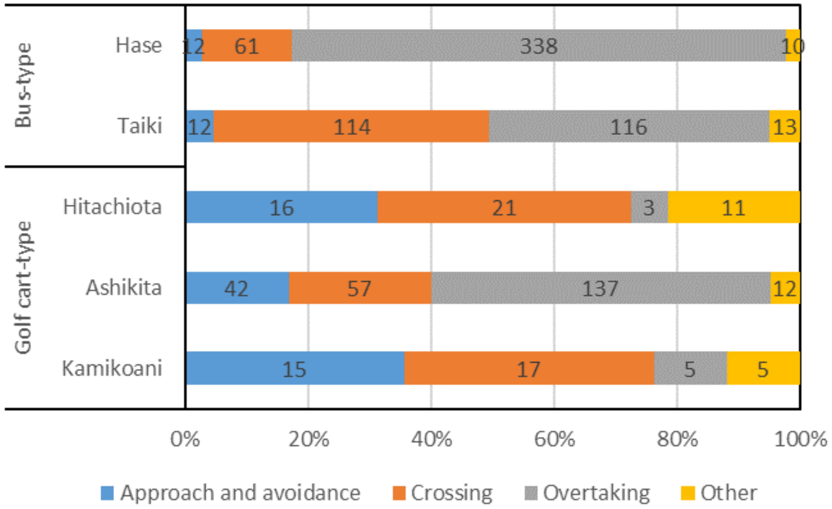
Definition of interaction



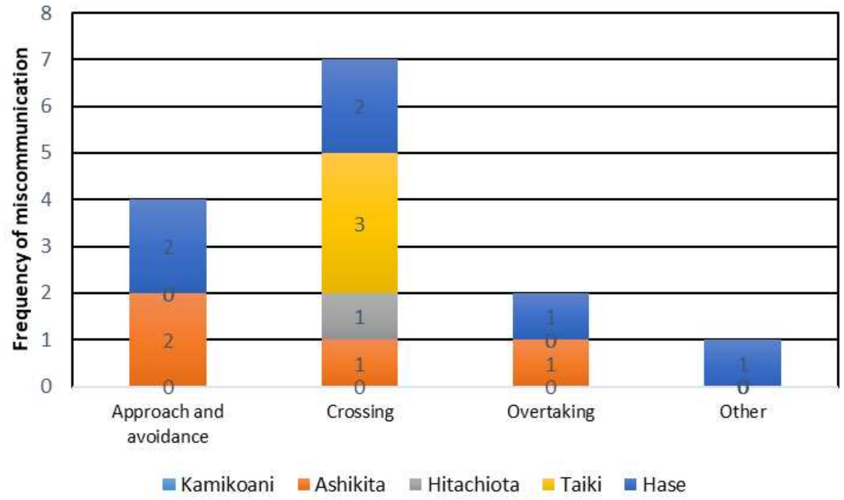
Definition of road environment



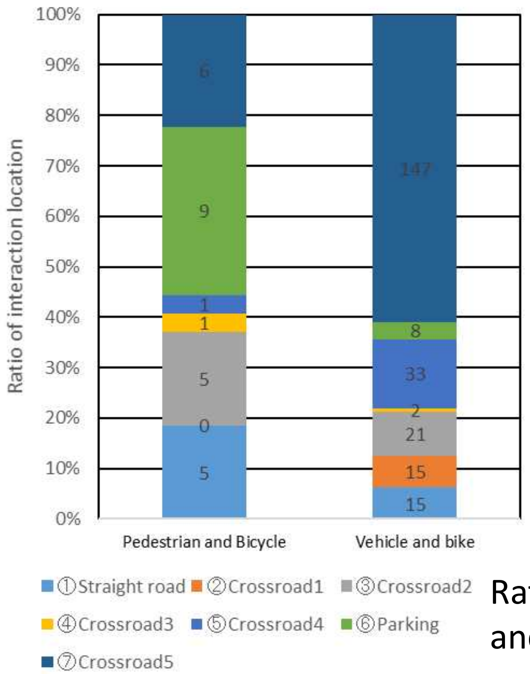
Frequency of each interaction type



Frequency of interaction based on target areas



Frequency of miscommunication in each target area



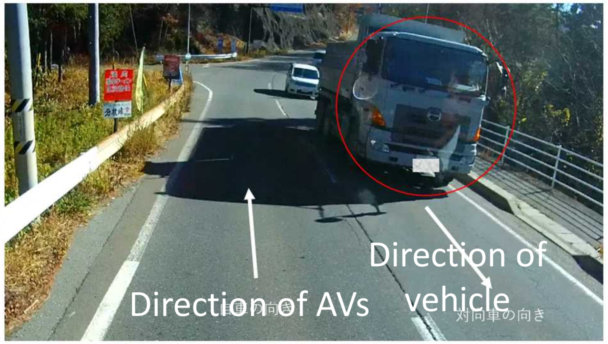
Ratio of location of approaching and avoidance

- Frequent over-takings occurred in target areas that included driving routes on main roads, and there are also occurred many interactions with pedestrians such as approaching and crossing in target areas where driving routes were mainly residential roads.
- There were many interactions between AV and pedestrians/vehicles on single roads, and there were also frequent interactions at parking lots or intersections (T-type roads, etc.).
- Miscommunication occurred in the case of interaction such as approaching or avoiding, crossing.

Examples for miscommunication observed in target areas

Miscommunication with group of pedestrians (in Ashikita)

- A group of pedestrians stopped because they did not understand the behavior of the AV.



Miscommunication with oncoming vehicle (in Minami-Alps)

- When conceding an oncoming vehicle on a narrow road, it was difficult to judge which vehicle should go first, and therefore the passing was not smooth.

Miscommunication with overtaking vehicle

- When the AV started from stopping state, there was a possibility that the following vehicle which was overtaking collided with the AV.

Miscommunication with a pedestrian (Minami-Alps)

- When the AV tried to make a right turn from the parking lot to the road, a pedestrian coming from the right side of the car stopped because she could not understand the behavior of the AV.

Miscommunication with an vehicle driving in parking area (in Taiki)

- When the AV conceded with another car while they were traveling in the parking lot, the driver could not judge which vehicle should go first because he/she did not understand the AV's intention

Understanding Current Communication between low-speed Automated vehicles and surrounding road users

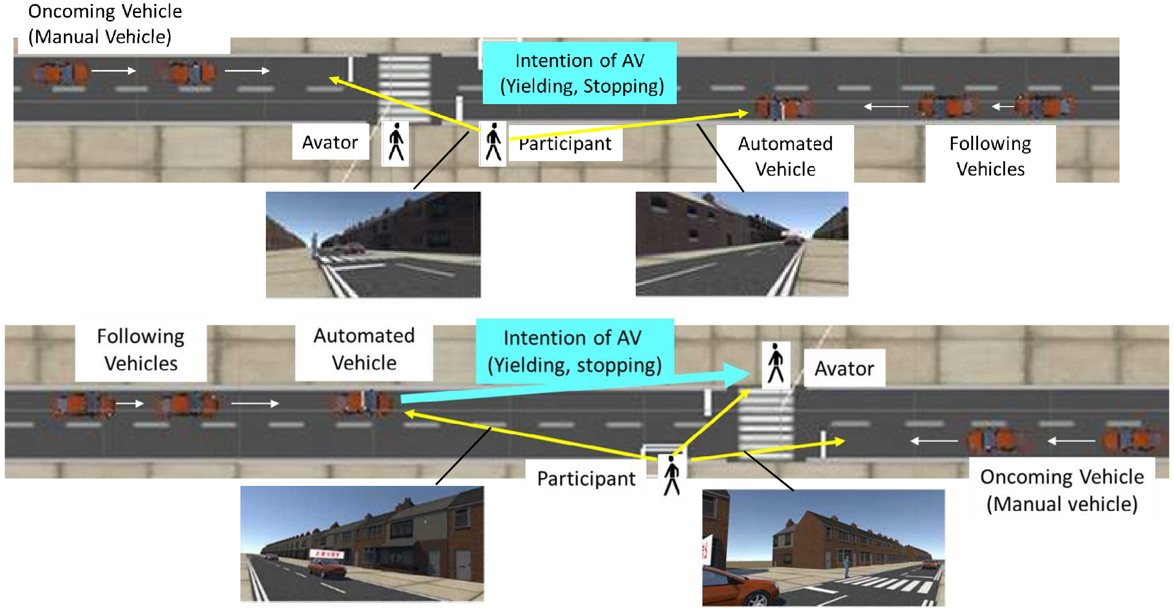
Results and discussion

- The type and frequency of interaction between AV and traffic participants are influenced by the road environment and traffic conditions in the target areas. In the target areas including main roads, there are many over-taking interactions with manual vehicles, and In the target areas including residential roads, there are many interactions between AV and pedestrian/manual vehicle such as approaching, avoiding and crossing.
- Overtaking interactions occur mainly in the road environment of single-road and T-type intersection when AV is stopping or going on straight section. In certain roads environment of T-type intersection, there also occurs overtaking interactions although AV turns on the left turn signal for turning left at the intersection. Traffic participants may misunderstand left turn signal of AV as a communication cue between AV and following vehicle.
- It is implied that miscommunication between AV and traffic participant is caused by the fact that the traffic participant does not understand the behavior and intention of the AV. In particular, since AV travels at low speeds, it may be difficult for traffic participants to recognize the behavior and intention of the AV based on its vehicle motion.
- It may be possible to realize safe and efficient communication between AV and traffic participants by providing the AV's intention such as yielding or staring to traffic participant appropriately in the case of interaction such as approaching, avoiding, and crossing and also by providing the situation of the road environment or traffic condition around the AV to them in the case of overtaking interaction.

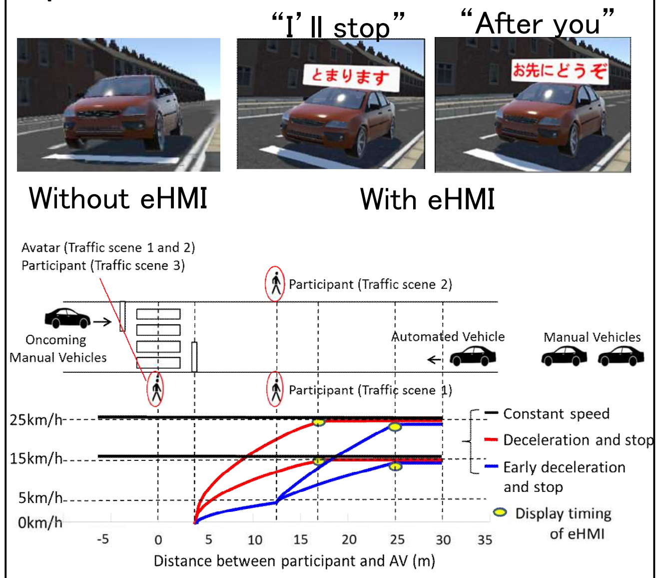
Analysis of communication with single traffic participants and multiple traffic participants, and analysis of factors affecting success / failure of communication

- Pedestrian's recognition and judgement to communication cue by using vehicle motion and eHMI

Single AV → Two pedestrians (Participant: Jaywalker)



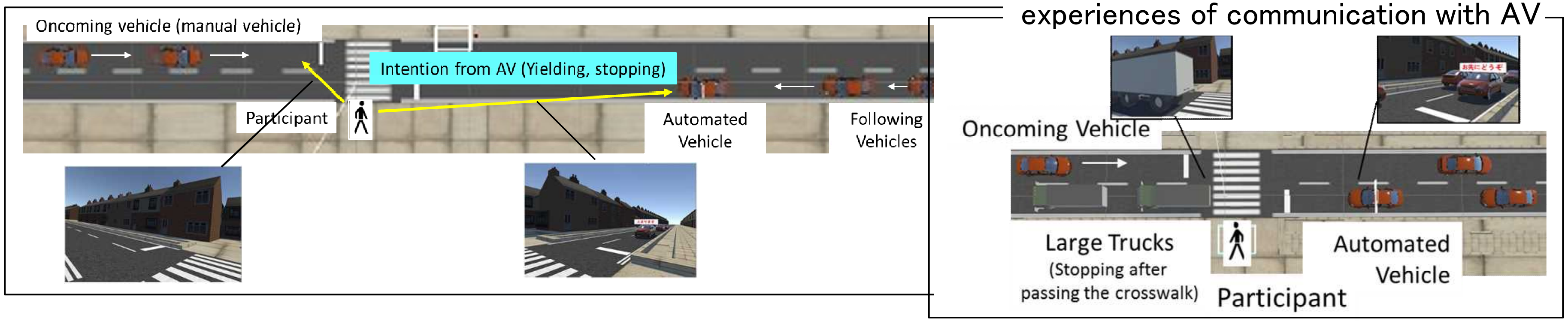
Specification of AV



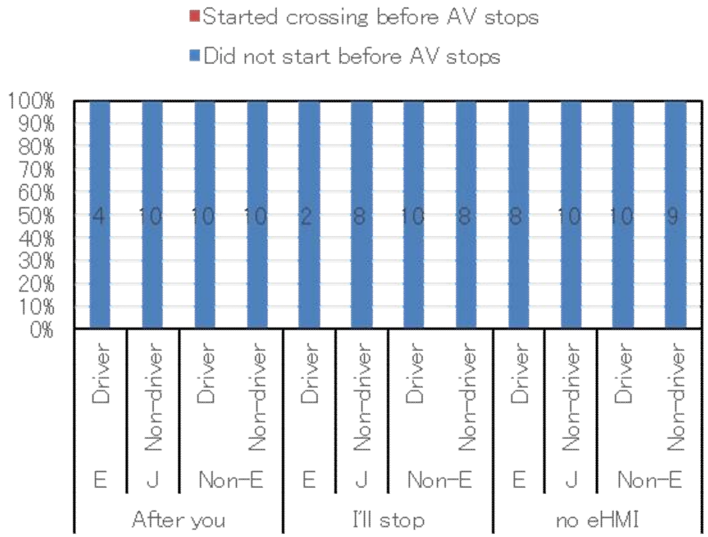
Vehicle motion

Single AV → One pedestrian

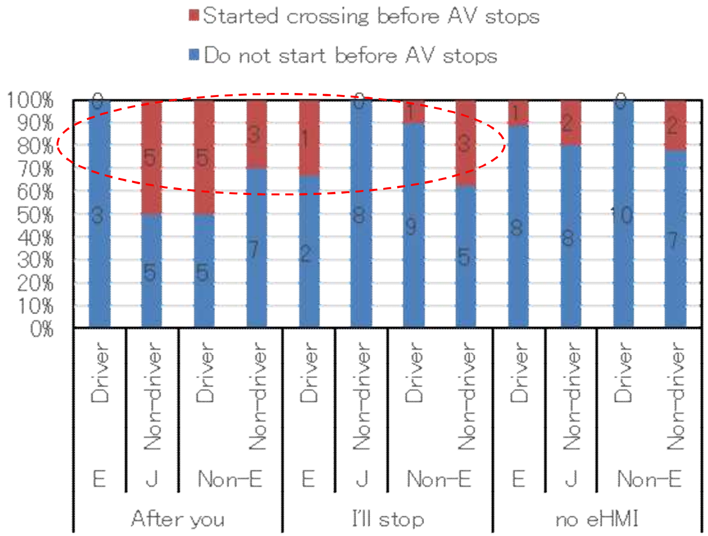
(Pedestrian's over-trust to AV by repeated experiences of communication with AV)



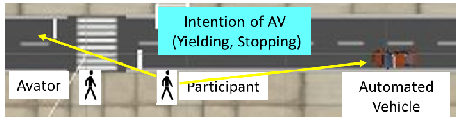
Jaywalker's crossing behavior based on communication between AV and pedestrian at crosswalk by using vehicle motion and eHMI



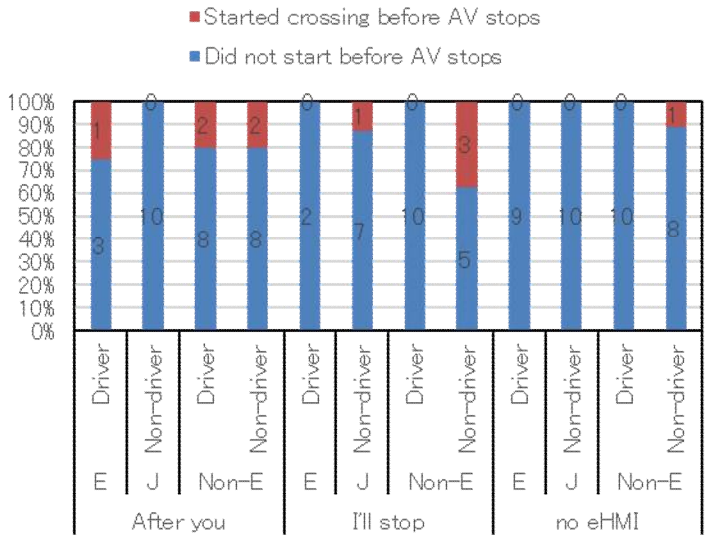
Deceleration-Stop (25→0km/h)



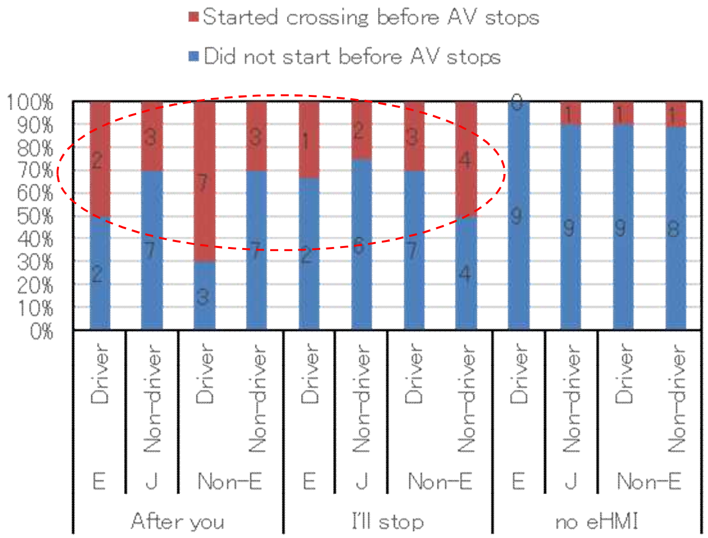
Early deceleration-Stop (25→5→0km/h)



- In the case of "Deceleration-Stop", jaywalkers rarely started crossing before the AV passed in front of them regardless of the initial speed.
- In the case of "Early deceleration-Stop", jaywalkers started crossing before the AV passed in front of them when the initial speed was low with the eHMI installed.



Deceleration-Stop (15→0km/h)

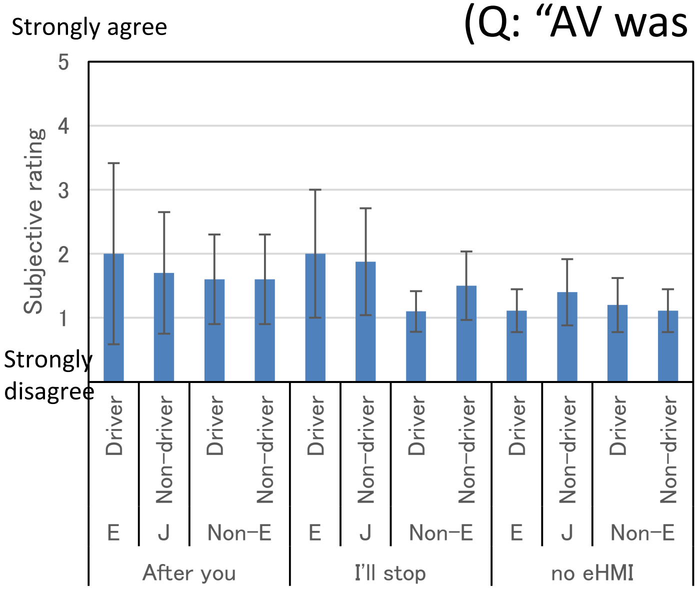


Early deceleration-Stop (15→5→0km/h)

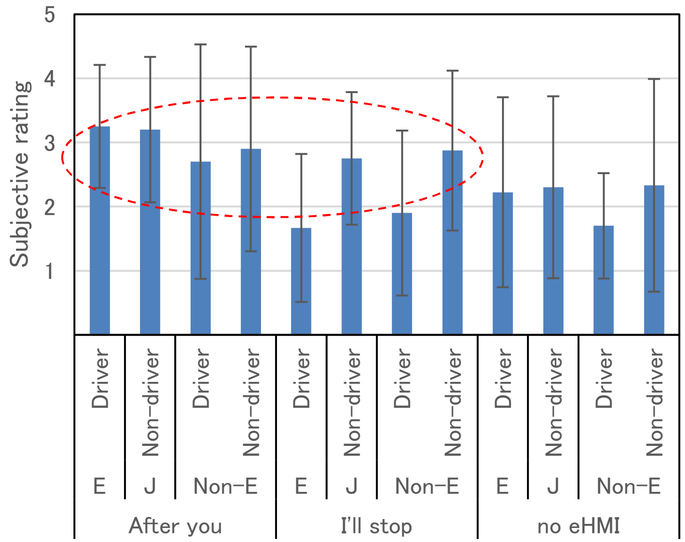
- In the case of communicating with a pedestrian on crosswalk by using vehicle motion such as "Early deceleration-Stop", if there is a jaywalker between the pedestrian and the AV, it is necessary to take measures such as not using the eHMI

Jaywalker's recognition based on communication between AV and pedestrian at crosswalk by using vehicle motion and eHMI

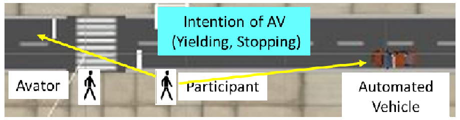
(Q: "AV was yielding to you.")



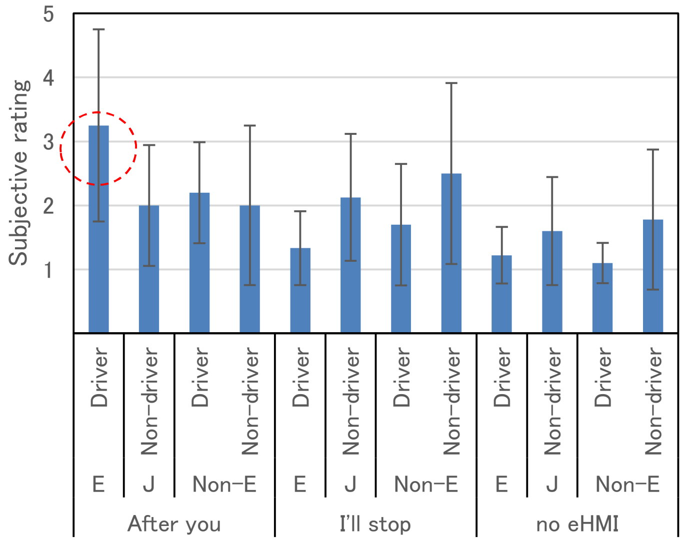
Deceleration-Stop (25→0km/h)



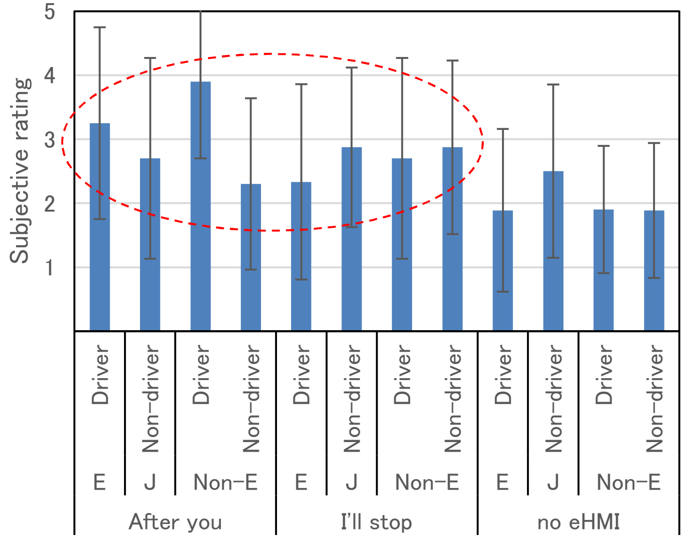
Early deceleration-stop (25→5→0km/h)



- In the case of "Deceleration-Stop", jaywalkers intended to recognize that the AV was yielding to them when using the low initial speed and eHMI, especially "After you".
- In the case of "Early deceleration-Stop", jaywalkers intended to recognize that the AV was yielding to them when using eHMI, independent of the initial speed.



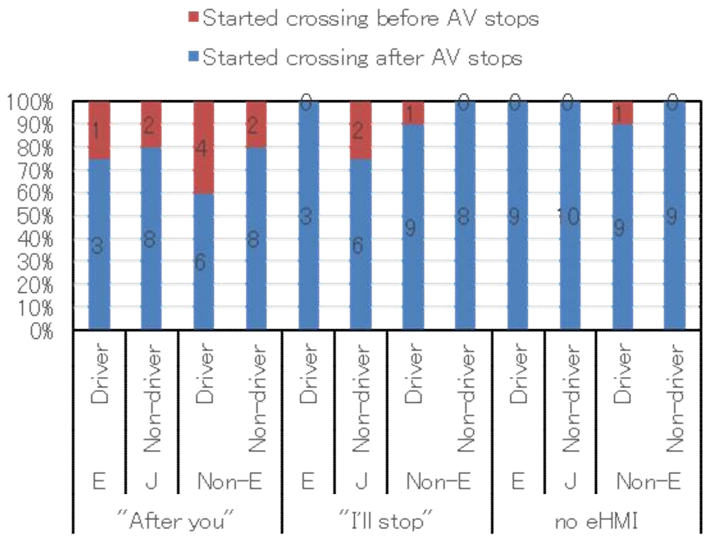
Deceleration-Stop (15→0km/h)



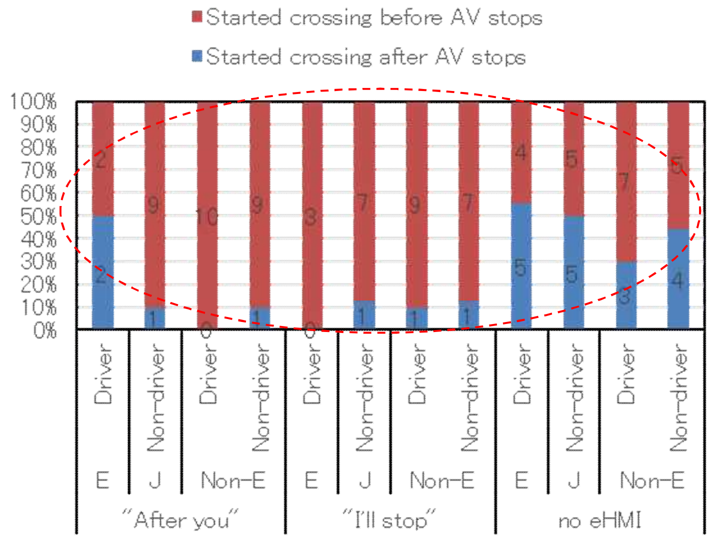
Early deceleration-stop (15→5→0km/h)

- In the case of communicating with a pedestrian on crosswalk by using vehicle motion such as "Early deceleration-Stop", if there is a jaywalker between the pedestrian and the AV, it is necessary to take measures such as not using eHMI and the vehicle motion of "Early deceleration-stop".

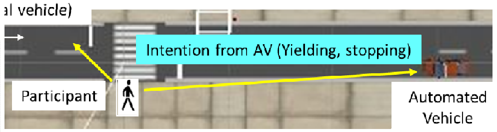
Pedestrian's crossing behavior based on communication between AV and pedestrian at crosswalk by using vehicle motion and eHMI



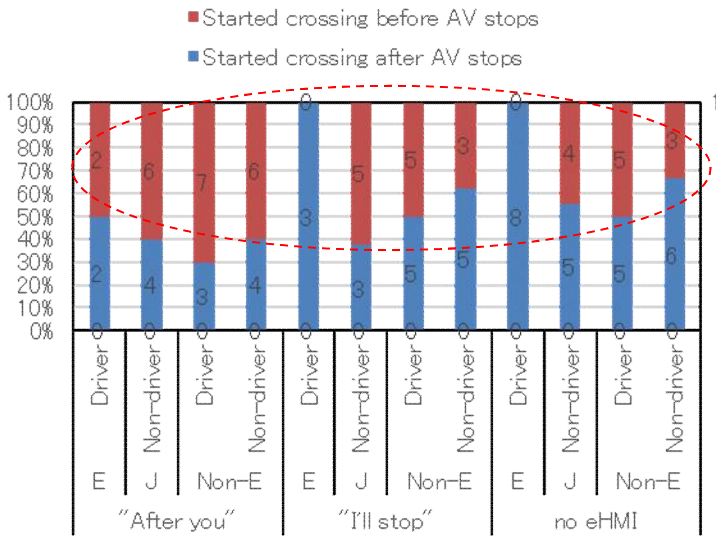
Deceleration-Stop (25→0km/h)



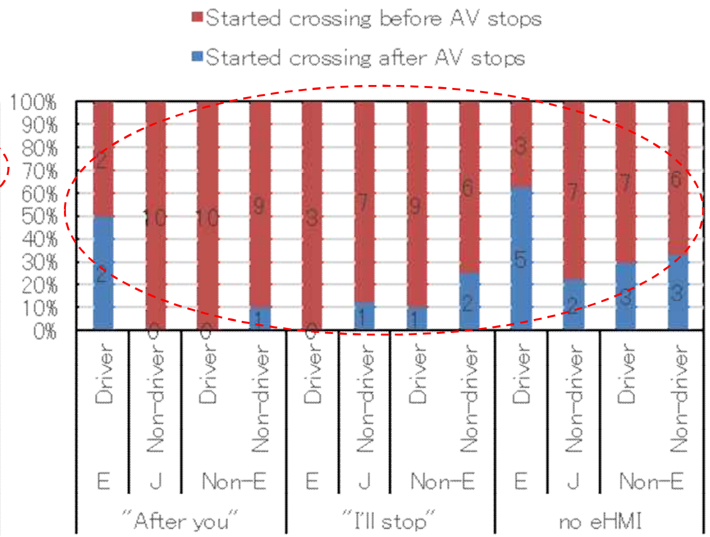
Early deceleration-Stop (25→5→0km/h)



- In the case of "Deceleration-Stop" with the low initial speed, half of the pedestrians on the crosswalk started crossing before the AV stopped at the stop line.
- In the case of Early deceleration-Stop", most of the pedestrians on the crosswalk started crossing before the AV stopped at the stop line, regardless of the initial speed.



Deceleration-Stop (15→0km/h)



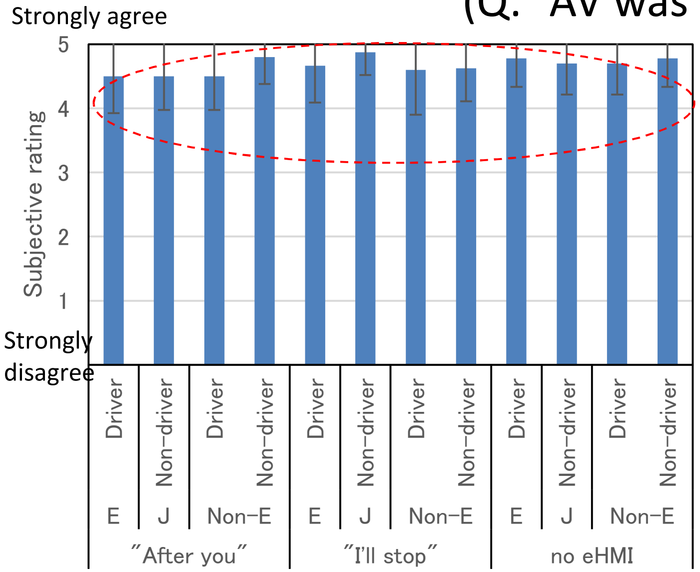
Early deceleration-Stop (15→5→0km/h)

- When communicating with a pedestrian on crosswalk by using "Early deceleration-Stop", it may be possible for the pedestrian to start crossing before an AV stops at stop line without using an eHMI.

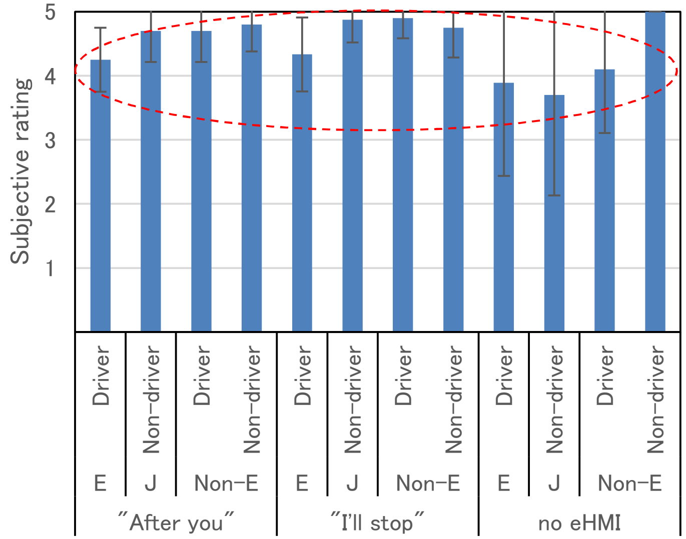
Usefulness of communication only by using vehicle motion

Pedestrian's recognition based on communication between AV and pedestrian at crosswalk by using vehicle motion and eHMI

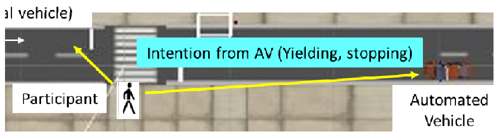
(Q: "AV was yielding to you.")



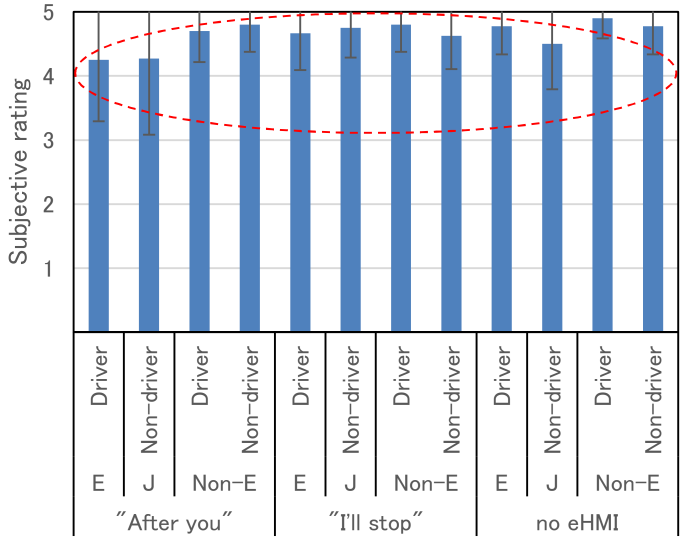
Deceleration-Stop (25→0km/h)



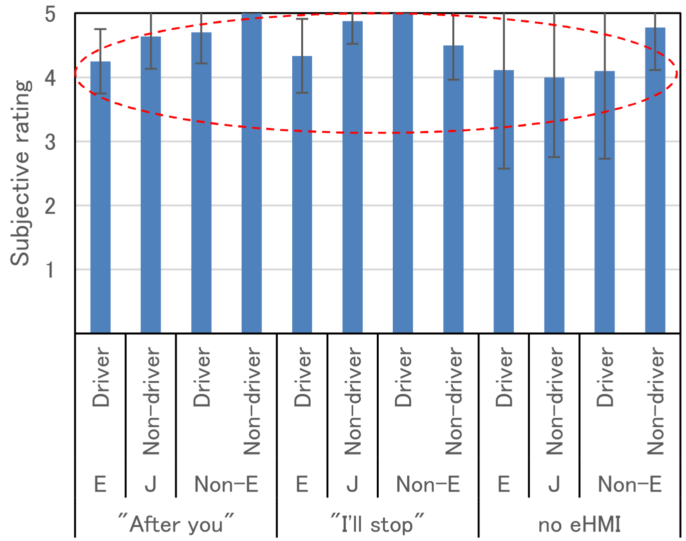
Early deceleration-Stop (25→5→0km/h)



- In both cases of "Deceleration-Stop" and "Early deceleration-Stop", pedestrians at the crosswalk tended to recognize that the AV was yielding to them regardless of whether the eHMI was installed or not.



Deceleration-Stop (15→0km/h)



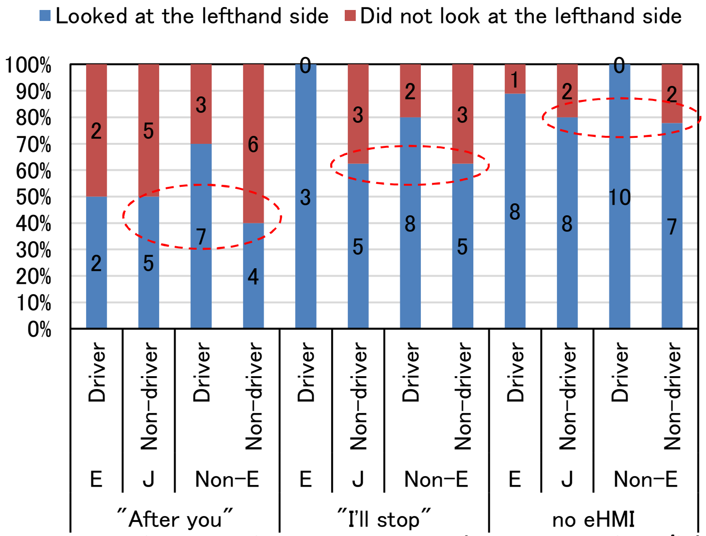
Early deceleration-Stop (15→5→0km/h)

- Pedestrians on crosswalk can recognize that an AV's is yielding to them only by using vehicle motion such as "Deceleration-Stop" or "Early deceleration-Stop".

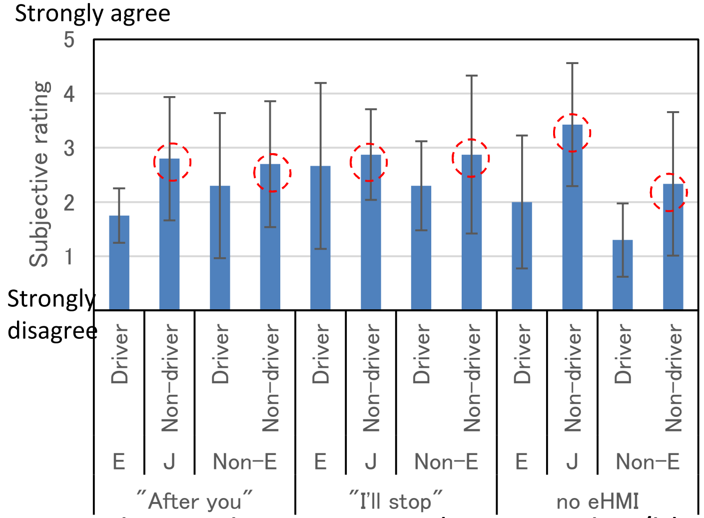
Usefulness of communication only by using vehicle motion

Pedestrian’s surrounding confirmation and over-trust influenced by repeatedly experiencing the communication between AV and pedestrian at crosswalk

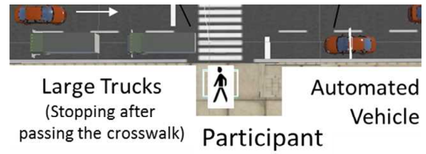
（Q:”AV was yielding to you after confirming the situation of the oncoming vehicle.”）



Early Deceleration-Stop (15→5→0km/h)



Early Deceleration-Stop (15→5→0km/h)



- When using the eHMI, especially “After you”, pedestrians crossing on the crosswalk tended not to check oncoming traffic situation, where it was difficult for the pedestrians to see directly because a large truck stopped at the side of the crosswalk.
- Non-driver's license holders also tended to misunderstand that the AV yields to them after checking the surrounding traffic situations.

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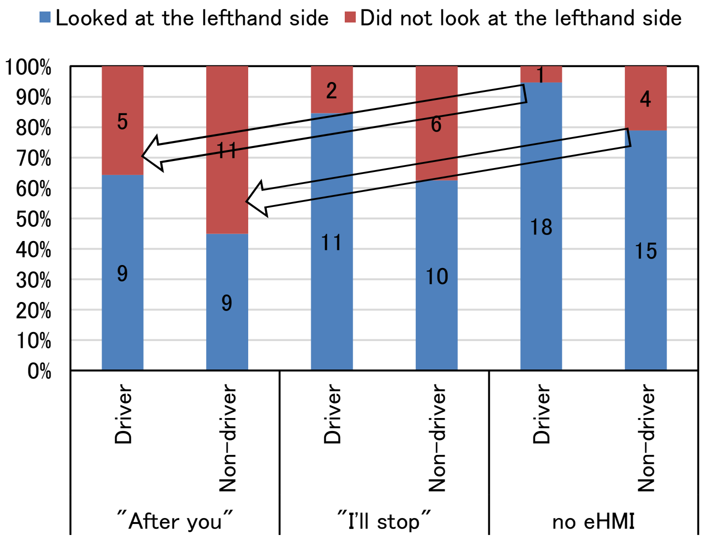
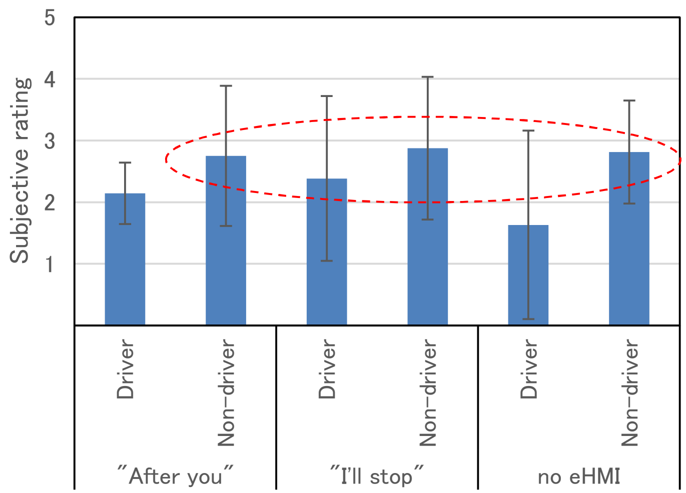
To prevent a pedestrian from misunderstanding such communication

- Design communication without eHMI
- provide knowledge and education to non-driver’s license holders.



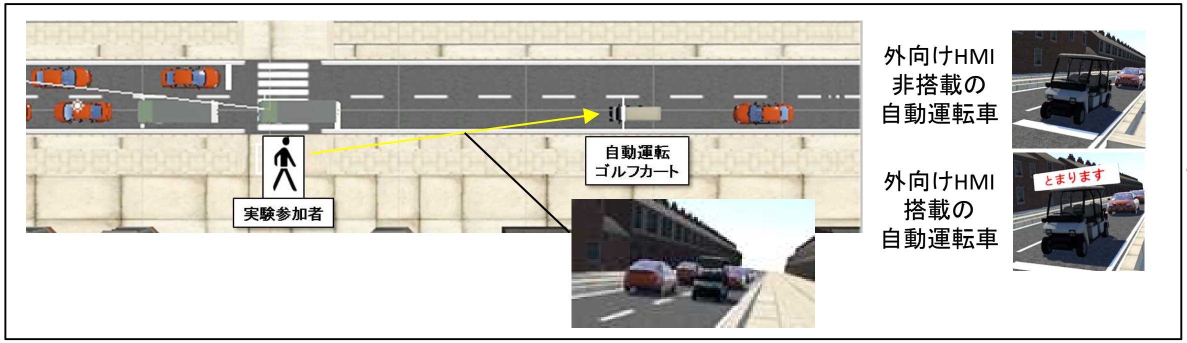
Early Deceleration-Stop (15→5→0km/h)

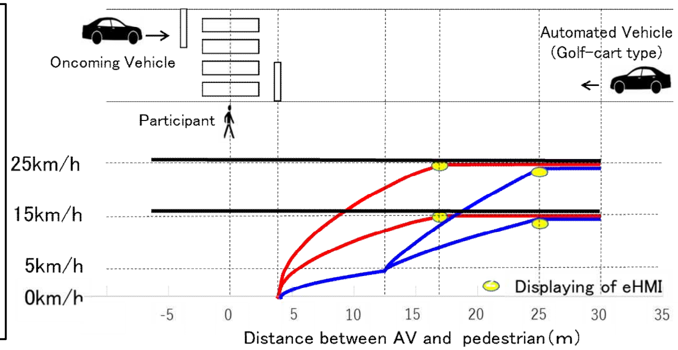


Early Deceleration-Stop (15→5→0km/h)

Preliminary study on communication between a low-speed AV for mobility and logistics service and a pedestrian at crosswalk

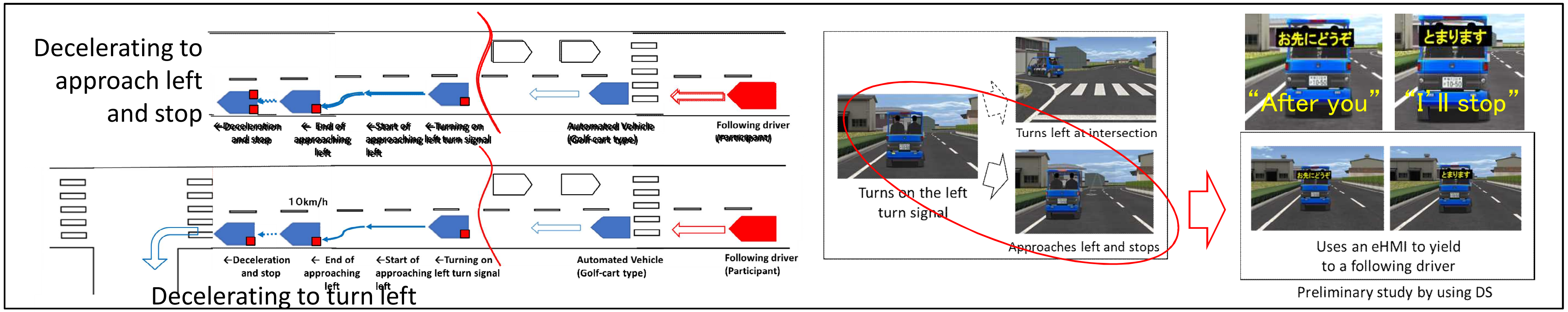
- Analysis of pedestrian's recognition / judgment to the communication cue from a low-speed AV (golf-cart type) to the pedestrian vehicle by using vehicle motion and eHMI.





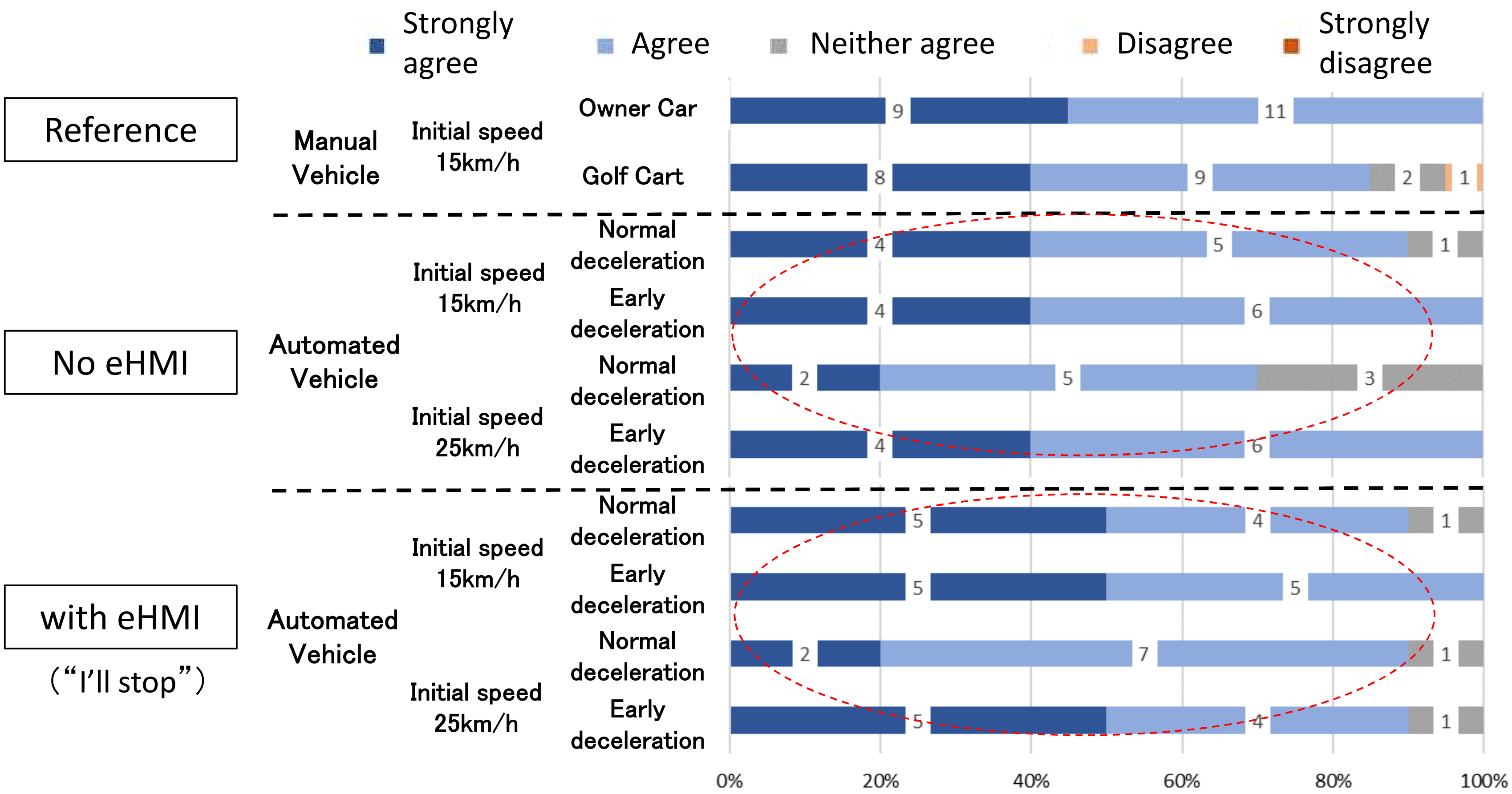
Preliminary study on communication between a low-speed AV for mobility and logistics service and a following driver

- Analysis of following driver's recognition / judgment to the communication cue from a low-speed AV (golf-cart type) to the pedestrian vehicle by using vehicle motion and eHMI.



Pedestrian's recognition based on communication between AV (Golf cart) and pedestrian at crosswalk by using vehicle motion and eHMI

(Q: "AV was yielding to you.")



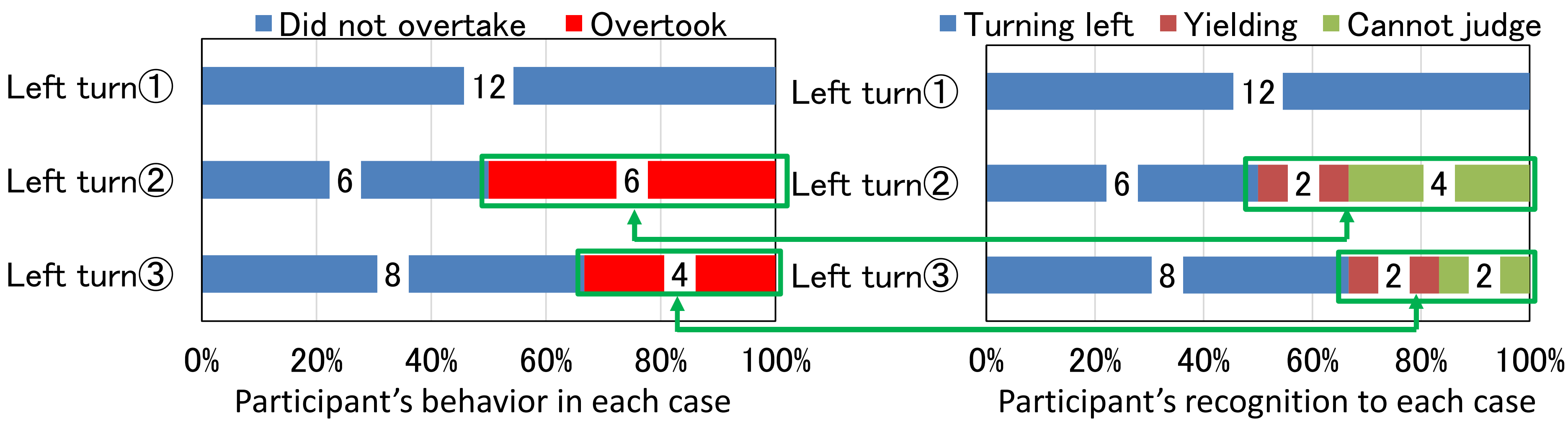
- Many pedestrians recognized that the AV was yielding to them regardless of the difference between the two types of vehicle motion and the difference between eHMI and no eHMI.
- It is implied that pedestrians can recognize an AV's intention by using vehicle motion with early deceleration and by lowering initial speed, even if an eHMI is not installed to the AV.

Following driver's behavior and recognition based on communication between AV (Golf cart) and following vehicle by using vehicle motion and eHMI

Left-turn ①: Trial of turning left before experiencing the experimental condition with the AV's intention to yield to the participant (following driver) by using left turn signal

Left-turn ②: Trial of turning left after experiencing the experimental condition with the AV's intention to yield to the participant (following driver) by using left turn signal

Left-turn ③: Trial of turning left after experiencing the experimental condition with the AV's intention to yield to the participant (following driver) by using eHMI



- **Overtakings were observed in the case of "Left turn②" and "Left turn③".**
  →Participants frequently experienced that the AV was yielding to them by using left turn signal and decelerating behavior. Such experience may induce them to confuse or misunderstand the AV's turning left and the AV's yielding to them.
- **"Left turn②" had more confusions or misunderstandings than "Left turn③".**
  →It is implied that may reduce to confuse or misunderstand two types of AV's intention such as "turning left" and "yielding to a following driver" by using eHMI.

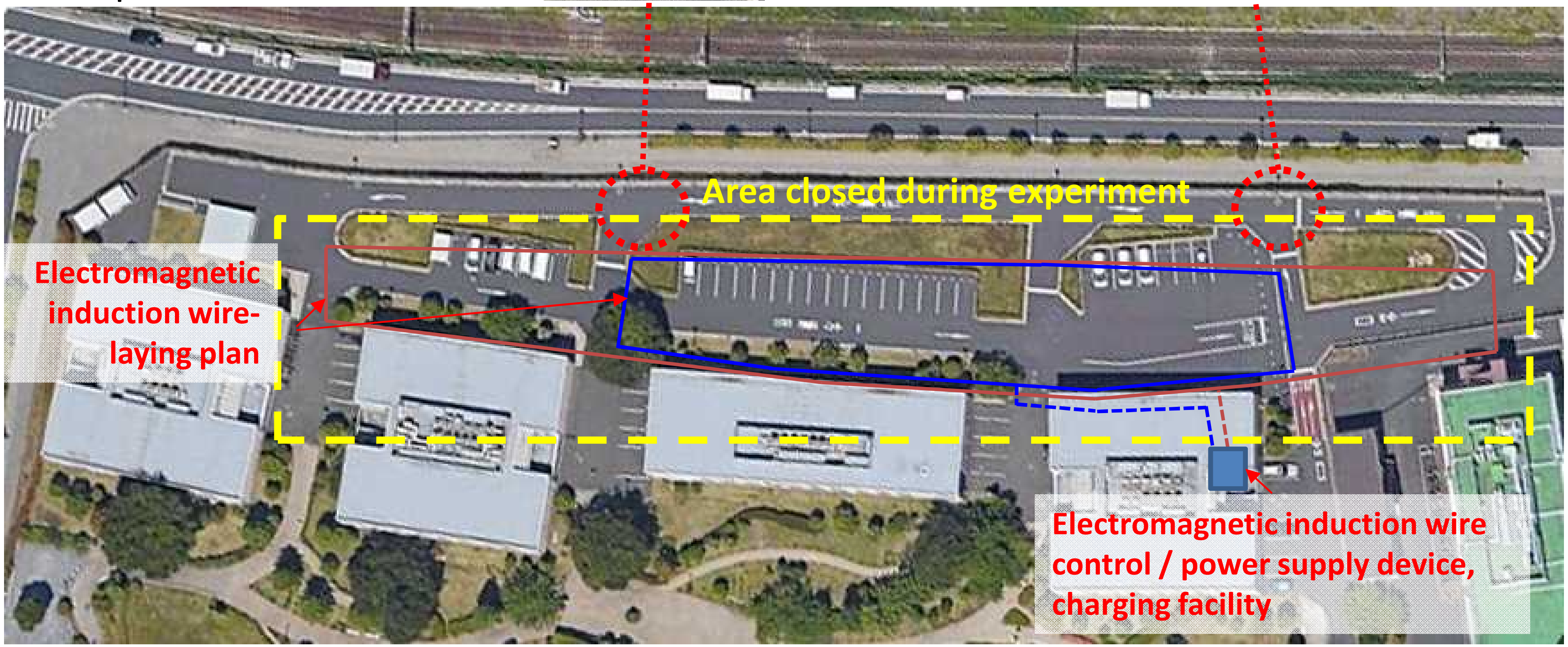
Production of experimental AV (Golf-cart type) and design of test track environment

Experimental AV

- Specification of the experimental AV (Golf-cart type)
  Video recording devices, driverless driving function, eHMI
- Various types of road environment to analyze communication between the AV and traffic participants

Intersection section

Straight road section



Keio University Shin-Kawasaki K[2] Town Campus Test Track Plan

Summary of Task A (1)

Analysis of communication between AV and traffic participant observed in FOT of automated driving “Michi no Eki”

- The type and frequency of interaction between AV and traffic participants are influenced by the road environment and traffic conditions in the target areas. In the target areas including main roads, there are many over-taking interactions with manual vehicles, and In the target areas including residential roads, there are many interactions between AV and pedestrian/manual vehicle such as approaching, avoiding and crossing.

- Overtaking interactions occur mainly in the road environment of single-road and T-type intersection when AV is stopping or going on straight section. In certain roads environment of T-type intersection, there also occurs overtaking interactions although AV turns on the left turn signal for turning left at the intersection. Traffic participants may misunderstand left turn signal of AV as a communication cue between AV and following vehicle.

- It is implied that miscommunication between AV and traffic participant is caused by the fact that the traffic participant does not understand the behavior and intention of the AV. In particular, since AV travels at low speeds, it may be difficult for traffic participants to recognize the behavior and intention of the AV based on its vehicle motion.

- It may be possible to realize safe and efficient communication between AV and traffic participants by providing the AV’s intention such as yielding or staring to traffic participant appropriately in the case of interaction such as approaching, avoiding, and crossing and also by providing the situation of the road environment or traffic condition around the AV to them in the case of overtaking interaction.

Summary of Task A(2)

Analysis of communication with single traffic participants and multiple traffic participants, analysis of factors affecting success / failure of communication and its negative effect

- When an AV tries to provide a communication cue to a pedestrian at a crosswalk by using vehicle motion of "early deceleration and stop“ and eHMI , if a jaywalker appears between the AV and the pedestrian, it is necessary to take measures such as not using eHMI or not using such vehicle motion and stop", in order to avoid jaywalker recognize the AV is yielding to the jaywalker.
- When an AV provides a communication cue to a pedestrian at a crosswalk, the pedestrian can recognize the AV’s intention of yielding to him/her only by using communication vehicle behavior such as "deceleration and stop" or "early deceleration and stop". The eHMI is not always necessary to communicate with the pedestrian. It is implied that the use of eHMI is limited or subsidiary for such communication even if eHMI is equipped with an AV.
- It is implied that repeated experience of communication from an AV equipped with an eHMI may reduce a pedestrian's checking behavior for the surrounding traffic situations when crossing and such a pedestrian also tends to misunderstand that the AV yields to him/her after checking the surrounding traffic situations. In order to prevent a pedestrian from misunderstanding such communication, it is necessary to design communication without eHMI and also to provide knowledge and education to non-driver’s license holders.

Summary of Task A(3)

Preliminary study on communication between a low-speed AV for mobility and logistics service and a pedestrian at crosswalk/a following driver

- When a low-speed AV for mobility and logistics services tries to yield to a pedestrian by using decelerating behavior, especially lowing the initial speed and using early decelerating behavior, many pedestrians can recognize that the AV's intention of yielding to them, even if an eHMI is not equipped with an AV.
- If a driver who is following to a low-speed AV for mobility and logistics service repeatedly experiences the AV's yielding behavior using the left turn signal and the decelerating behavior when the AV tries to yield to the driver, the driver may not be able to understand which the left turn signal indicates the AV's turning left or the AV's yielding behavior. When an eHMI is used for the communication between such AV and a following driver, it may be possible to avoid such confusion and misunderstanding by expressing the AV's intention to the following driver.

Production of experimental AV (Golf-cart type) and design of test track environment

- In order to conduct an experimental study on communication design between a low-speed AV and a traffic participant by using vehicle motion and eHMI, we have produced an experimental AV (golf-cart type). We also build a plan of test track environment by using campus roads and parking areas including a driving route (driverless possible) and its electromagnetic induction wire-laying plan / power supply facility.

Task B

Development of evaluation methods of driver’s OEDR (Object and Event Detection and Response) and HMI for enhancing driver’ take-over in a transition from automated to manual driving

National Institute of Advanced Industrial Science and Technology (AIST)

The University of Tokyo

Driver Readiness/ Availability

Readiness/availability is conceptually a dynamic state of the driver during automated driving that influences successive driver's takeover performance. (ISO/DTR 21959-1: 2018).

- Seating position
- Posture
- Engagement in NDRA (Non-Driving Related Activities)
  - Visually loaded
  - Cognitively loaded

  Phase 1

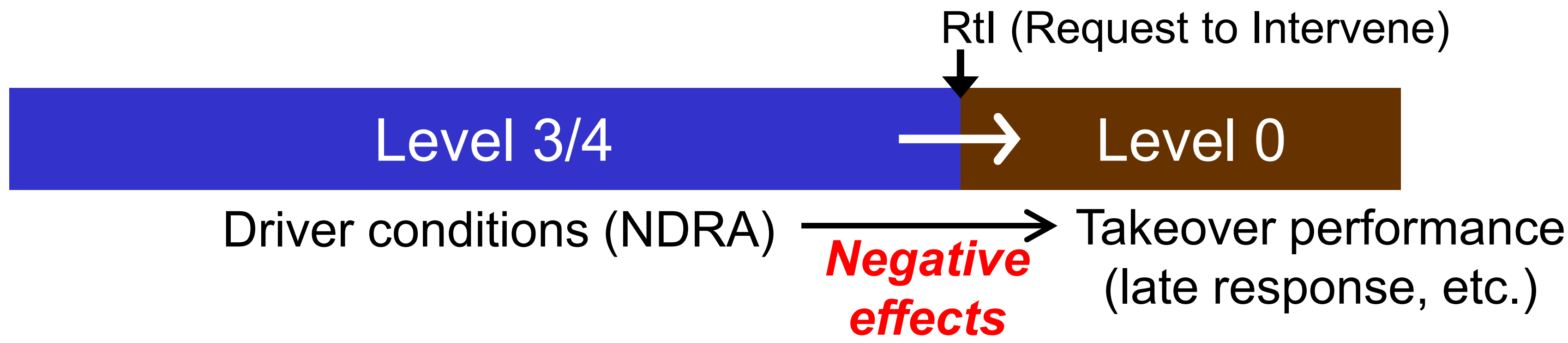
  - Emotional attachment
- Drowsiness

Phase 1

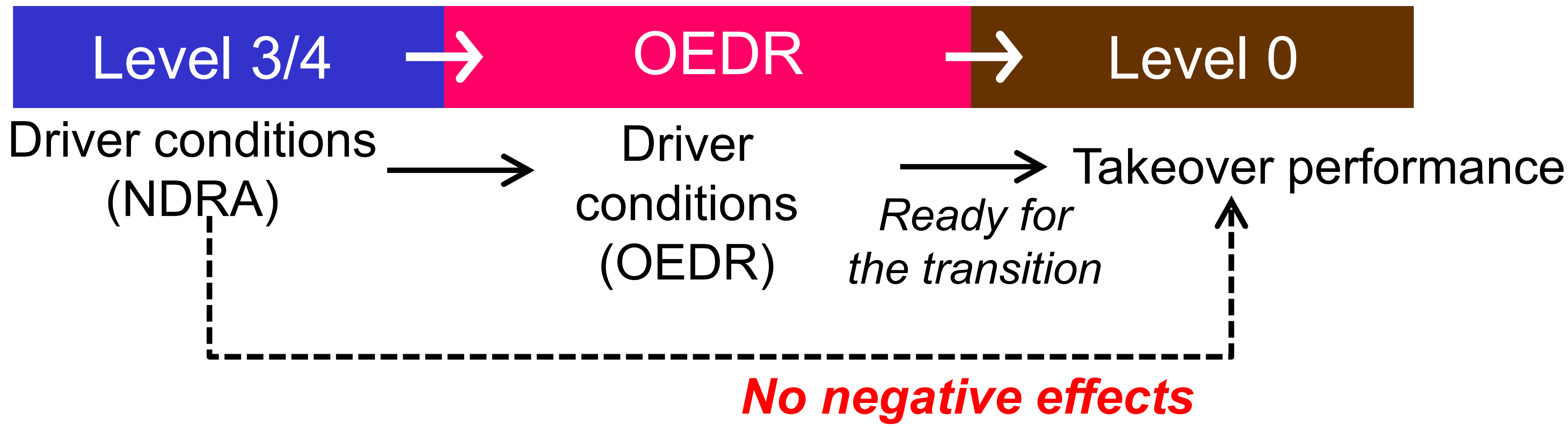
- Situation awareness
- Operating state / mode awareness

Phase 2

Appropriate transition from automated to manual driving
< Hypothesis>

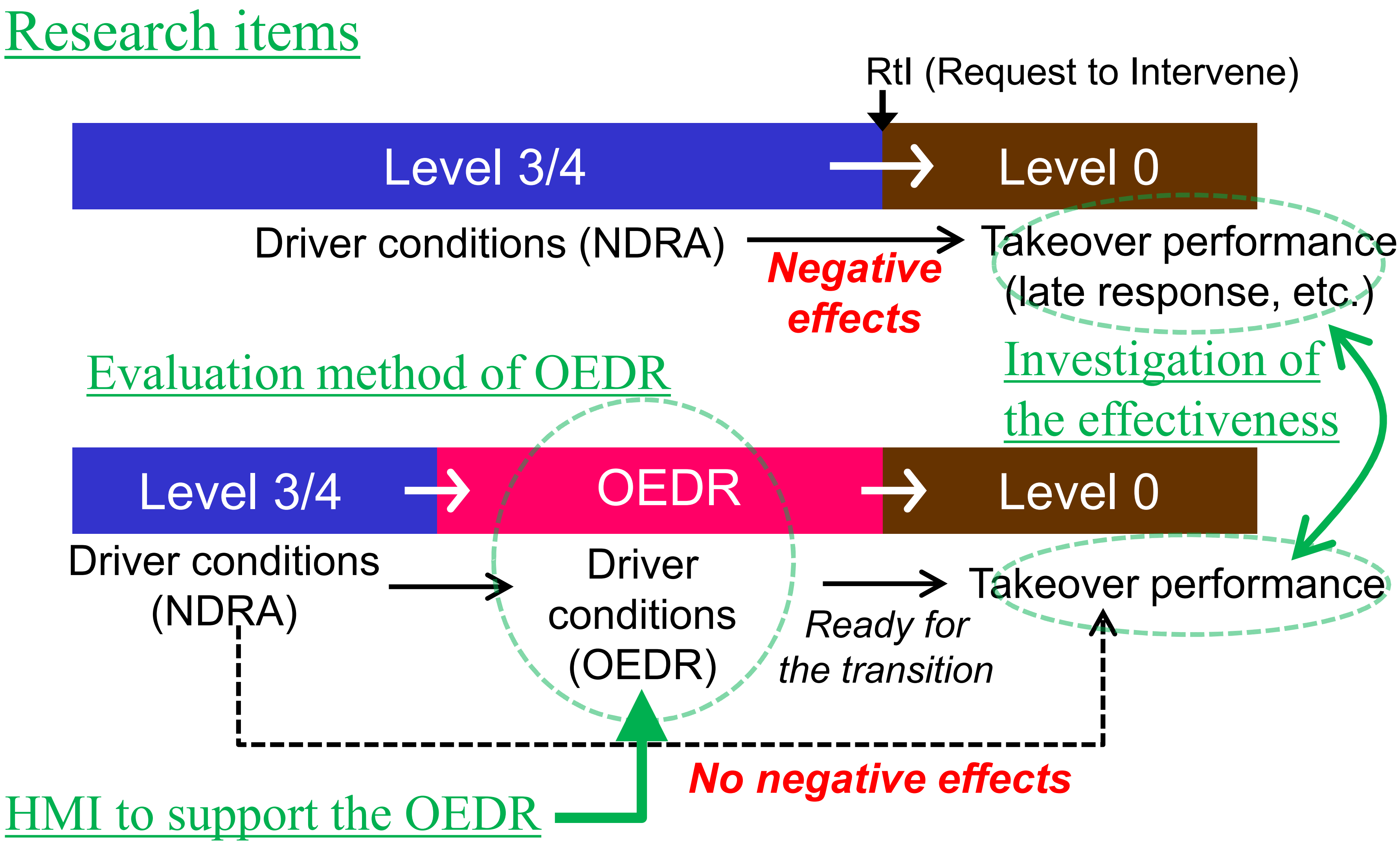


Driver' conditions in automated driving, including eye-off-road or mind-off-road states, influence negatively the takeover performances after the transition when the automated driving mode ceases and directly the driver drives manually.



Such negative effects would not be found, when OEDR condition is inserted between the automated driving and the manual driving and this process could enhance driver's situation awareness.

Appropriate transition from automated to manual driving
< Hypothesis>



Phase 2: FY2019-2021

① Comparison of task performance between different transition processes (Clarification of effective mode transitions) [AIST]

- Driving simulator experiment
- Focusing on the transition from “Level 3” of the automated driving system in highway

② Evaluation method of OEDR [AIST]

- Driving simulator experiment
- Focusing on the transition from “Level 3” of the automated driving system in highway

③ HMI helpful for OEDR and driver-initiated transitions [The University of Tokyo]

- Driving simulator experiment
- Focusing on the transition from “Level 2” of the automated driving system in urban/rural roads

Comparison of task performance between different transition processes (Clarification of effective mode transitions)

<u>Experiment methods</u>

(ODD: Operational Design Domain)

Aims:

- Confirm the hypothesis that the OEDR is necessary for smooth transitions from the level 3/4 to the manual driving
- Investigate effectiveness of presentation methods of ODD limitation
- Investigate indices to evaluate driver's situation awareness

Participants:

- 30 drivers (15 females) from 20 to 70 years old (average age: 45.7 years old)

Road traffic environments:

- Highways in AIST fixed-base driving simulator

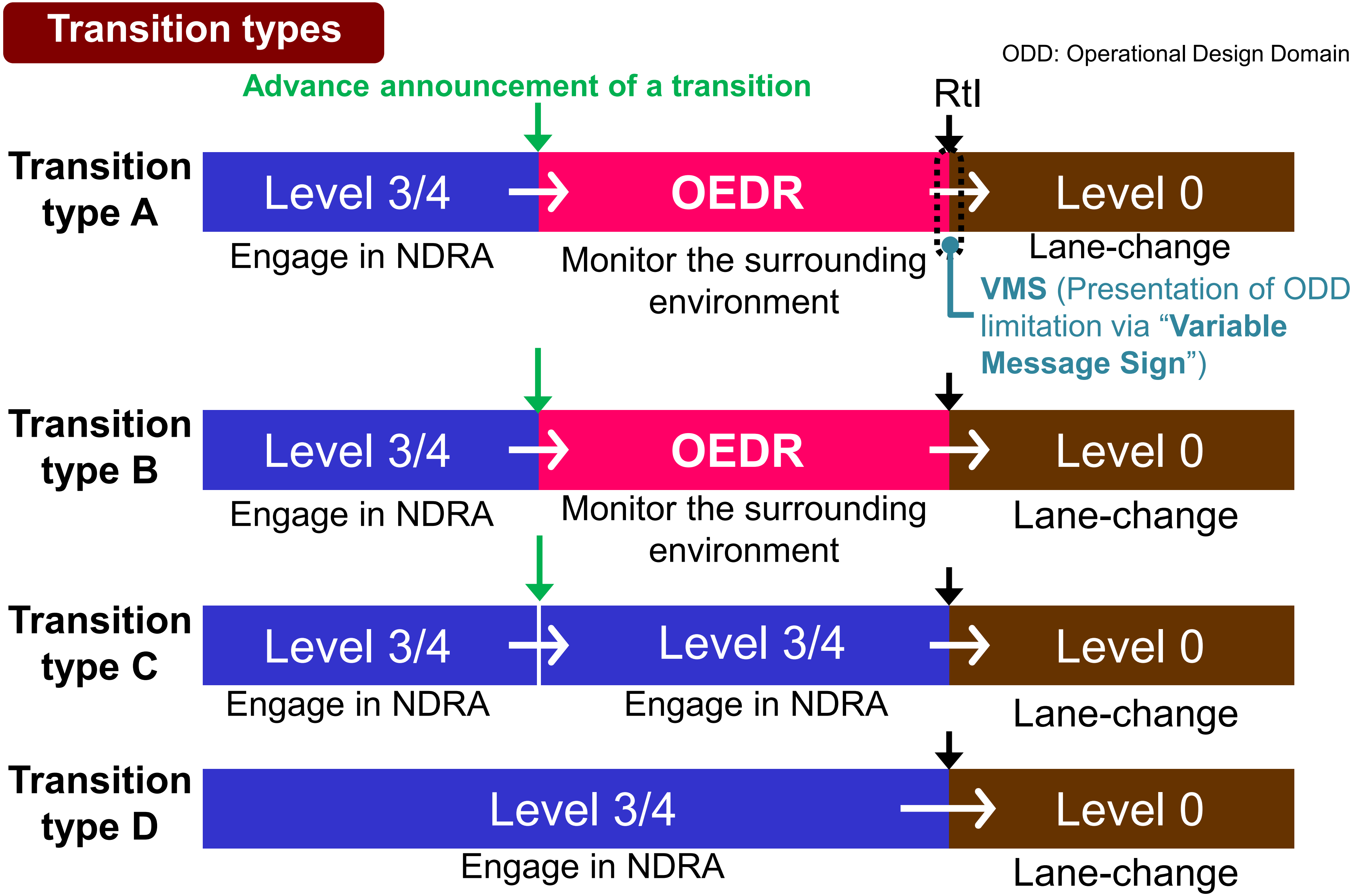
Dependent variables:

- Steering response time
- Successful rate of lane changing
- Lateral control performances in lane changing
- Eye movements

Independent variables:

- Transition types (4 conditions)

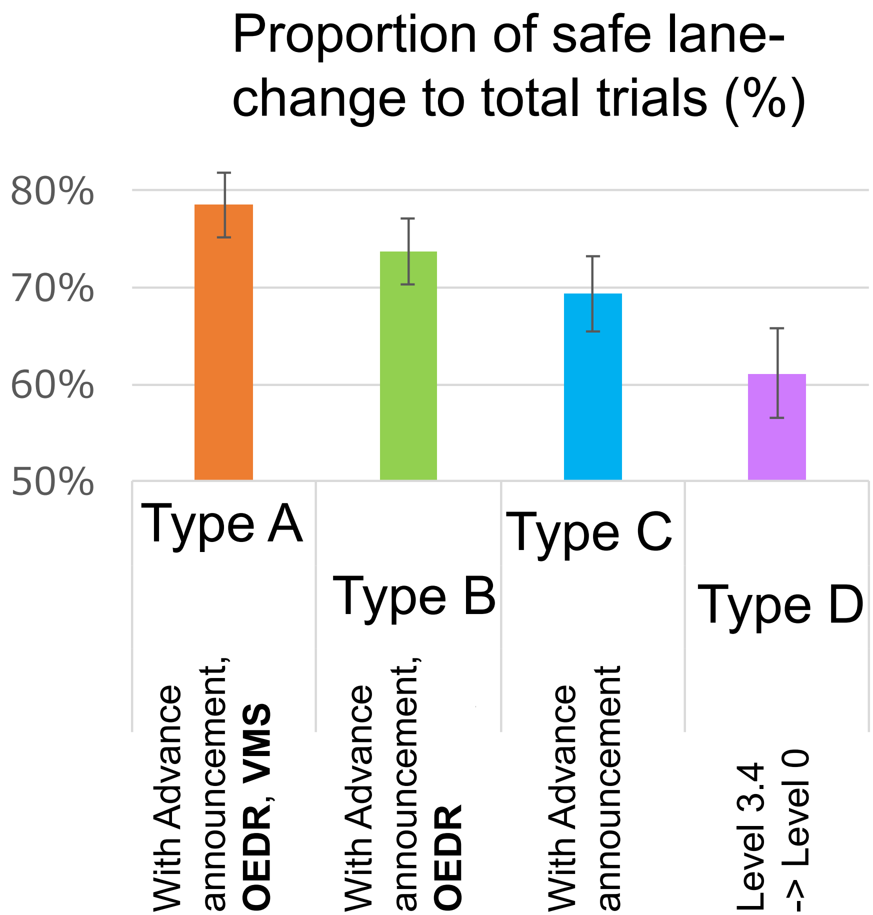
Comparison of task performance between different transition processes (Clarification of effective mode transitions)

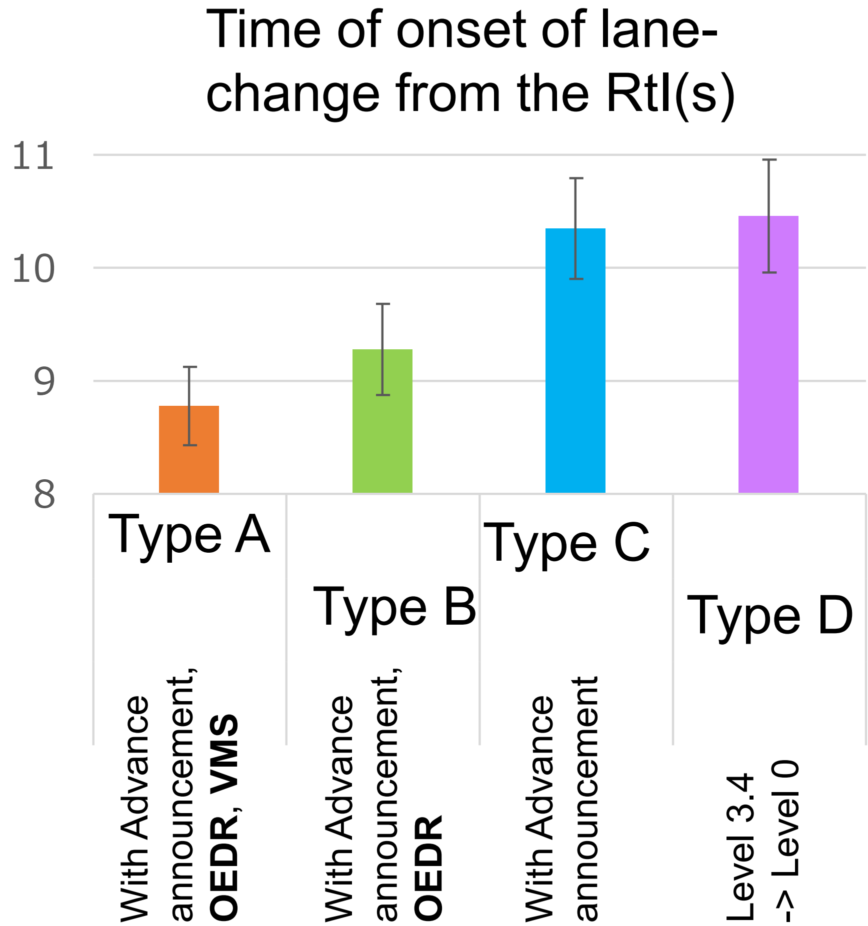


Comparison of task performance between different transition processes (Clarification of effective mode transitions)

Results 1: Driving performance after RtI

OEDR before the transition could contribute to safer and earlier lane-change

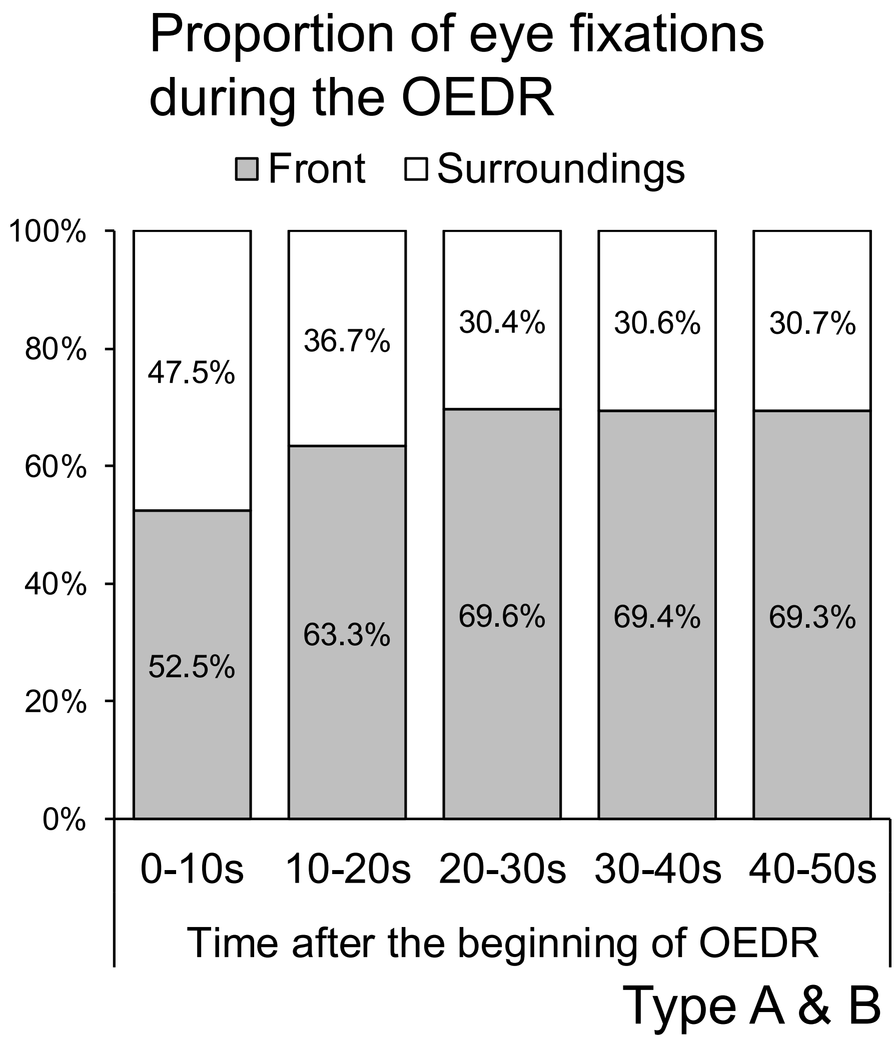


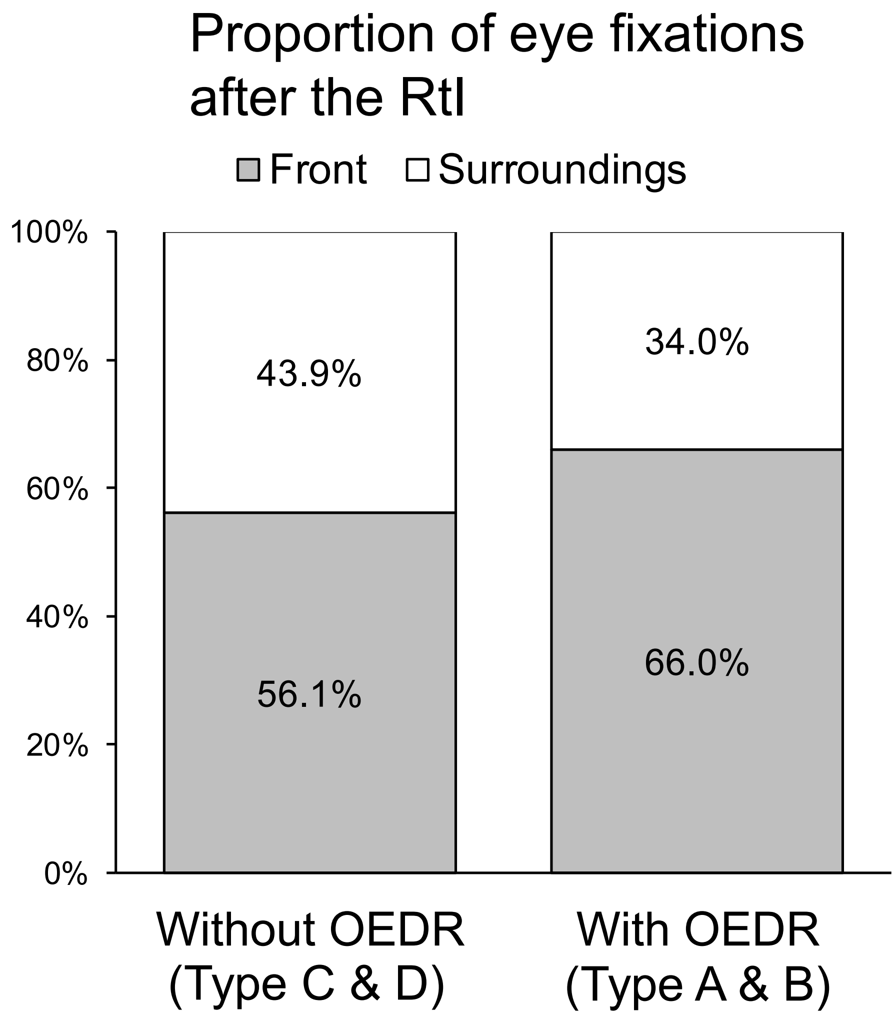


Comparison of task performance between different transition processes (Clarification of effective mode transitions)

Results 2: Eye movements

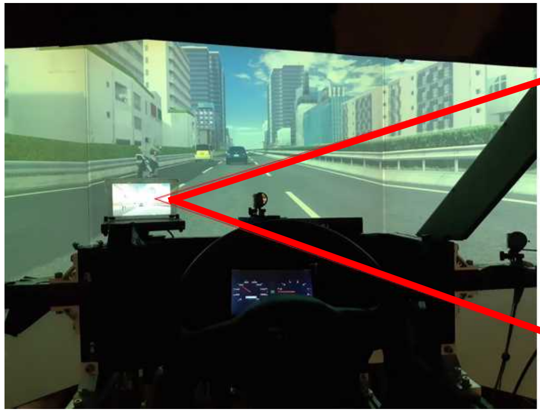
Rates of glancing at the front scene were stable (about 70%) 30 seconds after the beginning of OEDR





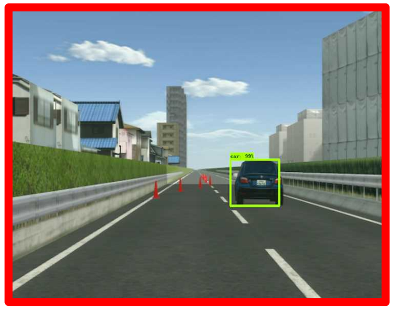
HMI helpful for OEDR and driver-initiated transitions

Purpose:
to analyze the effect of HMI that shows the information recognized by the system.



Undetected motorcycle

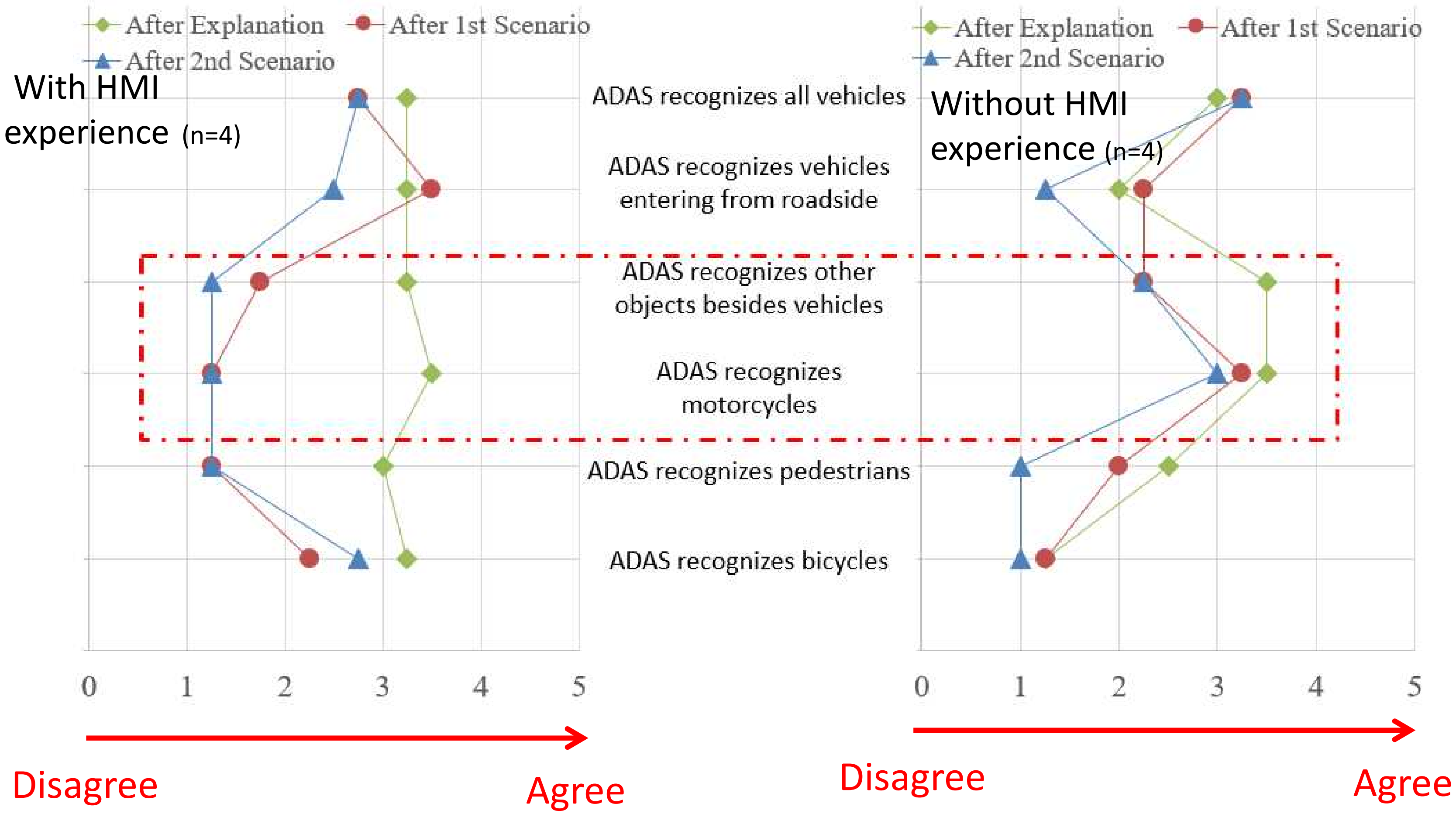
Intrusion from non-priority road



Undetected pylon

DS Experimental Results

Drivers with the experience of using the HMI that displayed the recognition situation of the system tended to understand the recognition limit.



Conclusions

Comparison of task performance between different transition processes (Clarification of effective mode transitions)

- Confirm that “OEDR before the transition” could lead to successful take-over
- Clarify time length (about 30 seconds) necessary to be aware of the surrounding conditions
- Suggest glancing rates (70% for front and 30% for the surroundings) in the driver conditions that he/she recognizes the situations around the driver’s vehicle.

HMI helpful for OEDR and driver-initiated transitions

- Indicate that HMI displaying the recognition situation by the automated system could contribute to enhancing driver’s understandings of the system recognition limitation

Task C

Education and Training for Users

University of Tsukuba

Topic in FY2019

Purpose

Based on the achievement of SIP-adus (2016~19), FY2019_Cii-1 aims to verify education contents of driving automation (DA) at SA Level3, and tends to reveal relations between drivers' attributions and education's effectiveness.

Method

Independent variables between subject

- Introductory general knowledge of DA: Yes/No
- Specific ADS*: Low speed (TJP) / Full speed (SLA)

Participant

Condition	Number		Average age		
	Male	Female	Male	Female	Total
Yes/Low	10	10	57.6	54.8	56.2
Yes/Full	10	10	57.4	54.2	55.8
No/Low	8	9	63.6	52.7	57.8
No/Full	7	8	51.6	56.8	54.3

Dependent variables

- Time length for comprehending instructed knowledge before driving
- Response time to request to intervene (RTI)
- Crash rate

*ADS: automated driving system

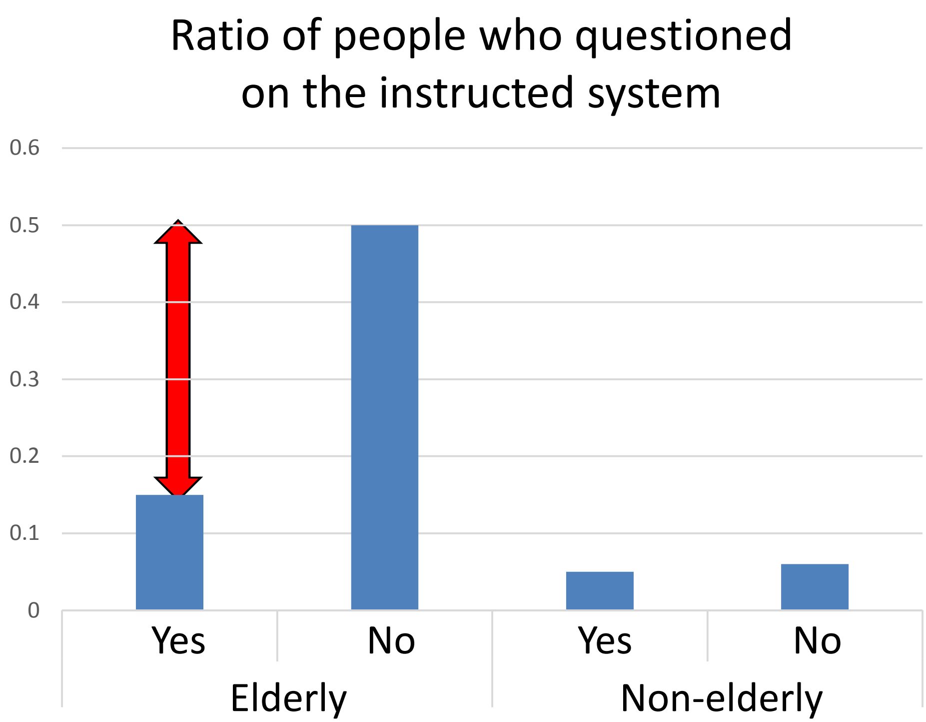
Method (cont.)

Procedure

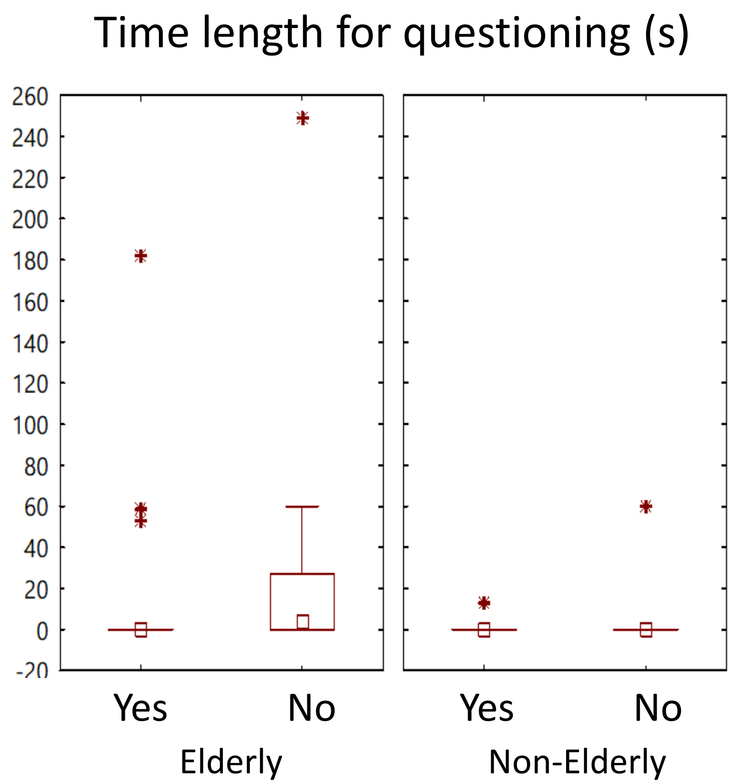
<table>
<tr><th rowspan="2">Experiment schedule</th><th colspan="2">Prior education</th></tr>
<tr><th>Yes</th><th>No</th></tr>
<tr><td rowspan="4">1st day</td><td>Explanation for 1st day</td><td rowspan="4">-</td></tr>
<tr><td>Inform consent</td></tr>
<tr><td>Instructing general knowledge of DA via video</td></tr>
<tr><td>Face-sheet / DBQ</td></tr>
<tr><td rowspan="7">2nd day</td><td colspan="2">Explanation for 2nd day</td></tr>
<tr><td>-</td><td>Inform consent</td></tr>
<tr><td colspan="2">Explanation and exercise of driving simulator (DS)</td></tr>
<tr><td colspan="2">Instruction and exercise of the specific ADS</td></tr>
<tr><td colspan="2">Explanation of take over control</td></tr>
<tr><td colspan="2">Data collection</td></tr>
<tr><td>-</td><td>Face-sheet / DBQ</td></tr>
</table>

Results

Comprehension to Instruction



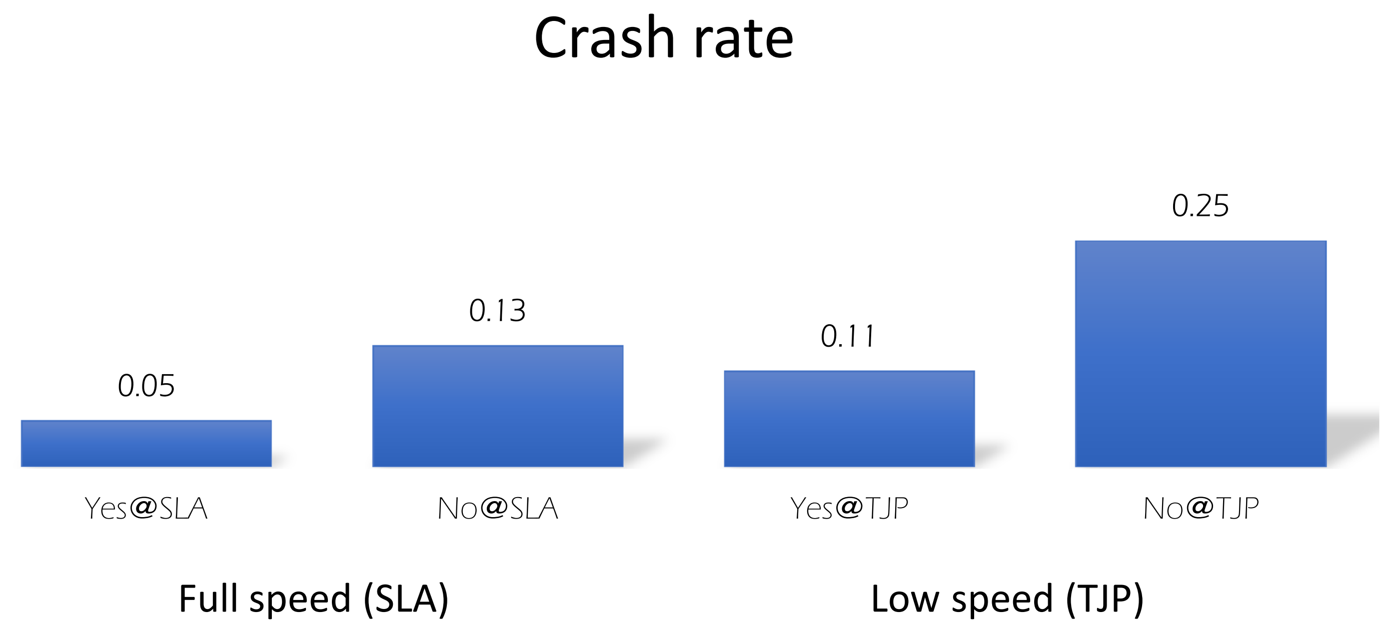
As for the elderly, the questioning ratio of the drivers who were instructed general knowledge of DA is relatively higher than those who weren't instructed.



It took some minutes for some of people who questioned on the instructions.

Results (cont.)

Driver performance @ the closed lane due to a disabled car



Crash rate for drivers who were instructed the general knowledge introductorily is lower than those who weren't instructed. The result doesn't change the system what was instructed.

Conclusion

- The experimental results imply that providing the general knowledge is effective on comprehending the usage of specific ADS.
- Especially for the elderly, it is suggested that drivers would use a specific ADS in a safer manner when they have known the general knowledge on DA in advance.