Cross-ministerial Strategic Innovation Promotion Program

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

FY 2019-2022 Report

Keio University
AIST
University of Tsukuba
Tokyoto Business Services

Aug, 2022

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

Understanding the communication

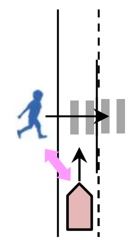
Automated Vehicle for Rural
Rural Mobility and Logistics Service
at Low Speed Traveling

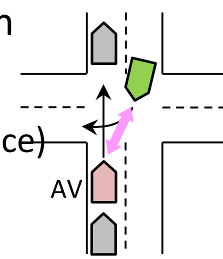
Communication

Pedestrians

- Basic road section
- Intersection
- Parking
  (shared space)

  ⋮





Communication

Drivers

Design

- ■ Communication Intention
- ■ Communication Method
  - Vehicle Motion
  - eHMI
    (external Human Machine Interface)
  - Roadside HMI
  - Road Marking
- ■ Traffic Education

Attribute of Traffic Participant

Transportation Society

Evaluation

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.

Extracting Use-Case of communication between AV and surrounding traffic participant

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,

Considering negative effect by using an eHMI

Applying the important Use-Cases to VR/DS experiments

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

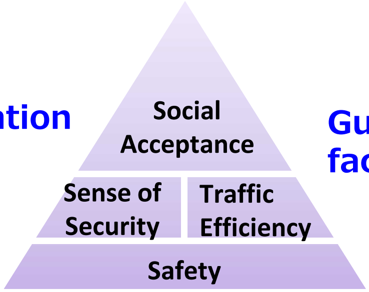
Vehicle motion, eHMI, roadside HMI, road marking, etc.
Knowledge necessary for AV, communication, limitation, etc.
(based on critical use-cases of communication)

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

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

（In field operational tests or field observations）

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



Guidance of educational factors on communication

Safe, secure and efficient communication between AVs and traffic participants

A-i Understanding current status of communication between low-speed AV for mobility/logistic service and traffic participants

Video data analysis at pedestrian environment

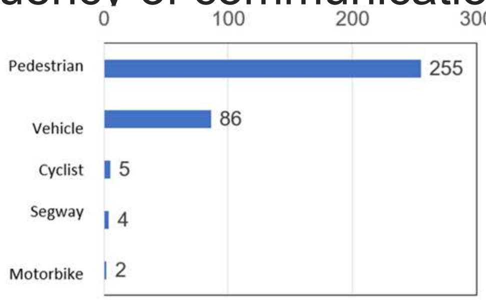
- Issue
  - Communication between low speed automated vehicle and pedestrian is not clear at real pedestrian environment.
  - The way how to reduce unsafe communication is not obvious.
- Objective
  - We aim to observe unsafe and inefficient communications between low speed automated vehicle and pedestrian.
  - We aim to discuss factors of the unsafe and inefficient communication.
  - We discuss how to reduce the unsafe and inefficient communication.
- Method
  - We used video data recorded at experiment for eight days at Gotenba Kogen Tokinosumika in Gotenba city in Shizuoka Prefecture.
  - We focused on unsafe and inefficient communications.
  - We used data about automated vehicle, road users, and road environment.

AV

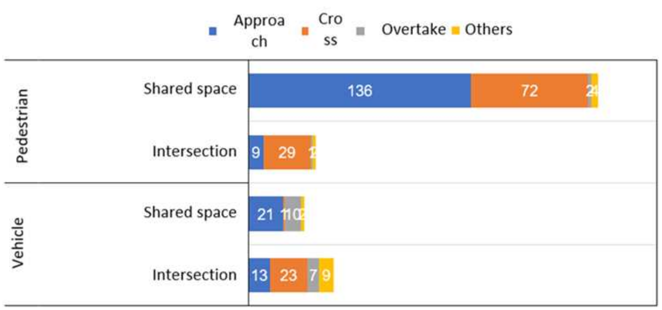
Target area
https://www.tokinosumika.com/guide/

Video data analysis at pedestrian environment

- Frequency of communications



Frequency of each road user



Frequency of pedestrian and vehicle

- Unsafe communication with pedestrian

Pedestrian with smartphone

Communication with old person

- How to reduce unsafe and inefficient
  - Different from vehicle road environment, we observed pedestrians who were using smartphone and careless pedestrian such as old and child pedestrian in pedestrian environment. We need to discuss other ways to reduce such situations.
  - Sound may reduce unsafe communications with pedestrians who were using smartphone.
  - eHMI may reduce inefficient communications with children who did not have high cognition ability.

Difference of communication between AV and conventional vehicle in FOT such as roadside station “Michi-no-Eki”

- Issue
  - Communication between low speed automated vehicle and pedestrian is not clear at real pedestrian environment.
  - The way how to reduce unsafe communication is not obvious.
  - Communications were not clear at parking
- Aim
  - Differences of unsafe and inefficient communication between AV and conventional vehicle is analyzed
- Method
  - 16 days worth of videos(September 2020~ October) at Akagikougen in Shimane.
  - We took the videos of parking and intersections near roadside stations where automated vehicle pass from a bird's-eye view.
  - 83 interactions of automated vehicle (all interaction) ,100 interactions of previous vehicle(50 each parking and intersections at random).

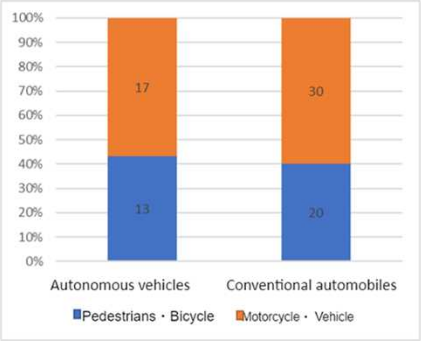
Automated vehicle (Golf-cart type)

Communication observation around parking lots

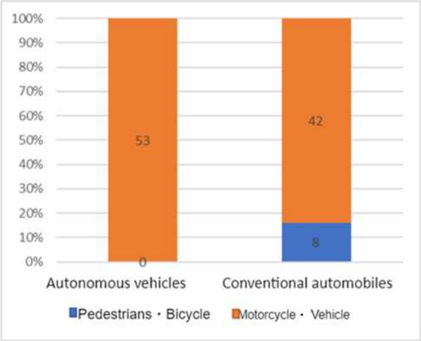
Communication observation around intersection

Comparison of communication between automated and conventional manual vehicles

- Result



Parking area



Intersection

AV's inefficient communication: Facing

AV's inefficient communication: Overtaking

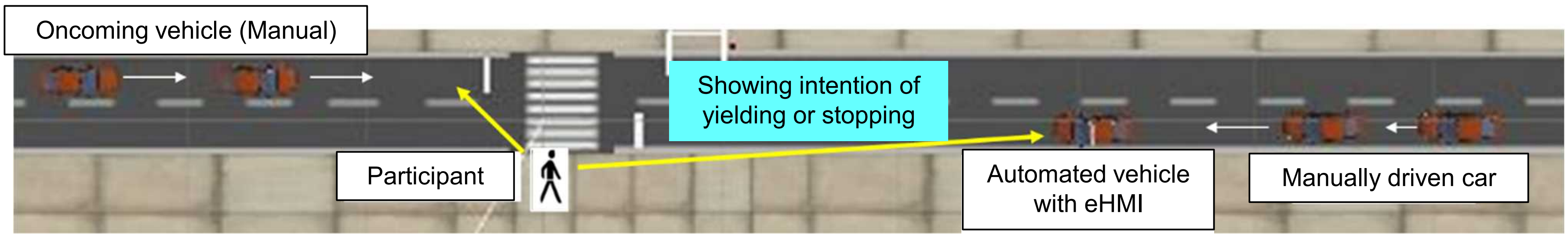
- Conclusion
  - AV's fixed trajectory and low priority in traffic caused ineffient at overtaking pedestrian.
  - When AV faced to other road users, low priority in traffic caused different vehicle behavior and confused other road users.
  - AV recognize road environment by sencer, therefore sometimes could not understand several vehicles was running continuously, and about to collision.

A-ii Analysis of communication between AV and single/multiple participants and extraction of factors influencing communication success or error

Applying a method to mitigate negative effects by eHMIs on automated vehicles

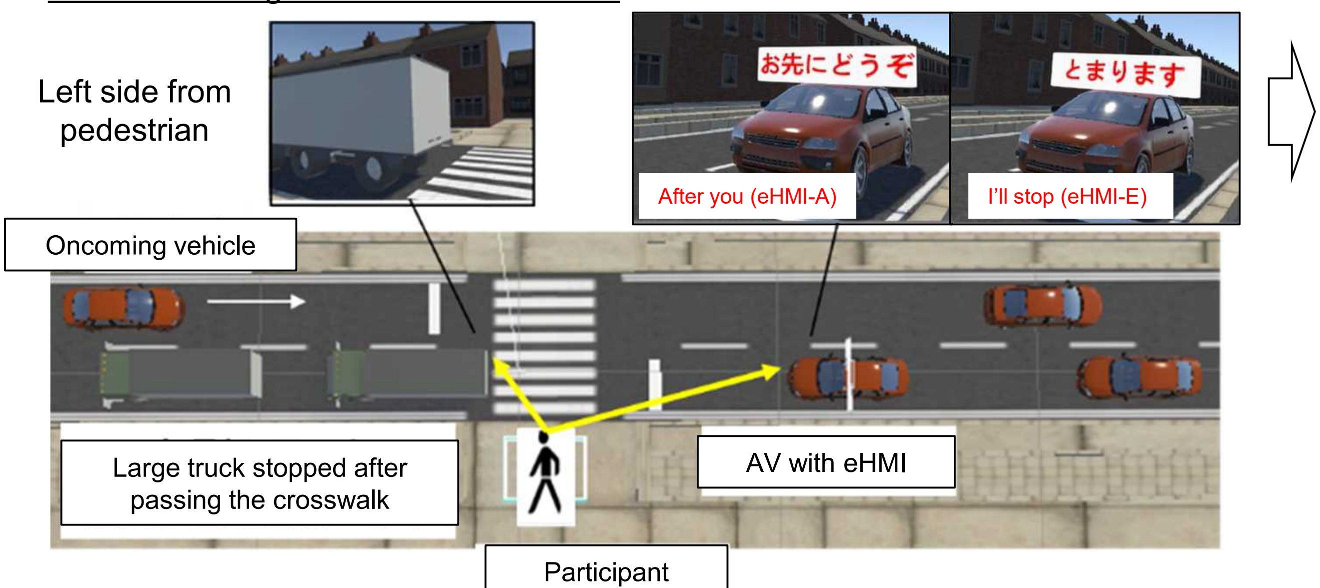
- To examine impacts of a mitigation method of negative effects by pedestrians' inappropriate reliance and trust towards eHMIs on low-speed automated vehicles

Traffic scenarios for the eHMI experience （1st~10th trial）



Scenario for negative effect（11th trial）

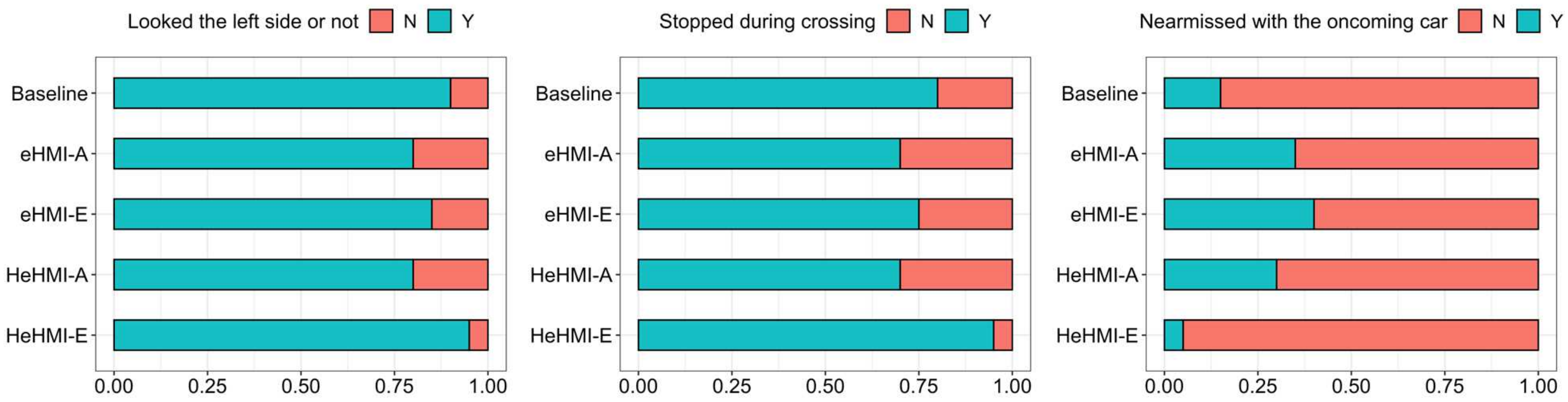
Message type



Mitigation method

The AV turns off the text message on the eHMI to arouse pedestrian attention to surrounding environments (HeHMI-A, HeHMI-E)

Results on pedestrian behavior during pedestrian-AV communication via eHMIs



Note: Baseline (no eHMI)

- For each condition, twenty participants undertook the VR experiment (overall, 100 participants)
- Pedestrians in the eHMI-A, eHMI-E, and HeHMI-A paid less attention to encountering environments compared to others
- Pedestrians who undertook the eHMI-E and HeHMI-E were more likely to stop on the zebra crossing with vigilance against traffic risk than those of the eHMI-A and HeHMI-A
- The number of near misses with the oncoming car in the HeHMI-E was the lowest among all conditions
- In general, giving egocentric messages via the eHMI could lead pedestrian exploratory behaviour rather than allocentric messages
- The method of negative effect mitigation (hiding text messages on the eHMI) is effective at pedestrian attention arousal, but limited to automated vehicles which provide egocentric text messages

A-iii Production of a low-speed, driverless experimental vehicle assuming Level 4 and implementation of eHMI

Preparation for external human machine interface used in Field Operational Test

- Information provision and contents from automated driving golf-cart to surrounding traffic participants
  - Information provision to following traffic participants

    Automated driving golf-cart always displays by using external human machine interface during automated driving

    “Automated vehicle”, “Driving at low-speed“, “Pass with care”
  - Information provision to surrounding traffic participants in front

    Automated driving golf-cart displays messages by using external human machine interface when decelerating or stopping, in order to yield to surrounding traffic participants.

    “I’ll stop”, “After you”, “In automated driving mode”

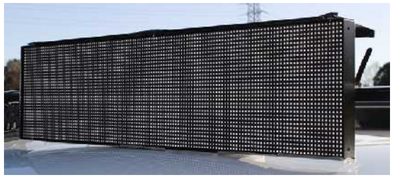
External HMI (front)

External HMI (rear)

Automated driving golf-cart, eHMI and attachment tools

- Automated driving golf-cart (Yamaha Motor Co., Ltd., Model: YG-ML)
  - Six passengers, with license plate (road-going vehicle)
  - Automated driving based on electromagnetic induction wire (controls vehicle speed by using RFID buried in the road)
  - Max speed: 20km/h in manual driving:, 12km/h in automated driving

- External human machine interface (eHMI)
  - Vehicle exterior display device (LED display panel, Koito Electric Industries, Ltd.)
    "Select Color" display device, Model: CS1302



AC100V
4.0kg

- Attachment tools for external human machine interface
  - Made of steel, screwed or sandwiched method at the time of installation

Front, on the dashboard
Made of steel 1.8kg

On the roof
Made of steel 2.2kg

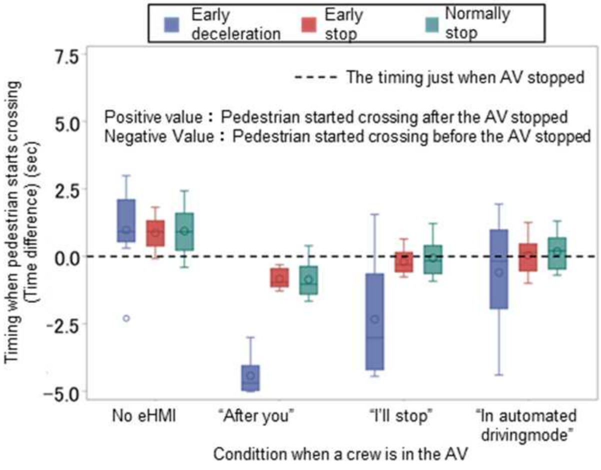
Rear, in the luggage space
Made of steel 5.0kg

A-ⅳ Study and proposal of eHMI, etc. for basic communication between low-speed AV and surrounding traffic participants in single roads and intersections

Pedestrian experiment on test track (campus road) for crossing case

- Issue
  - Communication support is needed to improve inefficient traffic situations when pedestrians cross in front of AV at pedestrian crossings.
- Aim
  - Analyzing the effects of eHMI, vehicle behavior, and the presence or absence of a driver on the perception, judgment, and psychology of pedestrians in autonomous driving service cars
- Method
  - Conducts at campus road (test track)
  - Set each experimental condition consisting of experimental factors such as eHMI, vehicle behavior, and presence or absence of crew
  - Subjects were healthy men and women in their 20s to 50s with a driver's license, and the total number of subjects was 32.
- Results and discussion
  - When eHMI is not implemented, regardless of the deceleration behavior, even if the AV stops, there is a tendency that the decision to start crossing is delayed immediately after that, because it feels that they do not feel to be yielded to.
  - By implementing eHMI, it is possible to judge the start of crossing at an early timing.
  - When there is no crew on board (unmanned state), the pedestrians' decision to start crossing is delayed for early deceleration compared to when there is a crew on board (early stop and normal stop are stable).
  - Condition of early deceleration and normal stop condition with eHMI "I'll stop" tends to increase pedestrians' anxiety due to the absence of crew.
  - Early stopping with eHMI tends to reduce their anxiety regardless of the presence or absence of crew

Automated vehicle (Golf cart type)



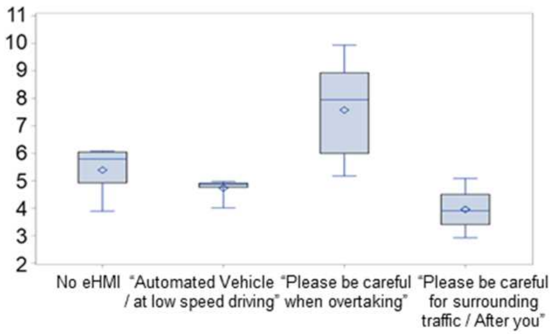
Result of crossing start timing

Following driver overtaking experiment on a driving simulator for overtaking case (study of messages)

- Issue
  - Dangerous events that may induce collisions, such as near misses and interference with oncoming vehicles, have been observed when a following vehicle overtakes a low-speed AV.
- Aim
  - For the driver of the following vehicle approaching the low speed AV, as an eHMI, analyze on their recognition, judgment, and psychological aspect in communication to reduce and suppress near misses and interference with oncoming vehicles.
- Method
  - Conducting experiments using a driving simulator environment
  - Participants were healthy general drivers with a driver's license, and the total number of subjects was 32.
  - Settings such as no eHMI, “Automated vehicle/Driving at low speed” (alternate display), “Be careful when overtaking”, “Be careful for surroundings/”After you” ”go ahead" (alternate display).
- Results and discussion
  - Increasing the time to see the surrounding situation in an overtaking situation by communicating “Be careful in overtaking".
  - Induces a decrease in the time required to see the surrounding in an overtaking situation.
  - when using eHMI with "Be careful in overtaking/After you"(alternately)
  - Suggests that not implementing an eHMI may increase the following driver's irritation, while implementing an eHMI may suppress the following driver's irritation.
  - Suggests the possibility of communicating the intention to yield to the following driver by using eHMI with "Automated vehicle/low speed driving" and "Be careful in overtaking".

Driving simulator experiment

Communication based on eHMI



Glancing time to surrounding situation in overtaking case

Following driver overtaking experiment on a driving simulator for overtaking case (study of vehicle behavior)

- Issue
  - When operating an autonomous vehicle, it deviates from the track of the autonomous vehicle and stops on the shoulder of the road to encourage the overtaking of the following vehicle, but it takes a lot of time and effort for the operator.

- Objective
  - Analyze whether unsafe scenes are observed when stopping in orbit

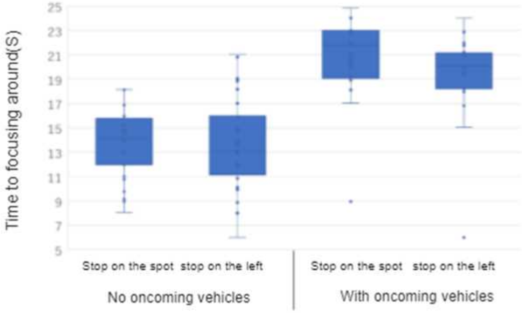
- Method
  - We conducted Driving Simulator experiment.
  - 32 participants were collected.
  - Set 4condition in the combination of (stop on the spot, stop on the left)×（No oncoming vehicles, With oncoming vehicles ）

- Result
  - There is no difference about focus time on road environment between the case of stop on the spot and stop on then left.

- Discussion
  - Stop on the spot increased somewhat annoying regardless of presence of oncoming vehicles or not.
  - Stop on the left could made yielding.
  - There is no big difference about focus time on road environment between the case of stop on the spot and stop on then left.

→ There may be an operation that encourages overtaking by stopping on the spot.

Experiment in Driving simulater



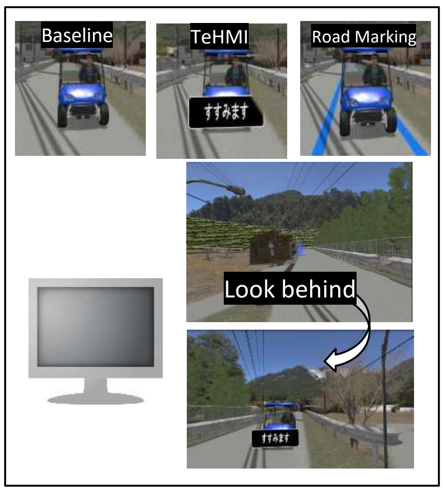
time to focusing around

A- Ⅴ Study and proposal of eHMI, etc. for basic communication between low-speed AV and surrounding traffic participants in shared space such as parking lots

Preliminary study on communication for approaching and avoiding case

- In a case that an AV approaches behind of pedestrians, pedestrians possibly do not know what they should do. As such unsafe and inefficient use cases occurred at shared space such as narrow road without roadside-belt in Michi-no-eki areas, assistance methods for pedestrian-AV communication should be considered
- This study carried out a video watching experiment targeting the cases of "approaching/avoiding" to seek possible communication assistance methods with 9 participants

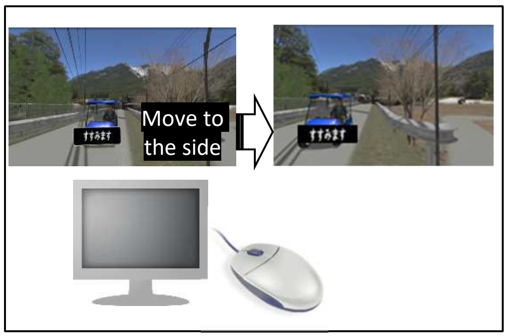
Experiment procedure: use case of “AV approaching-Pedestrian avoiding” at shared space such as narrow road without roadside-belt



Phase 1: Facing the approaching AV

(Understand the AV’s intention that wants pedestrians to give way)

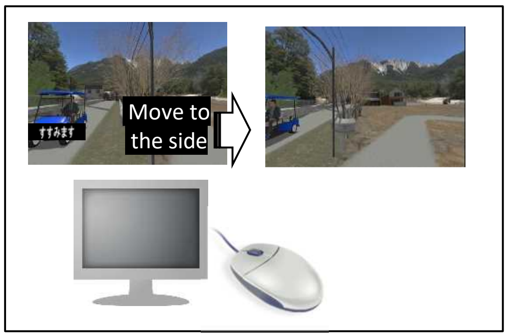
Phase 2: The AV wants to drive and ask pedestrians to give way



Move from AV’s driving route

① Investigating participants’ opinions on possible request methods when the AV asks “Please move from the road”

Phase 3: The AV wants to give further request when pedestrians moved from the road, but insufficient



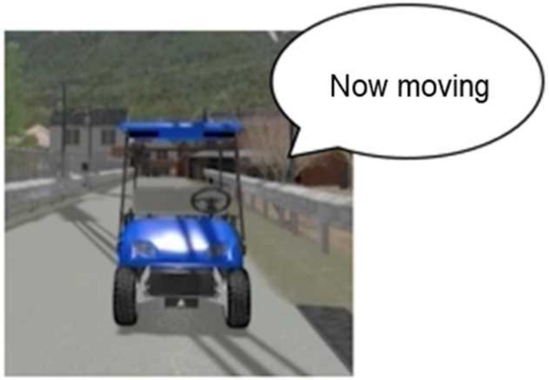
Move from the AV more

② Investigating participants’ opinions on possible request methods when the AV asks “Please move from the road more”

Study and proposal of communication method between low-speed AV and surrounding traffic participants at shared space such as narrow road without roadside-belt

- Efficient communication methods should be designed for a better communication between pedestrians and AVs at shared space such as narrow road without roadside-belt in Michi-no-eki areas where encompass several unsafe and inefficient interactions between road users and AVs
- The current study designed a communication assistance method based on results of video watching experiment and simulated this in VR environments
- This study aimed to investigate impacts of giving auditory message from AVs to pedestrians on their first impression and perception of AVs

VR experiment with "AV approaching-Pedestrian avoiding" use case at shared space such as narrow road without roadside-belt



Participants
- 4 females & 3 males

Mixed-experimental design
- 1st, 6th trials – between-subject (VeHMI)
- 2nd~5th trials – within-subject (Baseline, TeHMI, Road Marking)

Voice message
- First: "Now moving"
- When the AV asked pedestrians to further movement: "Please move from the road a little more"

Results: Video watching experiment for approaching/avoiding case at shared space such as narrow road without roadside-belt

- **Phase 1**: Facing the approaching AV; Participants' perception of AV's intention
  - Participants in the Baseline condition answered the AV thinks pedestrians as an obstacle of their driving route (e.g., "the AV wants move straightly", "The AV has stopped due to a pedestrian", or "I don't know what the AV want to do")
  - As the AV showed a text message of "Now moving" in the text-based eHMI (TeHMI), 8 of 9 participants responded the AV wants to go straight. One participant answered almost same response with the detailed request from the AV, "The AV wants me to move from the road because the AV wants to move straightly"
  - In the road marking condition, participants provided various answers compared to the TeHMI condition. More specifically, "the AV wants move straightly (45%)", "the AV wants you to move from the road (33%)", "The AV wants you to move from the blue road marking (11%)", and "the AV wants to park on the shoulder of road (11%)"

- **Phase 2**: How to lead participants to move from the road
  - In general, participants gave almost same responses to all conditions. The method using voice message was most suggested, and "Please move (from the road)" was the most suggested message content in all conditions.
  - Text messages via the TeHMI: **"Please move from the road"**, "In automated driving", "Now moving", "The AV cannot move (due to you)"
  - Voice messages from the AV: "Please move from the road (to the shoulder of road)", "Now moving", "Warning", "The AV cannot move (due to you)"
  - The message of "Please give way" was suggested as a possible venue in the Baseline unlike other two conditions.

- **Phase 3**: How to lead participants' further move from the road
  - In general, participants' responses were almost identical to those of Phase 2. Giving voice message of "Please move from the road" was the most preferred method
  - Providing specific number (e.g., X meters) and repeating the message might be helpful for making further move.

Results: Subjective ratings after experimental trials targeting at shared space such as narrow road without roadside-belt

Trial	Perception	Trust	Anxiety	Feeling of Safety
1st	2.29 (1.7)	2.86 (1.57)	2.58 (1.4)	3 (1.53)
Last	1.72 (0.95)	3.29 (0.76)	2.72 (0.95)	3.74 (1.38)

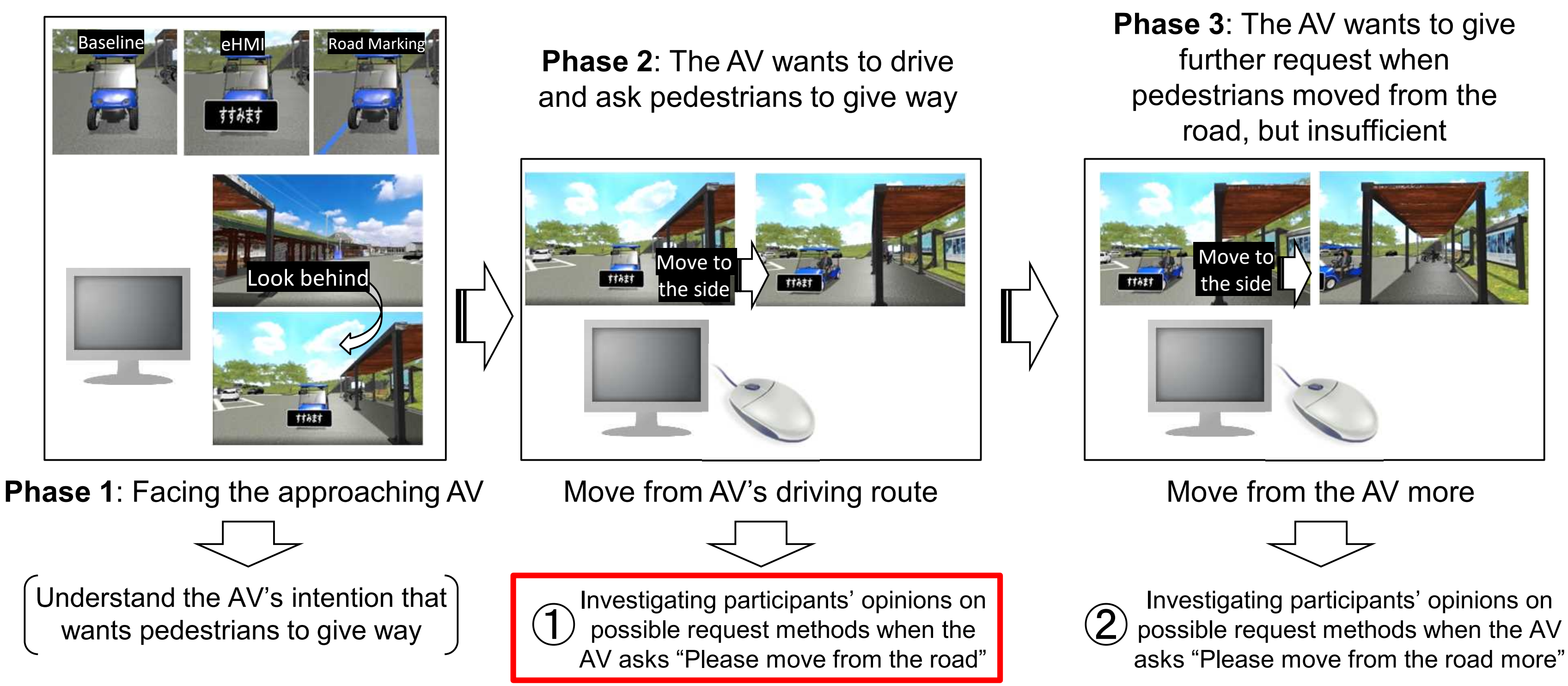
- One participant did not move from the road when facing the approached AV in the 1st trial, but the participant moved from the road in the 6th trial
- Whilst some participants did not move from the road in conditions simulating communication assistance methods (i.e., road marking, text-based eHMI), almost all participants moved from the road in the VeHMI condition
- Participants' ratings on the perception of AV's intention were lower in the 6th trial than the 1st trial
- Participants felt more anxiety of the AV in the last trial compared to the initial trial
- The ratings on participants trust and feeling of safety toward the AV were increased with the experience of trials (Trust: 2.86 -> 3.29; Feeling of Safety: 3 -> 3.74)
- As the 7 Likert scale was was used, giving voice message might be somewhat limited to lead participants' appropriate perception of AV's intention as well as to shape favourable attitude towards the AV

Note: direct comparison between the VeHMI and other conditions was difficult because different type of questionnaire was used in two VR experiments

Study and proposal of basic communication method between low-speed AV and surrounding traffic participants at shared space (parking lot)

- Use cases that pedestrians have difficulty in communicating with approaching AVs behind of them in several locations of Michi-no-eki areas.
- Parking areas do not have an explicitly distinguished zone for road users, thus assistance methods for pedestrian-AV communication should be considered with the characteristics of such area
- This study carried out a video watching experiment targeting the cases of "approaching/avoiding" to seek possible communication assistance methods with 9 participants

Experiment procedure: use case of "AV approaching-Pedestrian avoiding" in a parking area



Study and proposal of communication method between low-speed AV and surrounding traffic participants at shared space such as parking areas

- Efficient communication methods should be designed for a better communication between pedestrians and AVs at parking lots in Michi-no-eki areas where encompass several unsafe and inefficient interactions between road users and AVs
- The current study designed a communication assistance method based on results of video watching experiment and simulated this in VR environments
- This study aimed to examine impacts of giving auditory message from AVs to pedestrians on their first impression and perception of AVs

Experiment procedure: use case of "AV approaching-Pedestrian avoiding" in parking areas

Participants
- 5 females & 4 males

Mixed-experimental design
- 1st, 6th trials – between-subject (VeHMI)
- 2nd~5th trials – within-subject (Baseline, TeHMI, Road Marking)

Voice message
- First: "Now moving"
- When the AV asked pedestrians to further movement: "Please move from the road a little more"

Results: Video watching experiment for approaching/avoiding case at shared space such as parking lots

- **Phase 1**: Facing the approaching AV; Participants' perception of AV's intention
  - Participants in the Baseline condition reported "the AV wants move straightly", "The AV has stopped due to a pedestrian". Also, they responded "I don't know what the AV want to do" and "The AV just stopped"
  - As the AV showed a text message of "Now moving" in the text-based eHMI (TeHMI), 8 of 9 participants responded the AV wants to go straight. One participant reported "The AV wants a pedestrian to move from the road."
  - In the road marking condition, participants most responded "The AV wants move straightly" and "The AV wants a pedestrian to move from the road." They reported opinions relevant to road marking – e.g., "Please move from the line", "The AV wants to drive along with / on the line."

- **Phase 2**: How to lead participants to move from the road
  - In general, participants gave almost same responses to all conditions. The method using voice message was most suggested, and "Please move (from the road)" was the most suggested message content in all conditions.
  - Text messages via the TeHMI: **"Please move from the road"**, "In automated driving", "Now moving", "The AV cannot move (due to you)", "Warning"
  - Voice messages from the AV: "Please move from the road (to the shoulder of road)", "Now moving", "Warning", "The AV cannot move (due to you)", "Please move X meters away from the road (with specific number)"
  - The message of "Please give way" was suggested as a possible venue in the Baseline unlike other two conditions.

- **Phase 3**: How to lead participants' further move from the road
  - In general, participants' responses were almost identical to those of Phase 2. Giving voice message of "Please move from the road" was the most preferred method
  - Providing specific number (e.g., X meters) and repeating the message might be helpful for making further move.

Results: Subjective ratings after experimental trials targeting at shared space such as parking lots

Trial	Perception	Trust	Anxiety	Feeling of Safety
1st	1.5 (0.53)	3 (1.07)	3.38 (1.51)	4.25 (0.46)
Last	1.63 (0.74)	3.75 (0.88)	2.25 (0.89)	4.25 (0.46)

- Compared to other designs, giving voice messages was highly rated by participants throughout the experiment
- Except for ratings on the feeling of safety, changes in ratings between the first and last trials were observed
- The perception levels of the AV’s intention was slightly increased
- Participants got trusted the AV with the the experiment
- The experience of interaction with the AV reduced the anxiety levels
- As the 7 Likert scale was was used, giving voice message might be somewhat limited to lead participants’ appropriate perception of AV’s intention as well as to shape favourable attitude towards the AV

Note: direct comparison between the VeHMI and other conditions was difficult because different type of questionnaire was used in two VR experiments

Study and proposal of visual/voice communication method between low-speed AV and surrounding traffic participants at shared space such as narrow road without roadside-belt

- Following results obtained from previous studies (video watching and VR experiment studies), this study designed two methods with two messages for an efficient pedestrian-AV communication with pedestrians' pleasure
- Considering the actual need and frequency of use case occurrence in the Michi-no-eki area, shared space such as narrow road without roadside-belt was selected
- The objective of this study was to examine impacts of four communication designs on pedestrian-AV communication

VR experiment with "AV approaching-Pedestrian avoiding" use case at shared space such as narrow road without roadside-belt

Participants
- 21 females & 20 males

Mixed-experimental design
- 1st, 6th trials – between-subject
- 2nd~5th trials – within-subject

Baseline

TeHMI-R

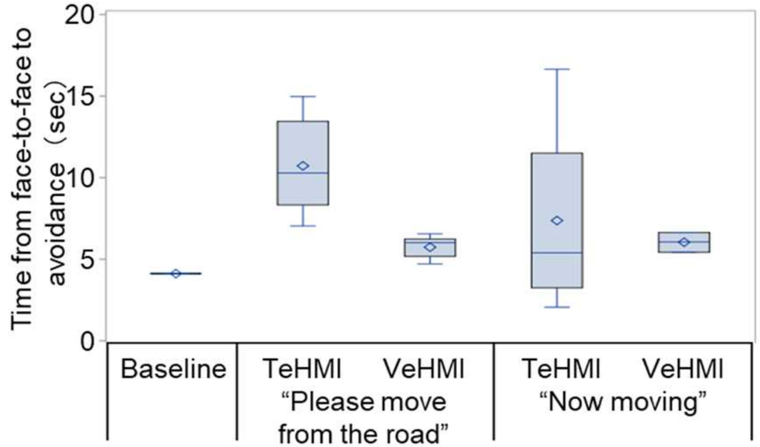
TeHMI-I

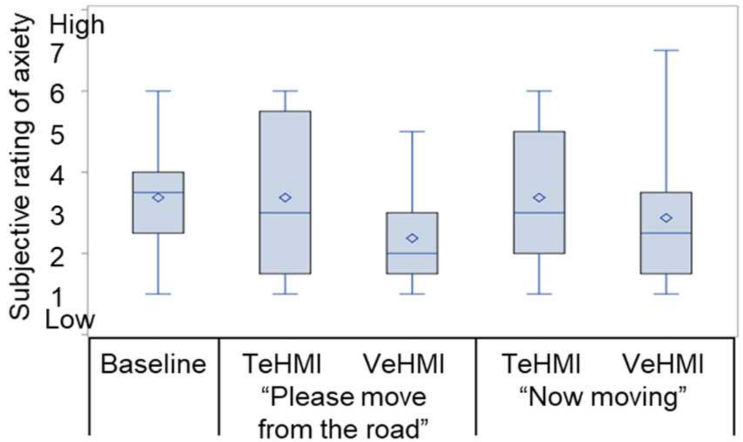
VeHMI-R

VeHMI-I

Results: Pedestrian behavior and attitude after the initial trial targeting at shared space such as narrow road without roadside-belt

Avoidance Type ¥ Number	Baseline	"Please move from the road"		"Now moving"	
		TeHMI-I	TeHMI-R	VeHMI-I	VeHMI-R
Sufficient Avoidance	1	5	6	6	4
No avoidance / Avoidance but insufficient	7	2	2	2	4
Others	0	1	0	0	0





- Participants showed sufficient avoidance leading AV's redriving when the AV provided information to pedestrians compared to the Baseline
- Voice messages from the AV led quicker avoidance from the road than text-based eHMIs
- Likewise, participants felt the higher levels of anxiety in the TeHMI than VeHMI conditions
- Results indicate giving a voice message of "please move from the road" is the most effective at leading pedestrians' quick perception of AV's intention and reducing the anxiety level in their initial interaction

A- vi Verification of communication method between AV and traffic participant in FOT around Road Station “Michi-no-Eki”

- Issue
  - It is not obvious that results about eHMI from experiment environment can be obtain at public road environment.

- Objective
  - We aim to examine if we can obtain similar results at public road environment and experiment environment.
  - In particular, we examine if eHMI improves unsafe in overtaking situation, and inefficient in pedestrian crossing situation.

- Method
  - We conducted Field-Operation-Test (FOT) at Iinancho, Shimane prefecture (June 25-July 5, 2022), and Miyama city, Fukuoka prefecture (July 15-July 23, 2022).
  - AV’s time schedule was based on the target area’s bus’s time schedule. AV run between each bus’s operation time.
  - Same vehicle type AV with target area’s bus was used in FOT.
  - Front eHMI message (2 messages): “I will stop”, “After you”
  - Backward eHMI message (2 messages): “Careful for overtaking”, “Low-Speed | In automatic mode (switching in 1sec)”

Front and back of AV

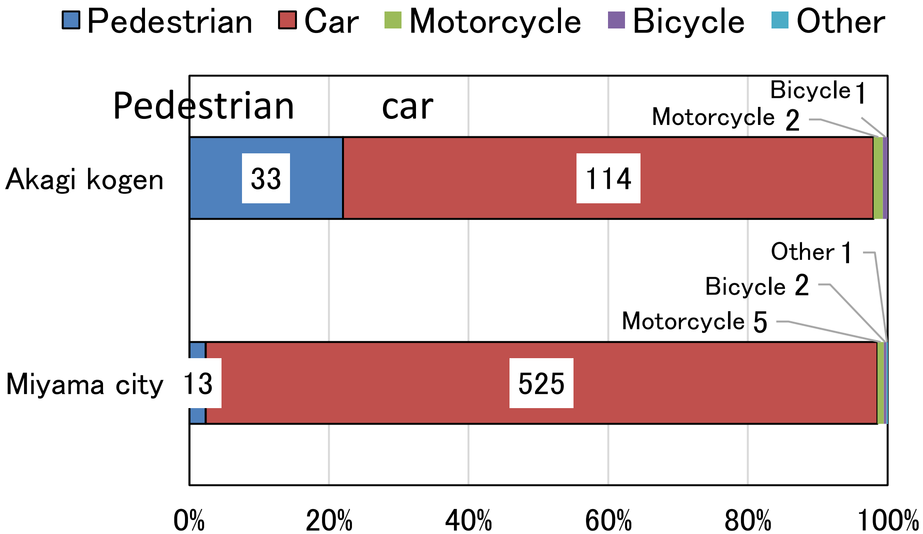
Iinancho route（https://www.ad-akagikogen.com/）

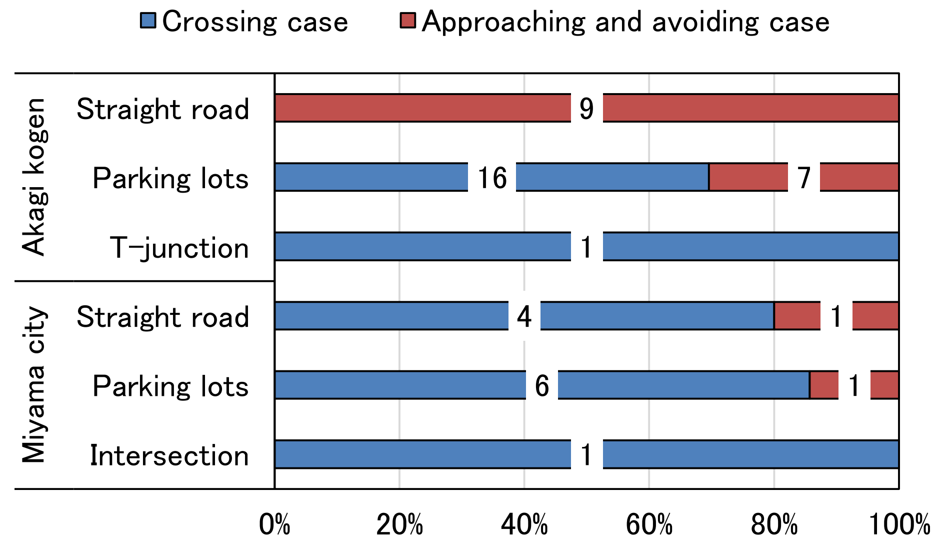
Miyama city route（https://www.city.miyama.lg.jp/s006/kurashi/140/jidouunten.html）

Observed communication at each FOT area

- Observed communication candidates[1] and cases with pedestrians

  [1] As an initial step, to avoid missing omissions, surrounding traffic participants within a certain distance were extracted. (including cases in which traffic participants did not look at AV)



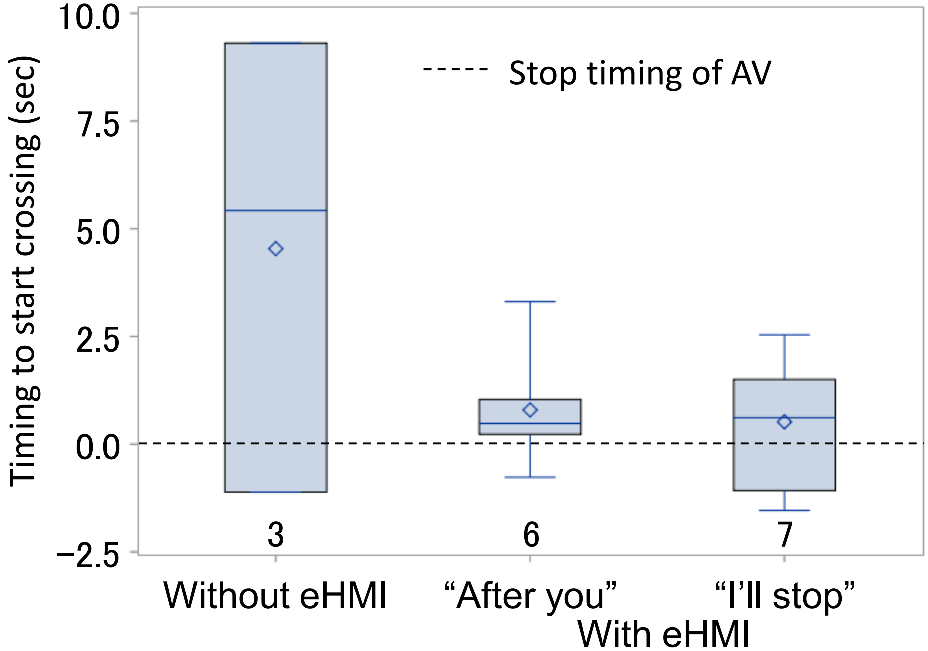


- Since most of the operation routes on the Akagi Kogen are residential roads, traffic volume is low, and most of the overtaking cases were observed on residential roads. Pedestrian crossing cases were observed in the parking lot of the road station.

- Since most of the operation routes in Miyama City are general national roads, traffic volume is high, overtaking cases are mostly observed on general national roads, and sidewalks are installed in many sections, approach and avoidance cases are few, and crossing cases are mostly observed.

Effects of eHMI on pedestrian crossing behavior

- Extracts and analyzes cases where pedestrians see the low-speed AV and start their action to cross.



Positive value means that the pedestrian start crossing after the AV stops.
(For example, it took 9 seconds from the timing when the AV stops until the timing when he/she starts crossing

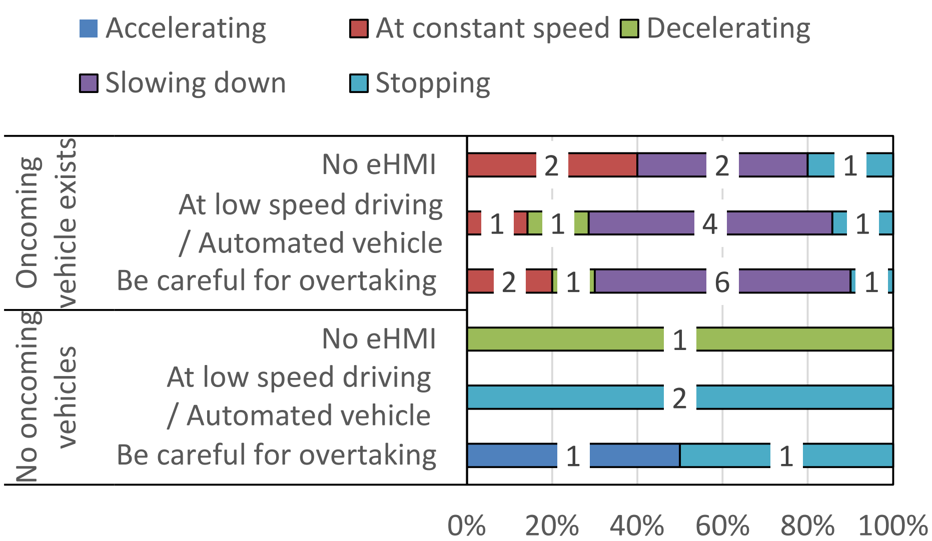
Negative value means that the pedestrian start crossing before the AV stops.
(For example, it took 1 second from the timing when he/she starts crossing until the timing when the AV stops

- Without eHMI, pedestrians may not be able to easily move to crossing action even if they see the stopping state of the low-speed AV, leading to inefficient crossing initiation.
- With the implementation of eHMI, pedestrians may be able to see the state of the low-speed AV and smoothly transition to crossing behavior near the timing of the AV stops.

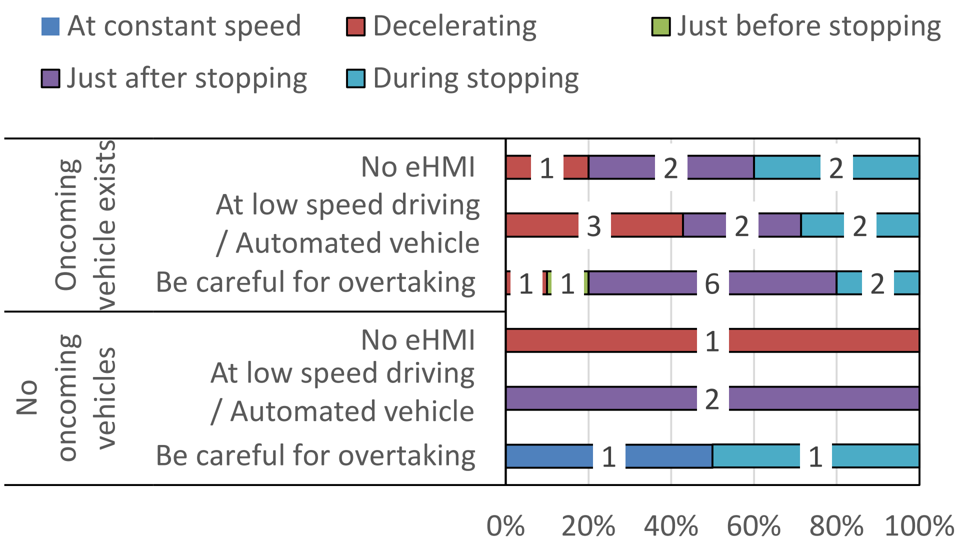
Need to collect and analyze more cases due to the small number of observations

Effects of eHMI on following driver's overtaking behavior

- Extraction and analysis of characteristics of overtaking behavior of following drivers with and without eHMI on residential roads around Road Station "Akagi-Kogen" (Excluding measurement errors. In the case of a group of following vehicles, only the lead vehicle was extracted.)



Driving conditions of following vehicles immediately before overtaking a golf cart



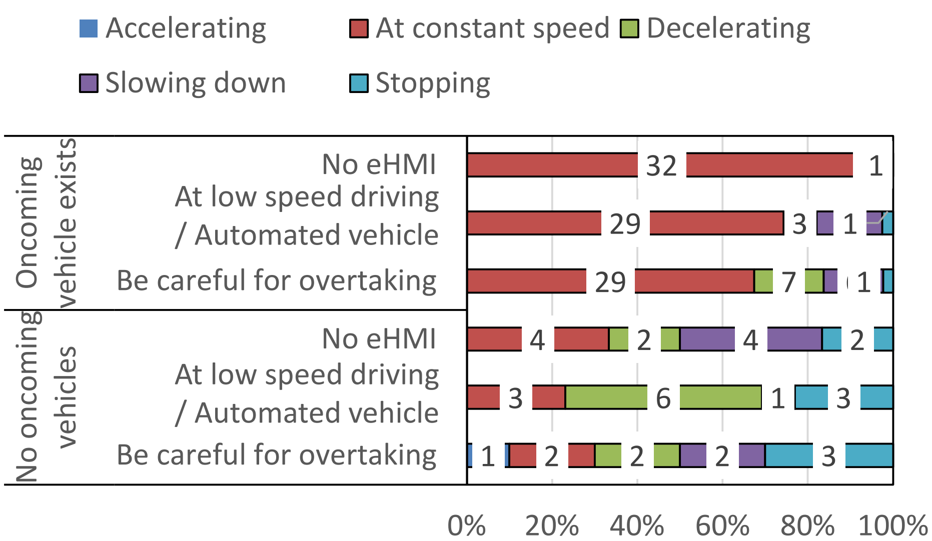
Driving condition of the golf cart at the start of overtaking by the following vehicle

- The road is a narrow road and the surrounding vehicles are running at low speeds of less than 30 km/h. The implementation of eHMI suggests the possibility of urging following vehicles to slow down or slow down before overtaking a golf cart.
- Regardless of the presence or absence of eHMI, we observed many cases in which the following vehicle started to overtake the golf cart while it was decelerating or before or after it stopped,

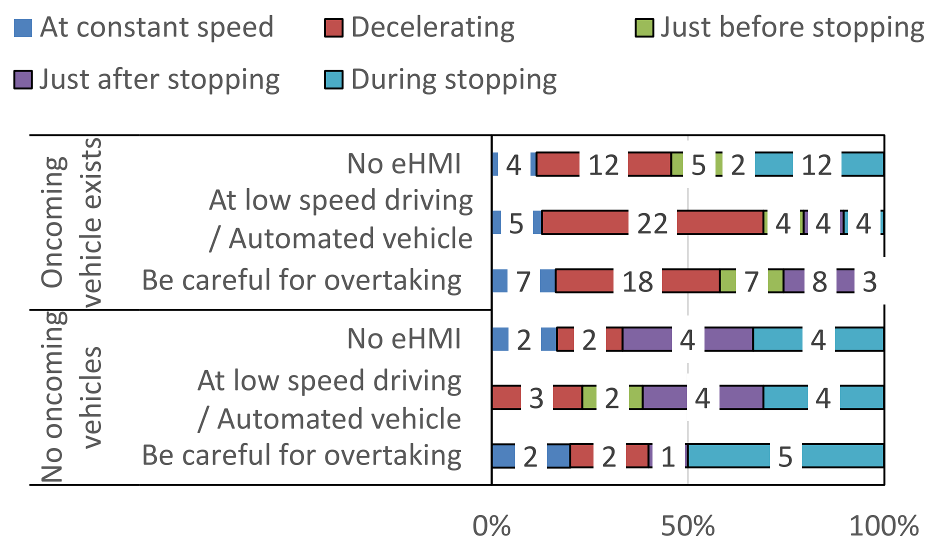
Need to collect and analyze more cases due to the small number of observations

Effects of eHMI on following driver's overtaking behavior

- Extraction and analysis of characteristics of overtaking behavior of drivers following with and without external HMI on a general national highway in Miyama City (Excluding measurement errors. In the case of a group of following vehicles, only the lead vehicle was extracted.)



Driving conditions of following vehicles immediately before overtaking a golf cart



Driving condition of the golf cart at the start of overtaking by the following vehicle

- The road is a general national highway and the speed difference between the golf cart and the surrounding vehicles is as large as 50 km/h, suggesting the possibility that the implementation of eHMI may prompt the following vehicle to slow down or slow down before overtaking the golf cart.
- Regardless of the presence or absence of eHMI, we observed many cases in which the following vehicle started to overtake the golf cart while it was decelerating or before or after it stopped,

Need to collect and analyze more cases due to the small number of observations

Comments from local residents and stakeholders

- Positive comments from local government officials, transportation operators, stakeholders, and pedestrians (residents, etc.) regarding the implementation of eHMI.

Remaining issues on overtaking case

- Rear-ending vehicle following the low-speed AV interfered with approaching oncoming traffic (several occurrences).

  - It is considered to be caused by the stopping position and timing of the low-speed AV when yielding to the following vehicle, as well as the road environment.

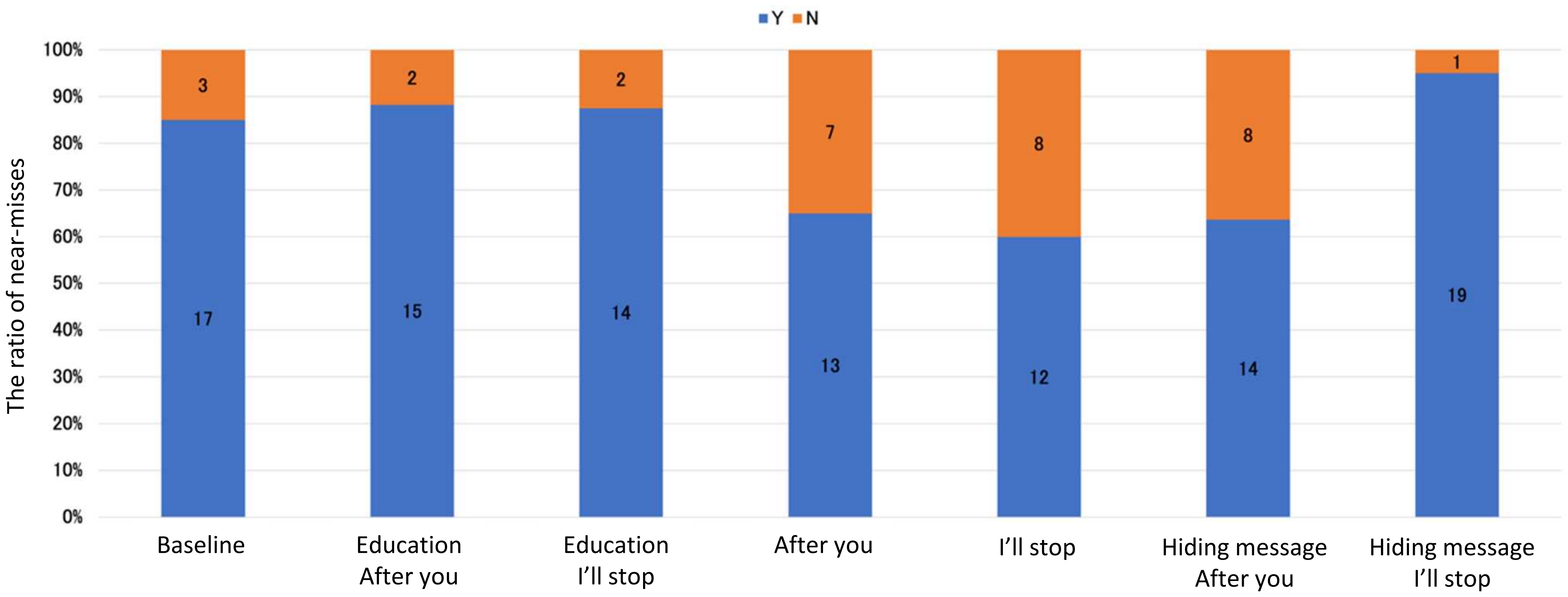
A-vii Education for mitigating negative effect of communication between AV and traffic participants

Giving prior education for participants to mitigate negative effects by eHMIs on automated vehicles

- To examine impacts of prior education on mitigating negative effects by pedestrians' inappropriate reliance and trust towards eHMIs on low-speed automated vehicles
- This VR experiment used the same traffic scenarios to those of A-ii
- Before undertaking the VR trial, all participants completed education materials and quiz based on this

Participants
I'll stop: 9 females & 8 malees; **After you:** 8 females & 8 males

Results: Pedestrian behavior during pedestrian–AV communication via eHMIs



- Negative effects were observed in both eHMI types
- Prior education reduced the number of near-misses with a manually driven car on the opposite driving lane compared to hiding text messages in the eHMI
- Effects of hiding a text message was limited to when the AV projected "I'll stop", but the prior education influenced both types of messages
- Prior education led not only pedestrians' attention arousal but also enhanced traffic safety

Summarized results of Task A (1)

A-i Understanding current status of communication between low-speed AV for mobility/logistic service and traffic participants

- Inefficient and unsafe communication between automated low-speed AV (automated service vehicle) and surrounding traffic participants are identified as “crossing cases”, “approaching and avoiding case”, and “overtaking case”.
- As a cause of inefficient and unsafe communication, it is suggested that the surrounding traffic participants do not understand the vehicle behavior and behavioral intentions of the automated driving service vehicle.

A-ii Analysis of communication between AV and single/multiple participants and extraction of factors influencing communication success or error

- Repeated experience of communication from an automated vehicle equipped with an eHMI may induce negative effects, such as reduced pedestrian awareness of surroundings when making crossing decisions and overconfidence in the AV to yield to pedestrians.
- Pedestrians' awareness of their surroundings before and during crossing was slightly improved by turning off the eHMI according to the surrounding conditions.
- Suggests that the reason for the lack of significant improvement is a lack of knowledge about technical limitations of low-speed automated vehicle

Summarized results of Task A (2)

A-iv Study and proposal of eHMI, etc. for basic communication between low-speed AV and surrounding traffic participants in single roads and intersections

Crossing case

- Condition without eHMI made pedestrians feel that they were not being yielded to even immediately after the low-speed AV stops, regardless of the deceleration behavior, and delayed the decision timing for starting to cross.
- Condition with eHMI (“I’ll stop" or “After you") provides pedestrians with an early decision to start crossing, and also contributes to reduce the sense of anxiety.
- In the unmanned state, early deceleration of low-speed AV delays the timing of decisions to start crossing and the eHMI (“I’ll stop”) induces a sense of anxiety more than when a crew member is on the AV.

Summarized results of Task A (3)

A-iv Study and proposal of eHMI, etc. for basic communication between low-speed AV and surrounding traffic participants in single roads and intersections

Overtaking case

- Using eHMI to provide “Be careful when overtaking/after you” (alternating display) for following drivers decreases the total glance time to the surrounding traffic in an overtaking situation.
- Using eHMI to provide “Be careful when overtaking" for following drivers increases the total glance time spent the surrounding traffic in an overtaking situation.
- The following drivers understand that they are yielded to by using eHMI of “Be careful when overtaking" or “Automated vehicle/driving at low speed" (alternating display).
- The condition without eHMI tends to increase the irritation of following drivers, while the condition with eHMI tends to decrease such irritation of following drivers.

Summarized results of Task A (4)

A-v Study and proposal of eHMI, etc. for basic communication between low-speed AV and surrounding traffic participants in shared space such as parking lots

Approaching and avoiding case

- Condition without eHMI makes it difficult for pedestrians to recognize that they are being asked to take avoiding action, resulting in inefficient traffic situations that do not lead to avoiding action

eHMI: requests to pedestrians such as "please move out the way," and the intent of low-speed AV such as "I'm going forward"

- The eHMI (using auditory voice message) has a short time from first encounter to avoidance, small individual differences among pedestrians, and low anxiety, but some pedestrians feel that they are forced to take action, so it is necessary to pay attention to the wording of the HMI.
- The eHMI (using visual text message) has large individual differences among pedestrians at the first encounter, and the time spent from the first face to avoidance may be long.
- Most of pedestrians do not know the technical limitations that prevent the low-speed AV from deviating from the electromagnetic guideline, and this may cause a lack of pedestrian understanding even when eHMI is implemented.

Summarized results of Task A (5)

A-vi Verification of communication method between AV and traffic participant in FOT around Road Station “Michi-no-Eki”

Verification of the effectiveness of eHMI in FOT - Crossing case and overtaking case -

<Crossing case>

- The condition with eHMI contributes to reduction of delay in pedestrian crossing decision and initiation in real road traffic environment.

<Overtaking case>

- On a national highway with a large speed difference from the low-speed AV, the condition with eHMI contributes that the following vehicles slow down or move slowly before starting overtaking.

<Future work>

- A small number of interferences between oncoming and following vehicles were observed. They may be caused by the road environment and the stopping position of the experimental AV when yielding to a following vehicle. A detailed study of communication methods is also necessary.

Summarized results of Task A (6)

A-vii Education for mitigating negative effect of communication between AV and traffic participants

Knowledge and Education for mitigating negative effect of communication between AV and traffic participants

- Prior education with a quiz is designed to enhance pedestrians’ understanding of AV’s capability and limitation then mitigate negative effects. Unlike limited effects of hiding (turning off) the eHMI’s message, the prior education are likely to mitigate negative effects in both message types (“I’ll stop”, “After you”). More specifically, the education is effective at preventing pedestrian careless behavior shaped by over-reliance on the AV’s capability.

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

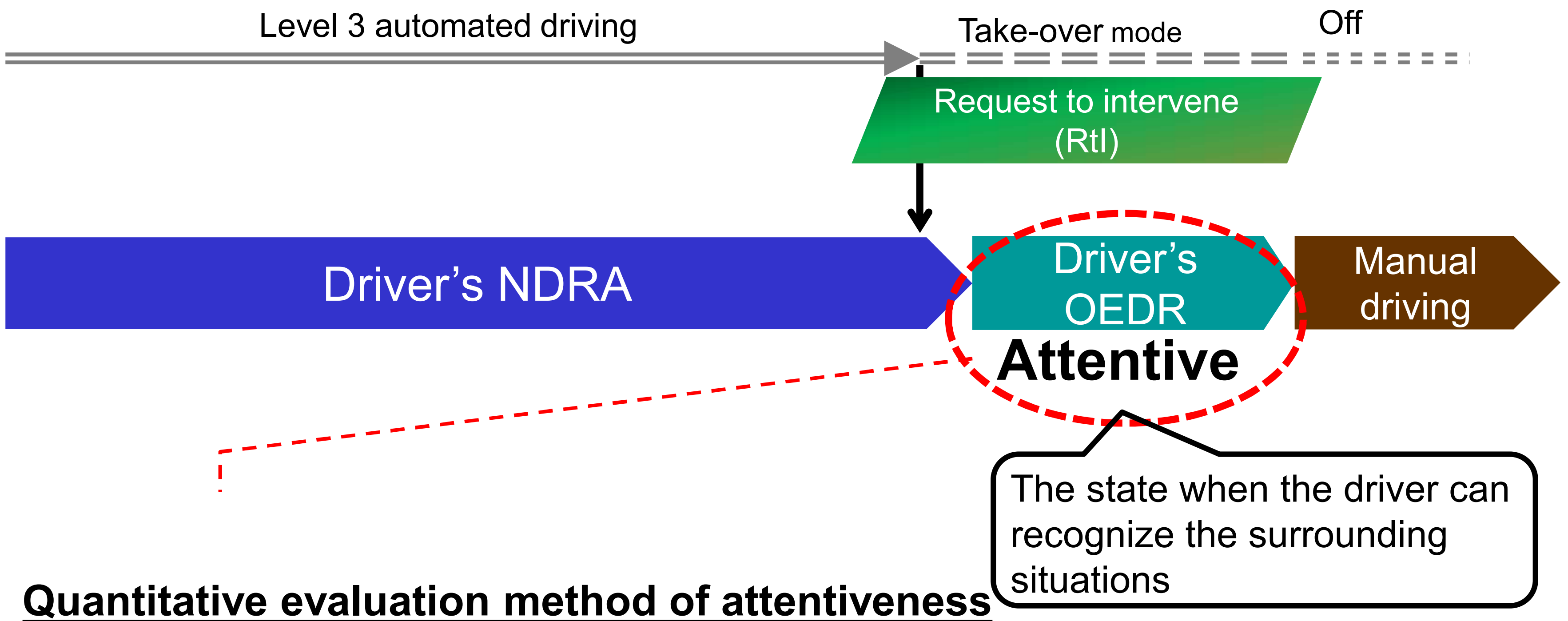
National Institute of Advanced Industrial Science and Technology (AIST)

The University of Tokyo

NDRA: Non-Driving Related Activities
OEDR: Object and Event Detection and Response

System-initiated transitions from automated to manual driving

Evaluation methods of attentiveness



Quantitative evaluation method of attentiveness

- **metrics**
- **variation of the metrics indicating an appropriate OEDR**
- **necessary time to construct an appropriate OEDR**
- **validate those metrics by comparing with standard evaluation methods**

HMI principles to promote driver's attentiveness

- **HMI that maintain the driver's attentiveness shortly after the request to monitor**

Task B

Understanding of principles for HMI development + Proposal of driver state (attentiveness) evaluation method

- Study 1
  - Safety after taking over control from automated driving with NDRA
  - Driver state evaluation by gaze behaviors
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
- Study 3
  - Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

Study 1: objective

**Understanding of principles for HMI development +
Proposal of driver state (attentiveness) evaluation method**

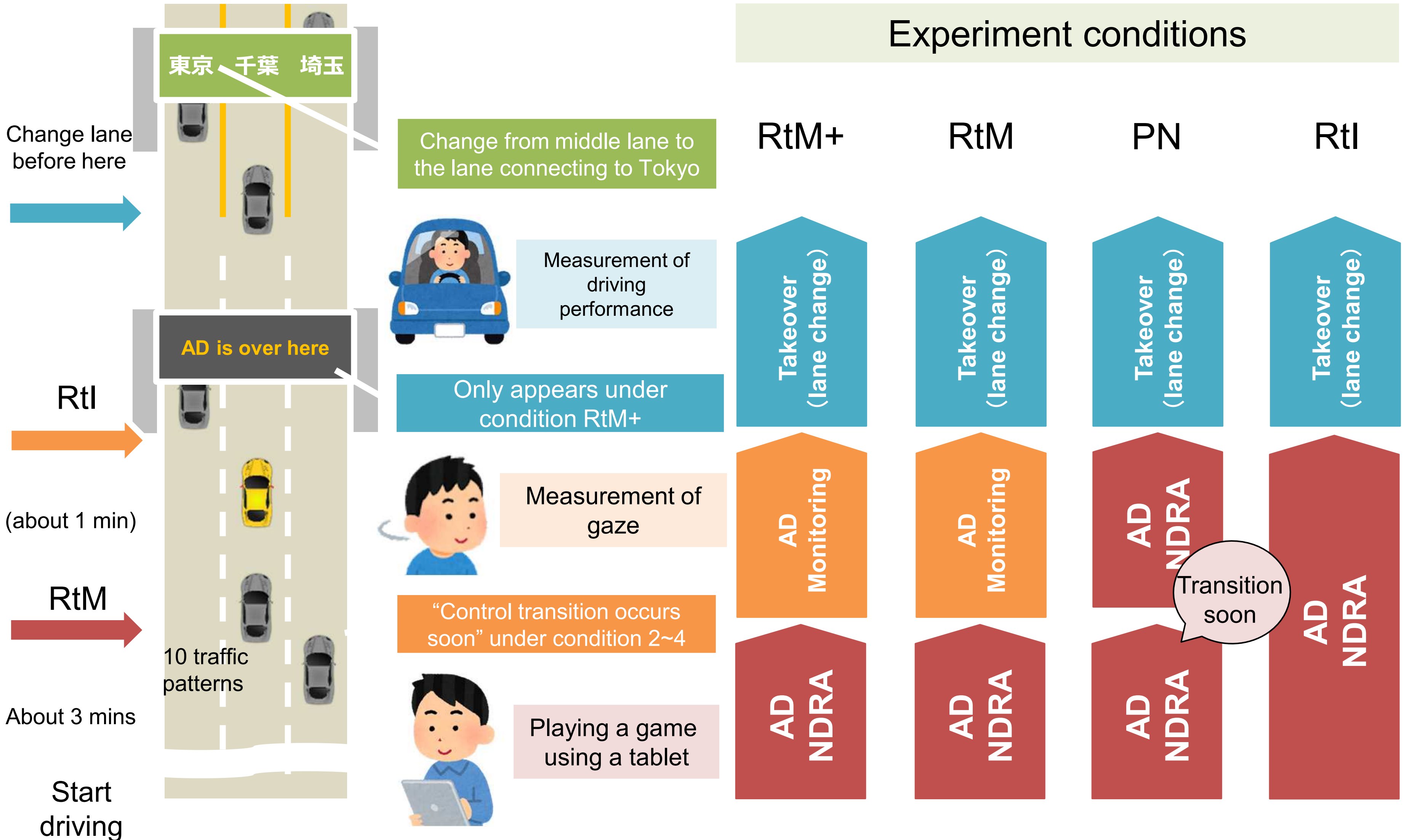
- Study 1
  - Safety after taking over control from automated driving with NDRA
  - Driver state evaluation by gaze behaviors
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
- Study 3
  - Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

Study 1: objective

- Safety after taking over from automated driving with NDRA
  - Assuming the situation of leaving ODD at the exit of the expressway (end of the section where automated driving is possible)
  - Evaluating safety of transition by comparing transfer methods under four conditions
    1. RtI: Takeover when NDRA is being implemented without prior notice
    2. PN: Takeover when NDRA is being implemented with prior notice
    3. RtM: [Stop NDRA] 1 min before RtI & Takeover after [Monitoring the environment]
    4. RtM+: [Stop NDRA] 1 min before RtI & Takeover after [Monitoring the environment] & α (add road infrastructure indicating transition point)

DS experiment scenario (Ten trials with various distribution of traffic)

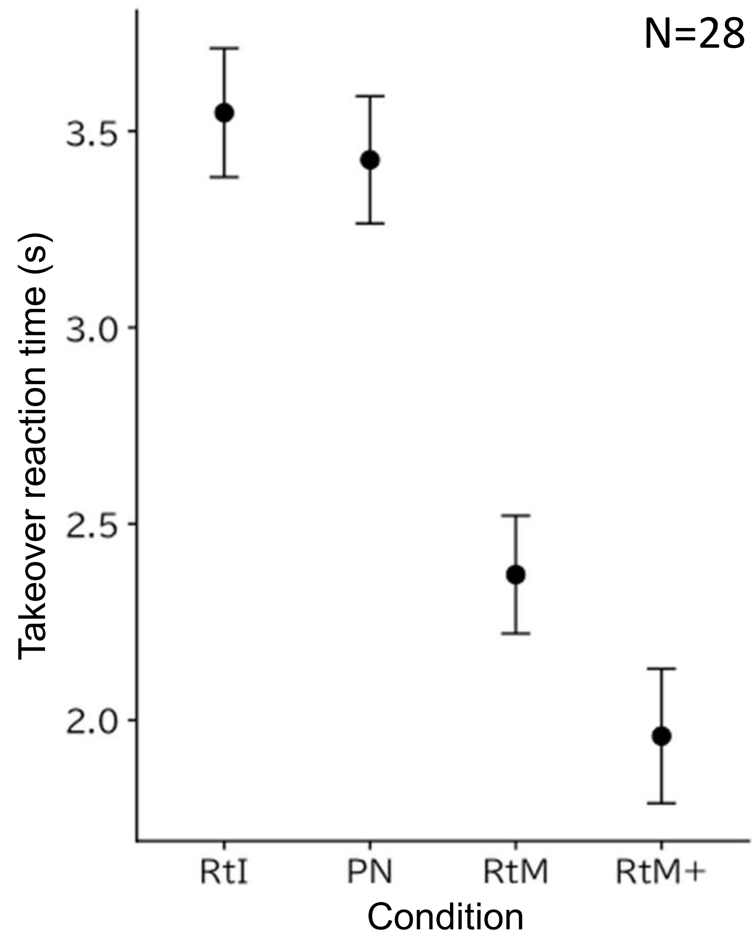
AD on highway → Transition before exit → Connecting to different destination



AD: Automated driving

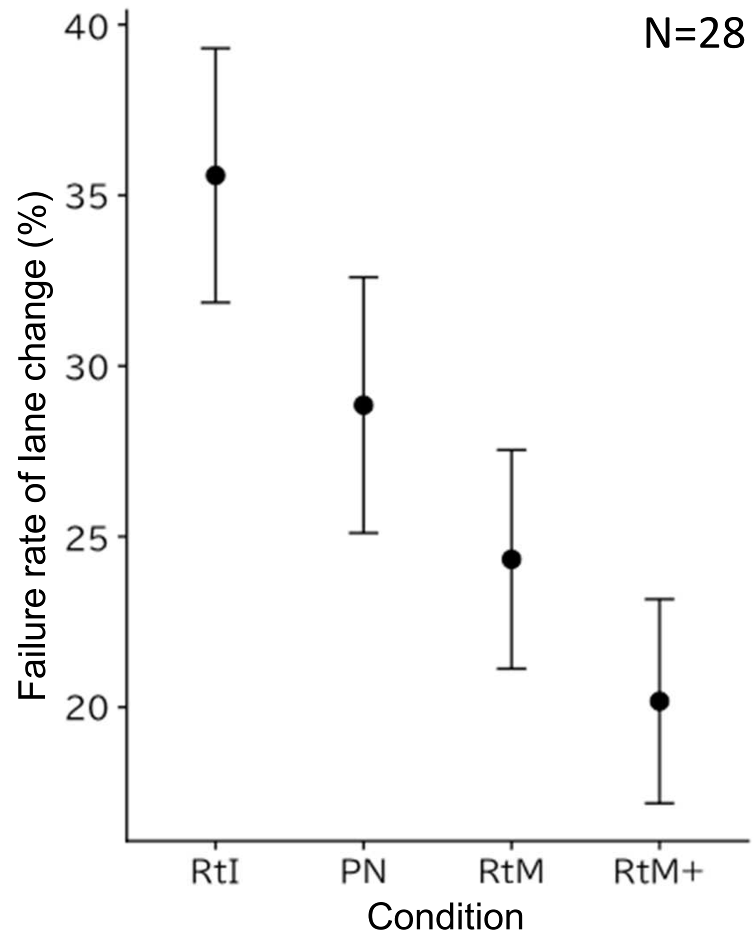
Study 1: results of takeover reaction time

- Takeover reaction time
  - [Stop NDRA]＋[Traffic monitoring] leads to faster reaction
  - Only prenotice (PN) does not affect RT
  - Road sign indicating transition point brings even faster reaction



Study 1: results of lane-change performance

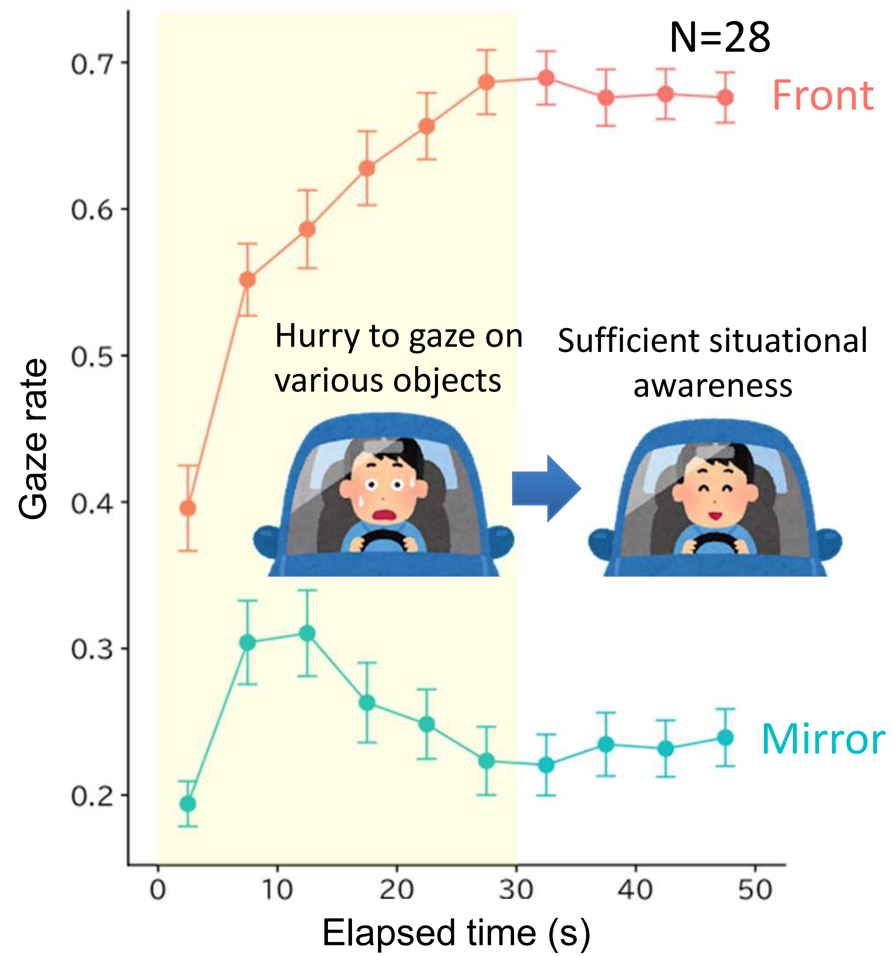
- Failure* rate of lane change
  - [Stop NDRA]＋ [Traffic monitoring] leads to less failure
  - The positive effect of prenotice (PN) is limited



* Crashed or failed to change lane within the lane-change section

Study 1: results of gaze behaviors

- Gaze on front
  - increases gradually after starting monitoring
  - becomes stable after around 30 s
- Gaze on periphery
  - increase to peak within 5 ~15 seconds
  - becomes stable after around 30 s



Study 1: summary

Understanding of principles for HMI development + Proposal of driver state (attentiveness) evaluation method

- Study 1
  - Safety after taking over control from automated driving with NDRA
    → Increased safety with [stop NDRA] + [traffic monitoring] for 1 min before transition
  - Driver state evaluation by gaze behaviors
    → Time-related changes of gaze behaviors after [traffic monitoring] for 20 ~ 30 seconds
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
- Study 3
  - Validation of visual behavior as driver state evaluation metrics by comparison with conventional method

Study 2: objective

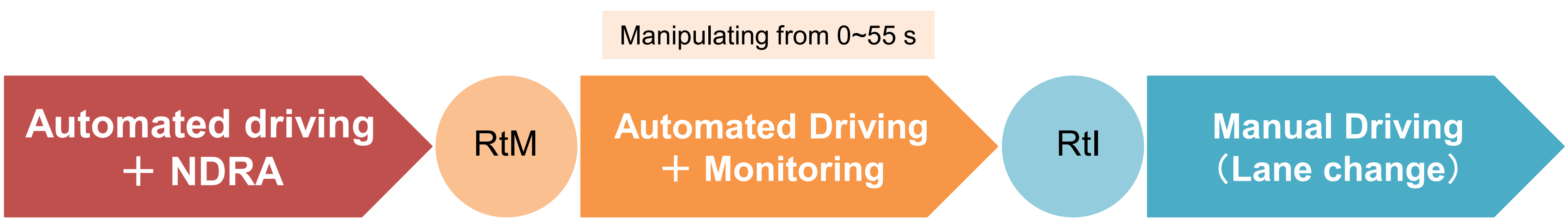
Understanding of principles for HMI development + Proposal of driver state (attentiveness) evaluation method

- Study 1
  - Safety after taking over control from automated driving with NDRA
  - Driver state evaluation by gaze behaviors
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
- Study 3
  - Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

Study 2: objective

Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA

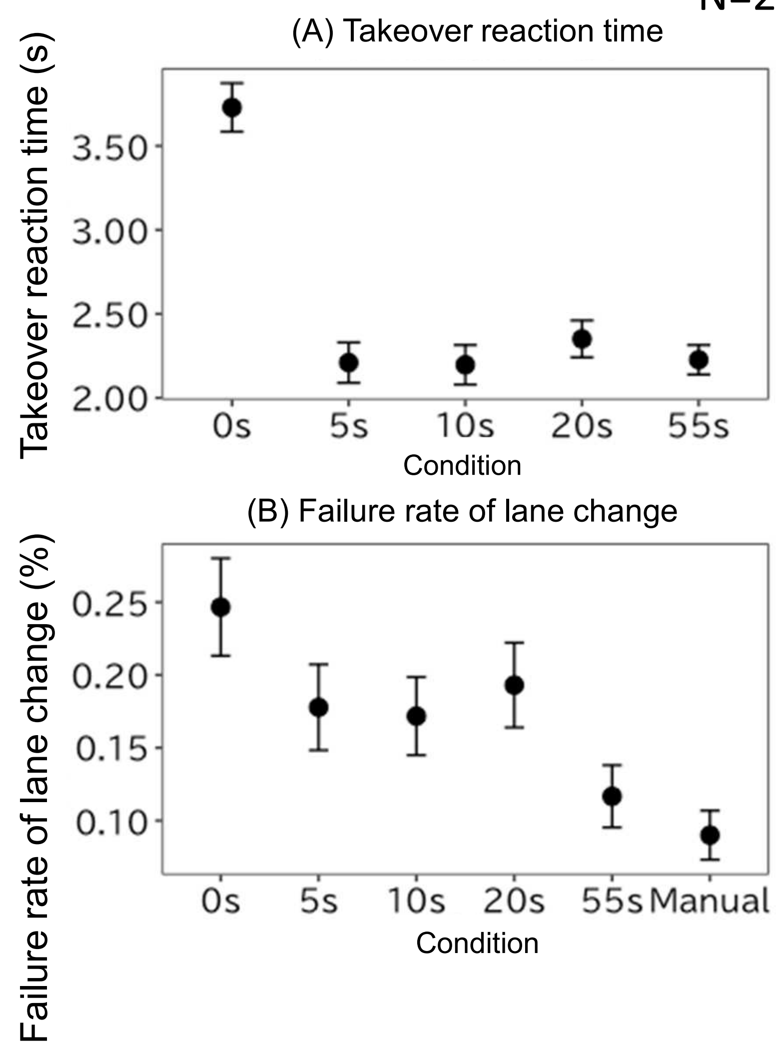
- Study 1 confirmed that safety increased with [stop NDRA] + [traffic monitoring] for 1 min before transition
- When shall [stop NDRA] + [traffic monitoring] be required ?
  - Compare the effect by performing for 0, 5, 10, 15, 20, 55 seconds
  - Compare with a manual-driving-only condition



Study 2: results of takeover performance

- Takeover reaction time
  - No difference among the conditions except the 0s condition
    - Time is needed to stop NDRA ?
- Lane change failure rate
  - Only 55s condition is significantly lower than without monitoring (0s) condition
    - Monitoring for 20s may be insufficient

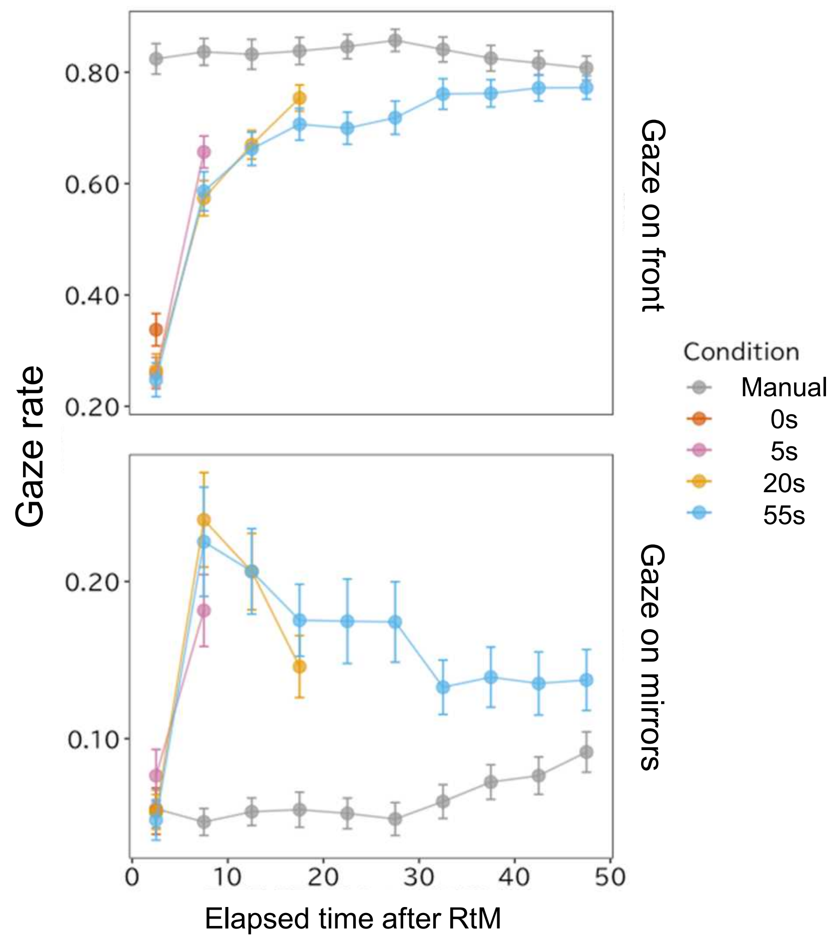
N=29



Study 2: results of gaze behaviors when monitoring the traffic

N=29

- Gaze on front
  - Increases from the beginning of monitoring
  - Becomes stable after 30s
    - Consistent with study 1
- Gaze on mirrors
  - Increases to peak after 5 ~ 15s
  - Becomes stable after 30s
    - Consistent with study 1



Study 2: summary

Understanding of principles for HMI development + Proposal of driver state (attentiveness) evaluation method

- Study 1
  - Safety after taking over control from automated driving with NDRA
  - Driver state evaluation by gaze behaviors
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
    - → [stop NDRA] & [Traffic monitoring] should be required at least 20s before RtI
- Study 3
  - Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

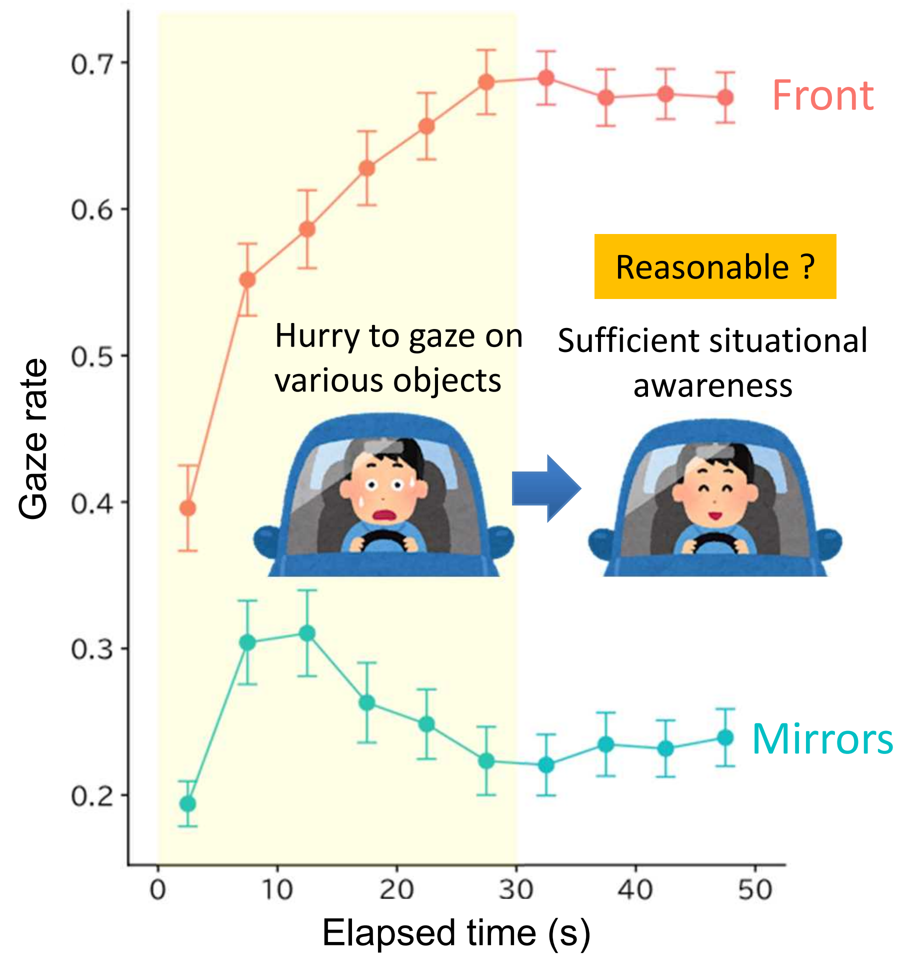
Study 3: objective

**Understanding of principles for HMI development +
Proposal of driver state (attentiveness) evaluation method**

- Study 1
  - Safety after taking over control from automated driving with NDRA
  - Driver state evaluation by gaze behaviors
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
- Study 3
  - Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

Study 3: objective

- Is gaze behavior valid as a metric for estimating driver state?
  - Hasty gaze behaviors immediately after stopping NDRA
  - Stable after 20-30 s
  - Takeover performance after reaching a stable state is good
- How valid is that?
  - Need to consider by comparing with another existing metric



Study 3: objective

Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

- Comparison with think-aloud method that is a typical measure of situation awareness
  - Verbalize and report the concurrent thought
    - Can identify the object of attention at specific time
    - Can be measured without interrupting the task
    - The number of reports can be small because it takes time to make one report
    - Unable to mention those events that occurred during reporting
    - Exploratory behavior occurs when there is nothing particularly noticeable
    - Requesting reports may make visual behavior unnatural

Study 3: method

- 20 Participants: 10 females and 10 males
- Other methods including the scenarios are all the same with the 55s condition of study 1

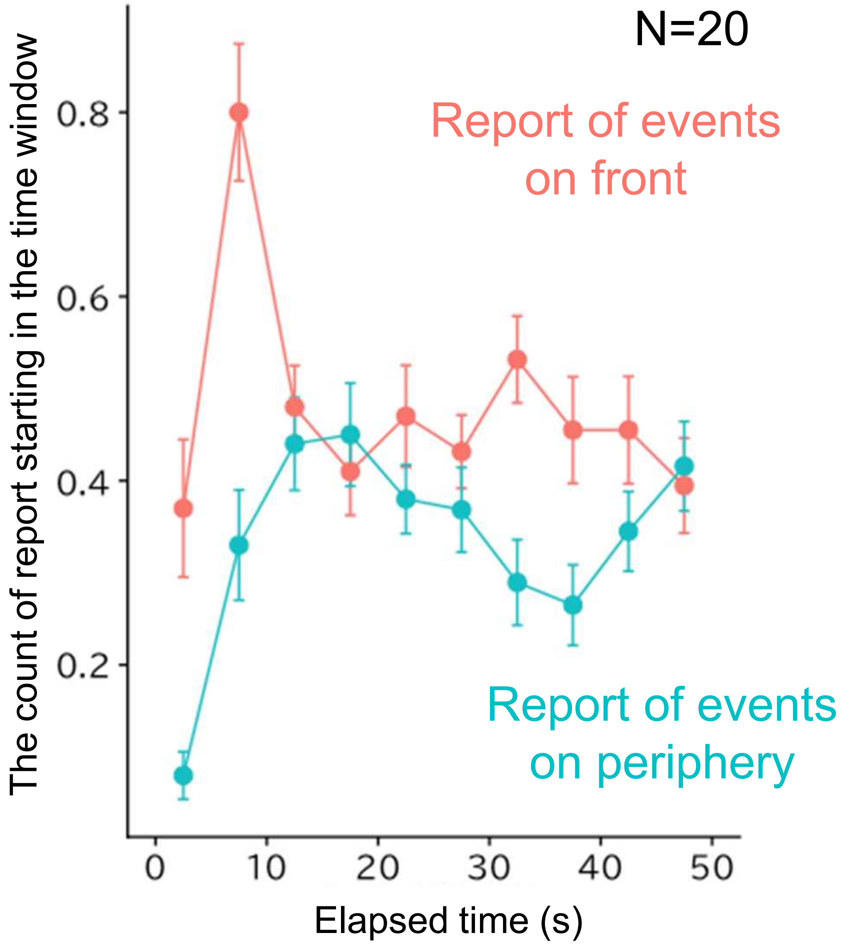
Automated driving ＋ NDRA → RtM → **Automated Driving ＋ Monitoring** → RtI → **Manual Driving（Lane change）**

Verbalize the thoughts during monitoring the traffic
e.g.,「vehicles on the right lane are faster than my car」
「the distance between my car and the lead car is getting smaller」

About 1 min

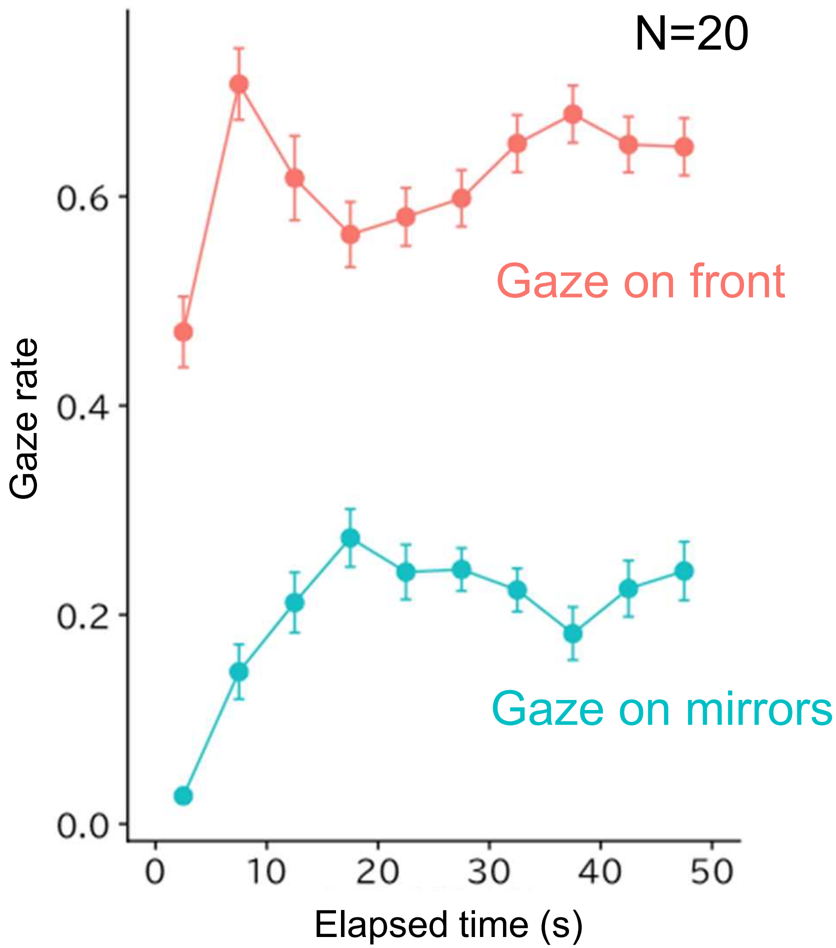
Study 3: results of the reporting frequency

- Events on front
  - Increase to peak for 5~10 s
- Events on periphery
  - Increase to peak for 15~20 s



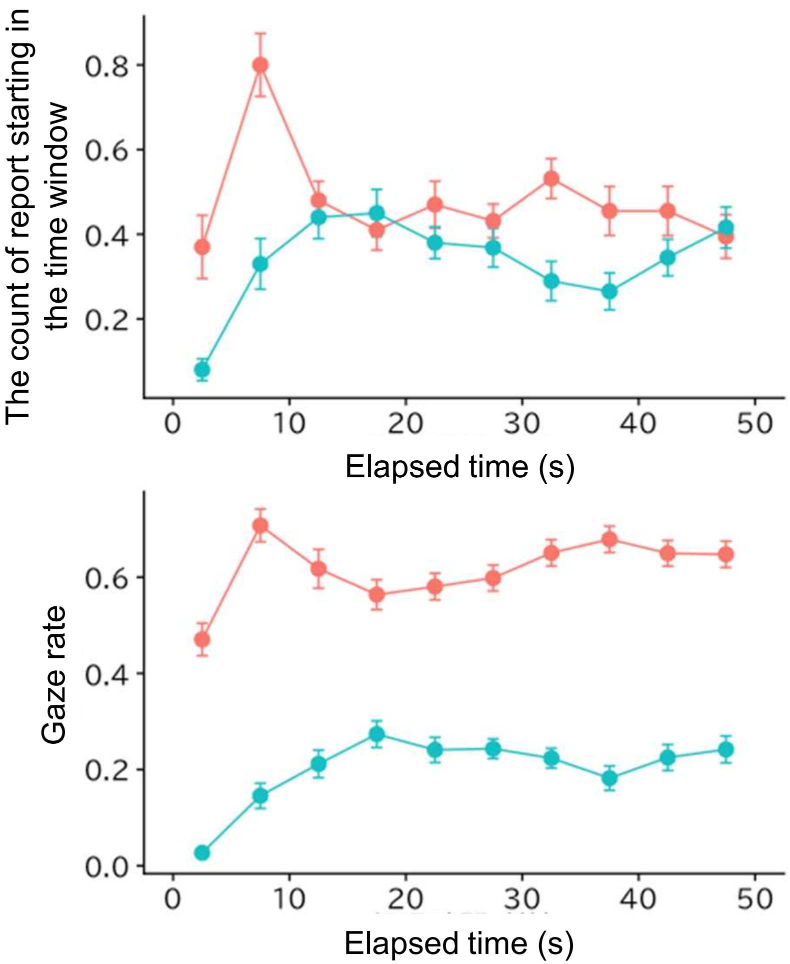
Study 3: results of gaze behavior

- Gaze on front
  - Increase to peak for 5~10 s
- Gaze on periphery
  - Increase to peak for 15~20 s



Study 3：results

- Comparison of conventional method (verbal reporting) and gaze behavior
  - Similar trend
  - The validity of gaze behavior as metrics is confirmed
- Comparison with Study 1 & 2
  - Trend in gaze behavior from the start of monitoring are similar
  - Gaze on front increases faster
    - Possible interference with the verbal reporting



Study 3: summary

Understanding of principles for HMI development + Proposal of driver state (attentiveness) evaluation method

- Study 1
  - Safety after taking over control from automated driving with NDRA
  - Driver state evaluation by gaze behaviors
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
- Study 3
  - Validation of gaze behavior as driver state evaluation metrics by comparison with conventional method

→ Consistency with typical estimation measures of situation awareness

Summary

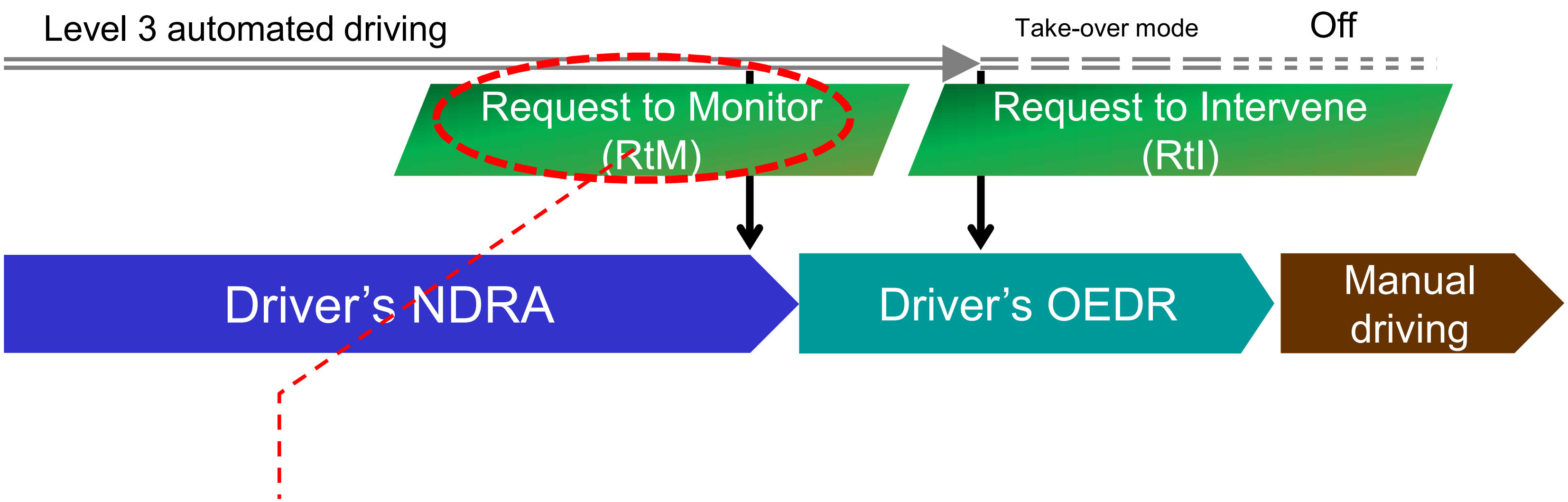
Understanding of principles for HMI development + Proposal of driver state (attentiveness) evaluation method

- Study 1
  - Safety after taking over control from automated driving with NDRA
    - → Increased safety with [stop NDRA] + [traffic monitoring] for 1 min before transition
  - Driver state evaluation by gaze behaviors
    - → Time-related changes of gaze behaviors after [traffic monitoring] for 20 ~ 30 seconds
- Study 2
  - Examination of necessary conditions for methods to improve safety after taking over from automated driving with NDRA
    - → [stop NDRA] & [Traffic monitoring] should be required at least 20s before RtI
- Study 3
  - Validation of visual behavior as driver state evaluation metrics by comparison with conventional method
    - → Consistency with typical estimation measures of situation awareness

System-initiated transitions from automated to manual driving

HMI principles of RtM to promote driver's attentiveness

RtM: Request to Monitor



Previous findings:
an OEDR phase shortly before an RtI improved driver's performance
(Success rate of lane change was higher with an OEDR)

Research questions:
How the drivers would response to a request to monitor and whether they would monitor the environment constantly
(Will their performance be affected by their monitoring behaviors)

MRM: Minimum Risk Maneuver

HMI principles of RtM to promote driver's attentiveness

Experiment design

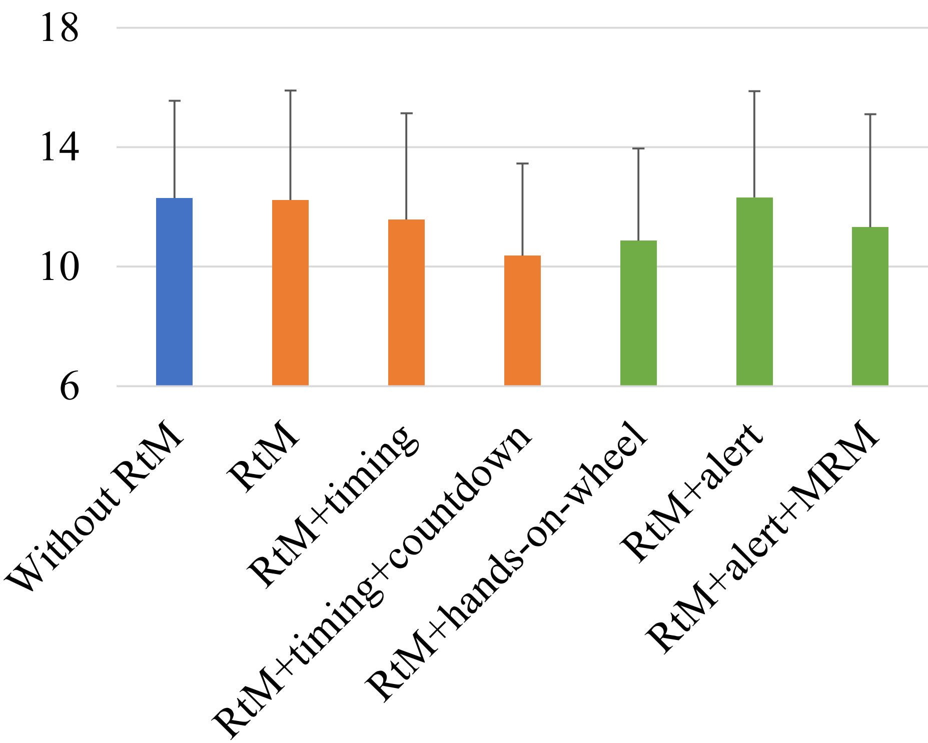
Condition 1	• RtM = 'the automation will turn off soon, please monitor the environment'
Condition 2	• RtM = 'the automation will turn off after 60 seconds, please monitor the environment'
Condition 3	• RtM = 'the automation will turn off after 60 seconds, please monitor the environment' + '30 seconds alert' + '5,4,3,2,1'
Condition 4	• RtM + hands-on-wheel
Condition 5	• RtM + real-time alert (buzzer when not monitoring)
Condition 6	• RtM + real-time alert + potential MRM implementation

- Instructions to participants
  - Drive in your daily manner. You can continue NDRA after RtM if you consider it is safe
  - You would win additional compensation (Money) if you achieved higher score of NDRA
- Experiment scale
  - Participants: 120 (between subject design, 20 *6 conditions)
  - 20～64 yeas-old, male: female = 1:1

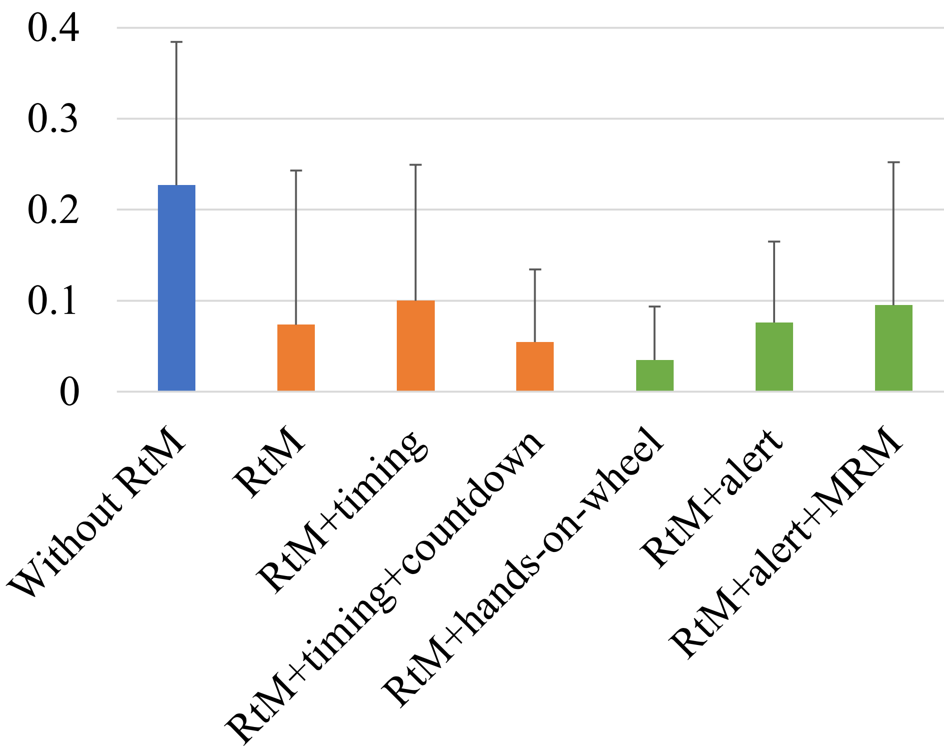
Results

Condition 1 RtM = 'the automation will turn off soon, please monitor the environment'
Condition 2 RtM = 'the automation will turn off after 60 seconds, please monitor the environment'
Condition 3 RtM = 'the automation will turn off after 60 seconds, please monitor the environment' + '30 seconds alert' + '5,4,3,2,1'
Condition 4 RtM + hands-on-wheel
Condition 5 RtM + real-time alert (buzzer when not monitoring)
Condition 6 RtM + real-time alert + potential MRM implementation

Time to complete lane change (s)



Crash rate (%)



- With RtM (OEDR phase), the crash rate was significant lower
- RtM + timing + countdown brought lower crash rate and faster lane change
- Hands-on-wheel brought lowest crash rate
- Neither buzzer nor MRM led to better lane change performance

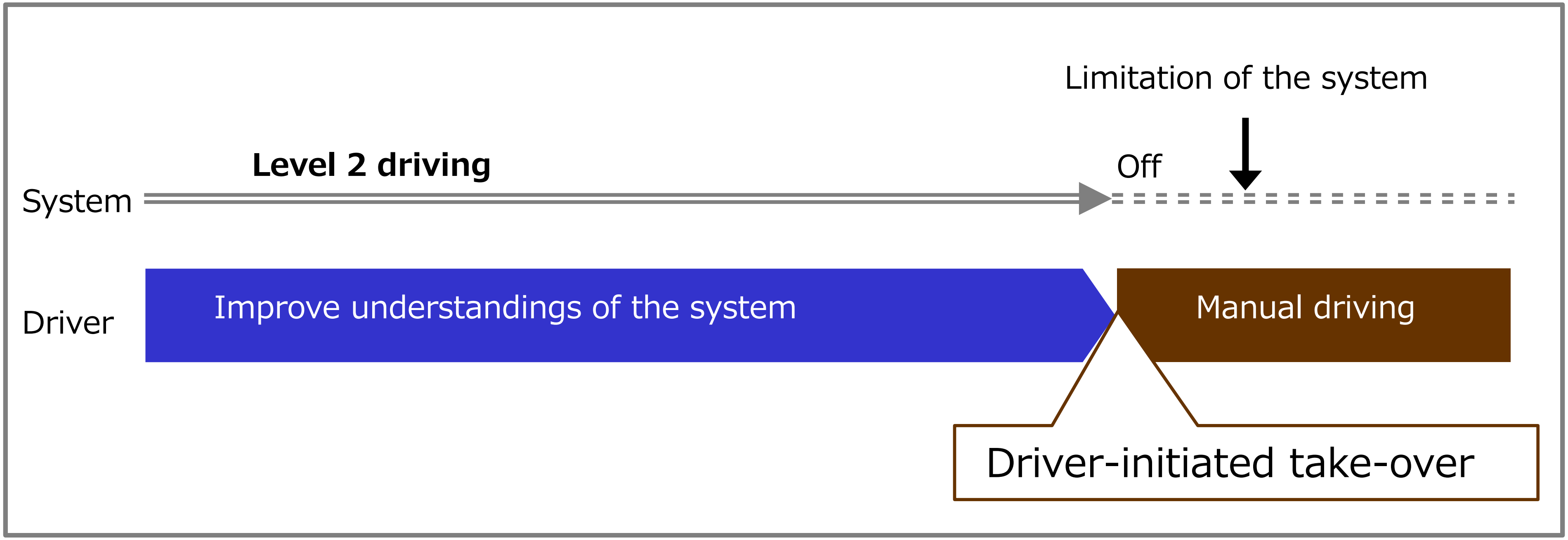
Summary

The positive effect of an RtM was re-confirmed	• More successful lane changes and less crashes
The information of RtM matters	• Accurate timing together with a countdown led to better performance
HMIs promoting monitoring behavior	• Hands-on-wheel brought highest success rate of lane change • Real-time alert and MRM did not affect driver's performance

Driver-initiated Take-over from Automated to Manual Driving

The University of Tokyo

Human factor issues from automated driving to driver-initiated take-over



- Evaluation methods for drivers' understandings of the system, and HMI requirements to enable appropriate system understanding and response

- Level 2 driving on general roads

Research of Human Machine Interface for Driver-initiated Take-over

Driver-initiated transition from automated driving to manual driving mainly occurs in level 2 driving. To expand the level 2 driving, which is currently limited to expressways, to general roads with many hazards, it is necessary to show that drivers can respond appropriately based on an appropriate understanding of the system and achieve a quicker reaction.

To enable the safe application of level 2 driving on general roads, especially near signalized intersections, human machine interfaces (HMIs) were proposed to improve drivers' attention levels and responses to risks. Driving simulator experiments were performed to investigate the influences of the proposed HMIs on driver behaviors.

Initiatives at the University of Tokyo

Experiment 1: Evaluation methods for drivers' understandings of the system
A driving simulator experiment was performed to identify the difference in driving behavior between level 2 driving and manual driving.

Experiment 2: HMI to prompt system understanding
An HMI was proposed to present real time results of image recognition by the systems to drivers, and its effectiveness was evaluated with a driving simulator experiment.

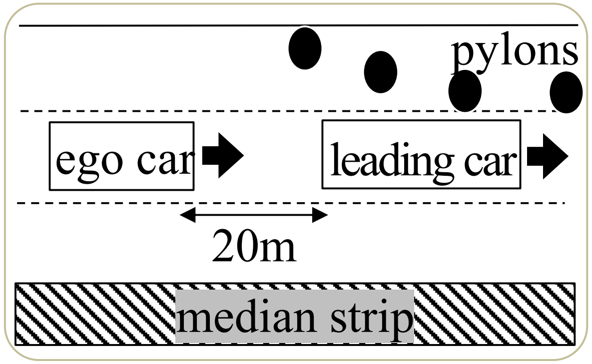
Experiment 3: HMI requirements to enable appropriate system understanding and response for moving straight ahead at intersections
Principles of HMI requirements for driving straight through intersections with level 2 system, assuming current level 2 functionality (no traffic signal recognition included)

Experiment 4: HMI requirements to enable appropriate system understanding and response for right and left turns at intersections (Year of 2022)
Principles of HMI requirements for turning right and left at intersections with level 2 system, assuming current level 2 functionality (no traffic signal recognition included)

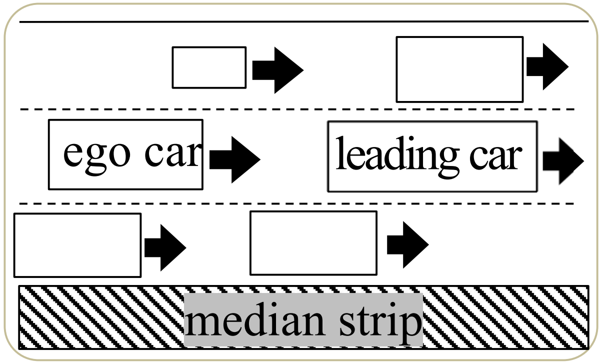
Experiment 1:

Objective: establish a measurement method to evaluate driver's system understanding status.
Method: compare driving behaviors, including eye-gaze behaviors, during level 2 automated driving and manual driving.

In the experimental scenario, three potential risk scenes that require attention to the surroundings occurred multiple times.



①Pylon for lane regulation



②Overtaken by multiple motorcycles

③Fog

Surrogate Reference Task (SuRT)

	Operation	SuRT
1	Manual	Without
2	Level 2	Without
3	Manual	With
4	Level 2	With

Findings:

Gaze time and p-value of t-test

(1) Without SuRT

	Manual(s)	Level 2(s)	p value
Front	659	528	0.0010
Right	15.3	23.8	0.21
Left	16.6	49.2	0.017
Speedometer	41.8	14.8	0.039
Right mirror	13.5	20.6	0.068
Left mirror	3.56	5.60	0.081

* Significance level: 5%

(2) With SuRT

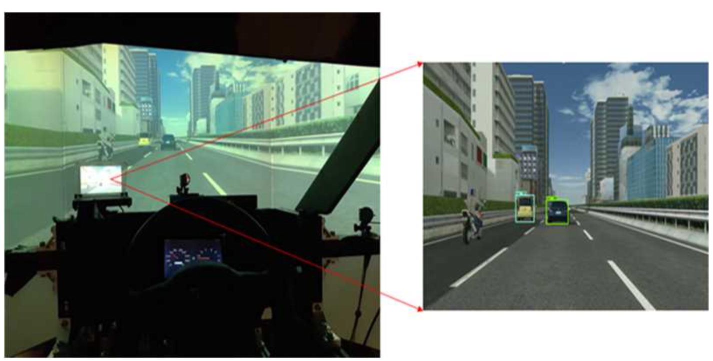
	Manual(s)	Level 2(s)	p value
Front	541	316	0.0035
Right	7.38	12.1	0.063
Left	10.7	18.4	0.10
Speedometer	29.9	11.7	0.046
Right mirror	15.1	28.7	0.0043
Left mirror	2.19	3.65	0.20
SuRT	92.8	224	0.0062

Significant differences in gaze time were observed in multiple areas. It was found that gaze time to the front and the speedometer were significant shorter during level 2 driving than during manual driving, for both without and with SuRT conditions. For other areas, there was a tendency that the gaze time became longer when level 2 driving was used.

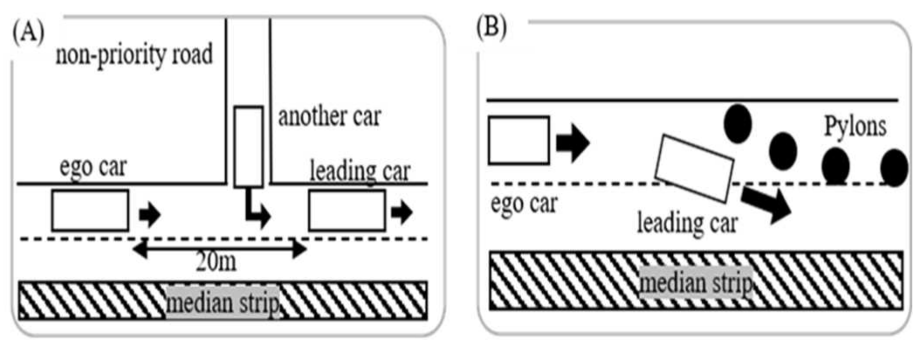
Experiment 2

Objective: Propose a new HMI to promote proper understandings of level 2 automated driving systems and to enable safe operation of level 2 automated driving even in complex traffic environments.
Method: Propose an HMI that directly presents the real-time recognition result of the traffic situation ahead by the system to drivers and evaluate its effectiveness with a driving simulator experiment.

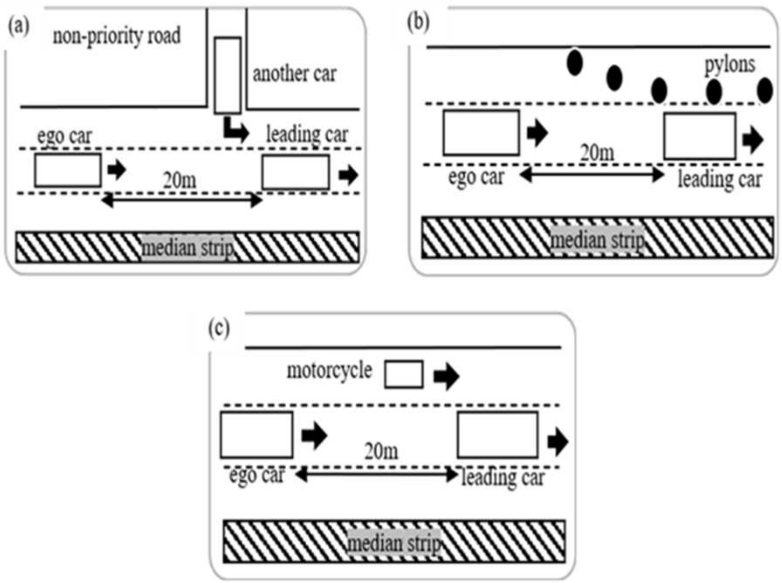
Two types of actual risk scenes (collision will occur without driver intervention) and three types of potential risk scenes (no accidents will occur) are prepared, and two types of scenarios (i) and (ii) that combine them were used.



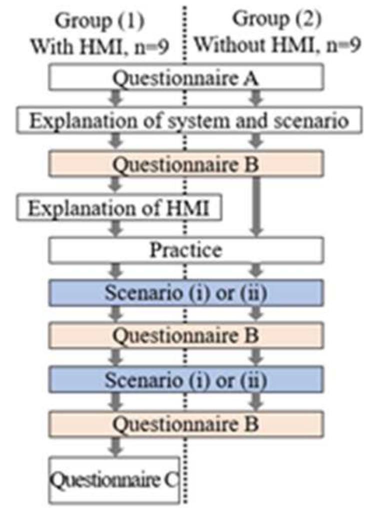
Proposed HMI



Actual risk scenes

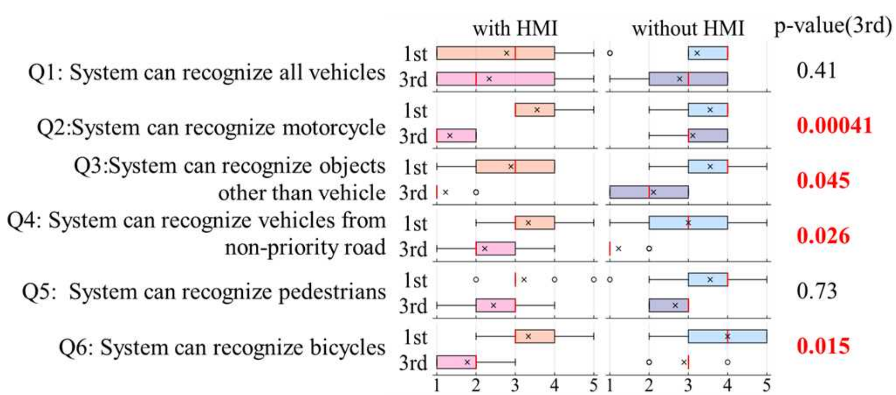


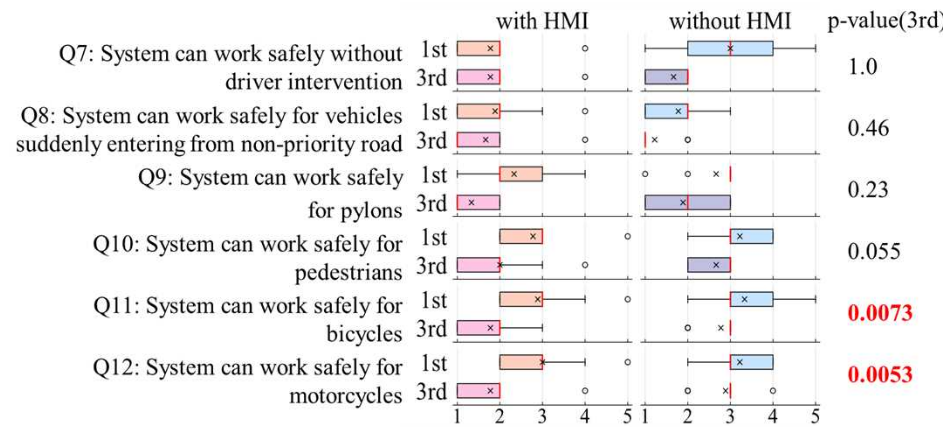
Potential risk scenes



Experimental procedure

The experiment was conducted for 18 participants with the approval of Ethics Review Board, the University of Tokyo.





For the questionnaire, 1 means "Do not agree at all" and 5 means "Completely agree". X and ○ indicate average values and outliers, respectively.

Questionnaire results indicated that an improvement in system understanding could be achieved by presenting information with the proposed HMI.

Experiment 3

We will investigate the method for evaluating understanding of the system and the HMI requirements for level 2 driving on general road assuming driving with the current level 2 functionality (no traffic signal recognition included).

Risk factors at signalized intersections: (1) collisions with other vehicles, (2) the changes of traffic lights

Experiment 3-1
Investigation of HMI requirements for preventing accidents with other vehicles at intersections during level 2 driving on general roads

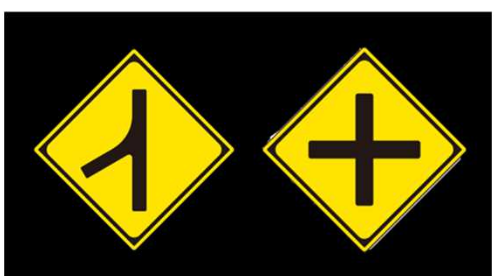
Experiment 3-2
Investigation of HMI requirements for traffic signal changes at intersections during level 2 driving on general roads

Experiment 3-1

The purpose of this experiment is to investigate the requirements of HMI to prevent vehicle-to-vehicle accidents near signalized intersections by appropriate driver-initiated takeovers while applying level 2 driving.

Two kinds of HMIs were applied, of which one is the static HMI to notify the approach to intersections and confluences based on static map information , and the other is sensor HMI which presents real time results of image recognition by the level 2 system.

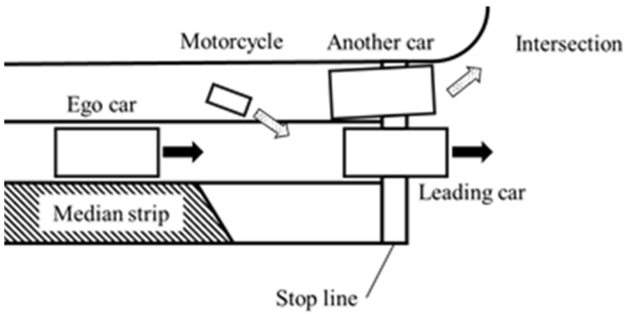
Static HMI



Presented by HUD

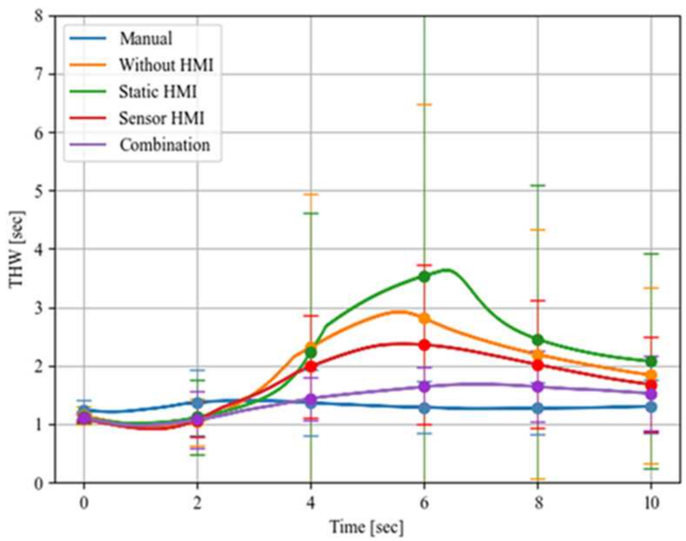
Sensor HMI

During the experiment, the ego vehicle follows the preceding vehicle in the second lane at 60 km/h. A motorcycle in the first lane suddenly interrupts in front of the ego vehicle near the signalized intersection, and a collision will occur if the drivers do not take over.



Risk scene near the signalized intersection

Driving simulator experiment was conducted with 15 participants under 5 conditions (manual operation, level 2 + without HMI, level 2 + static HMI, level 2 + sensor HMI, level 2 + combination of static HMI and sensor HMI).



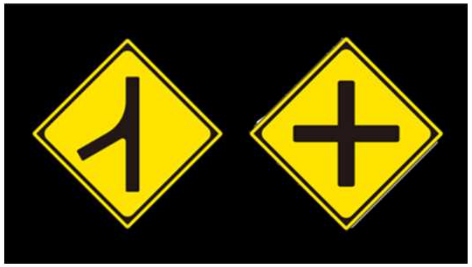
The results show that under the HMI combination condition (static HMI + sensor HMI), the time headway (THW) was maintained relatively close to the reaction in manual operation.

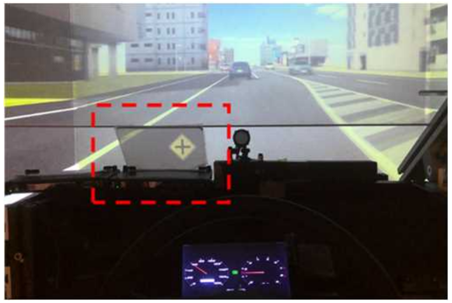
Experiment 3-2

When traffic signal recognition is not included in the level 2 driving, drivers need to take over and stop the vehicle by themselves if the signal turns red when the vehicle is approaching a signalized intersection while following the preceding vehicle with ACC.

Two kinds of HMIs were proposed, of which static HMI is to notify the approach to intersections and confluences based on static map information and dynamic HMI is to present information of traffic signal and lane regulation based on dynamic information from the infrastructure. The presented traffic signal information is the predicted color of the traffic signal when the ego vehicle reaches the signalized intersection.

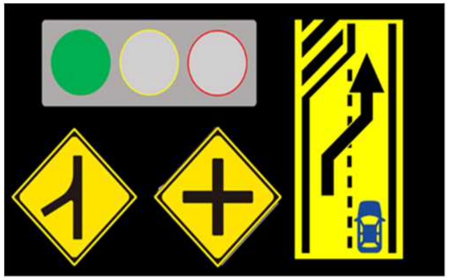
Static HMI



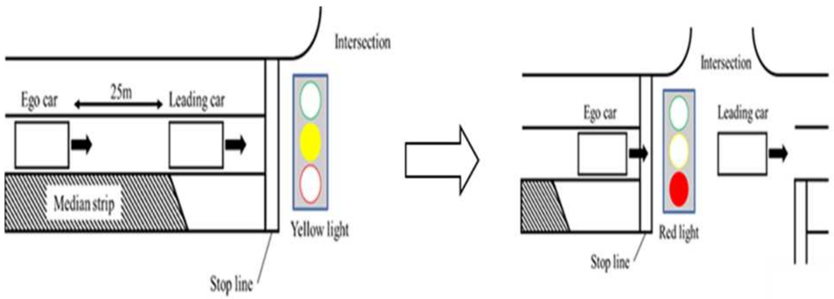


Presented by HUD

Dynamic HMI



During the experiment, the signal turns yellow when the ego and the preceding vehicles approach the signalized intersection where the actual risk occurs. The preceding vehicle passes through the intersection without stopping, while the ego vehicle will confront a red signal if drivers do not take over.



Intersection where the actual risk occurs

Driving simulator experiment was conducted with 16 participants under four conditions (manual operation, level 2 + without HMI, level 2 + static HMI, level 2 + dynamic HMI).

	Stop before the stop line	Parts of the vehicle cross the stop line	Stop inside intersection	Traffic light ignorance
Manual	16	0	0	0
Level 2 + without HMI	7	3	1	3
Level 2 + static HMI	10	4	0	1
Level 2 + dynamic HMI	10	1	2	0

No traffic light ignorance occurred with dynamic HMI.
The number of times that a driver could stop before the stop line increased with dynamic HMI compared to that without HMI.

Summary of results to date

Experiment 1: Evaluation methods for drivers' understandings of the system
Eye gaze measurement is effective in assessing the drivers' attention level.

Experiment 2: HMI to prompt system understanding
Presentation of object recognition results based on sensor information is effective in improving knowledge of system functional limitations.

Experiment 3: HMI requirements to enable appropriate system understanding and response for moving straight ahead at intersections
(1) Combining a sensor HMI that presents object recognition results with a static HMI that notifies the approach to intersections is effective in preventing vehicle-to-vehicle accidents at intersections.
(2) Presenting information about the predicted traffic signal with a dynamic HMI is effective for the safe passage at intersections when the traffic signal changes.

Existing problem: HMI requirements to enable appropriate system understanding and response for right and left turns at intersections are still unclear.

Experiment 4 (Year of 2022)

The experiments were performed to investigate the principles of HMI requirements for turning right and left at intersections with level 2 system, assuming current level 2 functionality (no traffic signal recognition included).

Experiment 4-1
Investigation of HMI requirements for preventing accidents with other vehicles when turning right at intersections

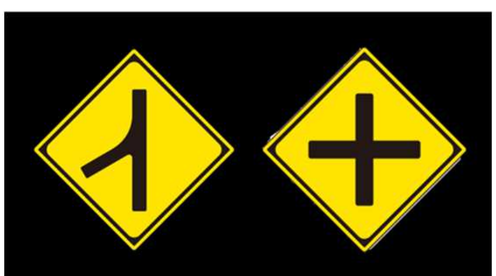
Experiment 4-2
Investigation of HMI requirements during traffic signal change when turning left at intersections

Experiment 4-1

The purpose of this experiment is to investigate the requirements of HMI to prevent vehicle-to-vehicle accidents at intersections by appropriate driver-initiated takeovers while applying level 2 driving.

Two kinds of HMIs were applied, of which one is the static HMI to notify the approach to intersections and confluences based on static map information , and the other is sensor HMI which presents real time results of image recognition by the level 2 system.

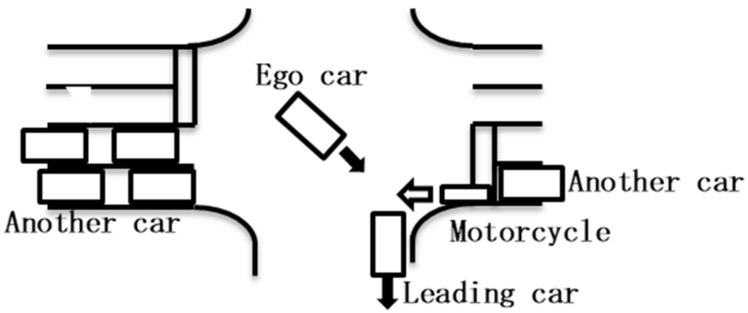
Static HMI



Presented by HUD

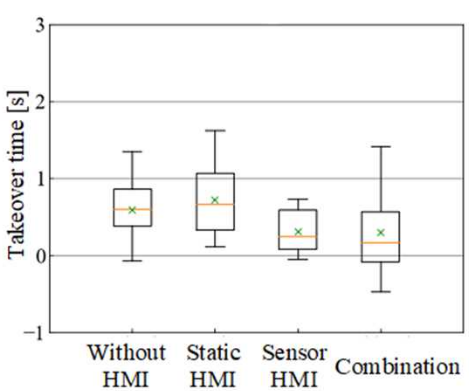
Sensor HMI

Driving simulator experiment was conducted with 15 participants under 5 conditions (manual operation, level 2 + without HMI, level 2 + static HMI, level 2 + sensor HMI, level 2 + combination of static HMI and sensor HMI).



At the intersection where the risk occurred, a motorcycle appeared from the blind spot of a stopped oncoming vehicle when the ego vehicle was turning right at intersections. If the participants did not takeover in time, the ego vehicle would collide with the motorcycle.

Takeover time during the risk scene



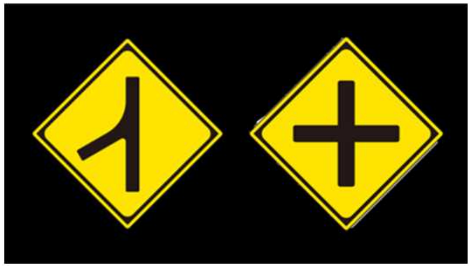
Results showed that the takeover time tended to be shorter in the condition when the sensor HMI and static HMI was combined . It was considered that drivers recognized that the motorcycle was out of the recognition range of the system by observing the presented object recognition results.

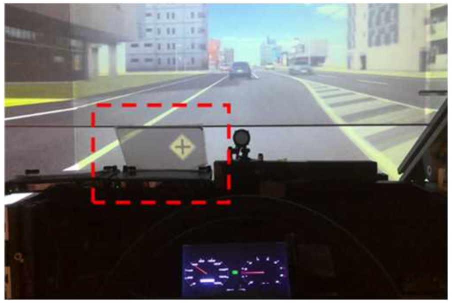
Experiment 4-2

When traffic signal recognition is not included in the level 2 driving, drivers need to take over and stop the vehicle by themselves if the signal turns red when the vehicle is approaching an intersection while following the preceding vehicle with ACC.

Two kinds of HMIs were proposed, of which static HMI is to notify the approach to intersections and confluences based on static map information and dynamic HMI is to present information of traffic signal and lane regulation based on dynamic information from the infrastructure. The presented traffic signal information is the predicted color of the oncoming signal when the ego vehicle reaches the intersection.

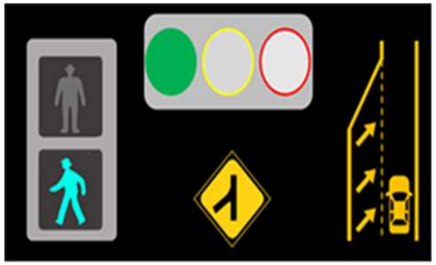
Static HMI



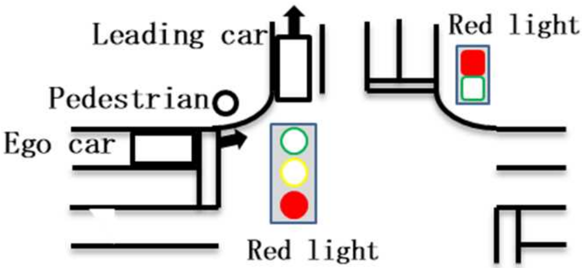


Presented by HUD

Dynamic HMI

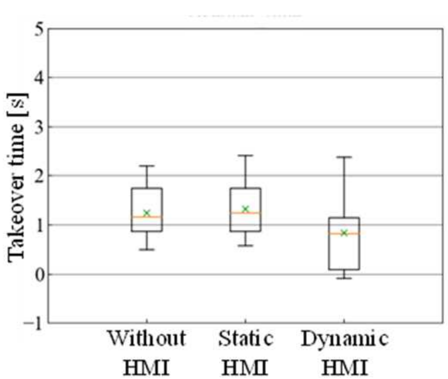


Driving simulator experiment was conducted with 16 participants under four conditions (manual operation, level 2 + without HMI, level 2 + static HMI, level 2 + dynamic HMI).



At the intersection where the risk occurred, the preceding vehicle turned left when the traffic signal for vehicles was yellow, while the signal would change to red when the ego vehicle turned left. The ego vehicle would ignore the red signal if the drivers did not takeover.

Takeover time during the risk scene



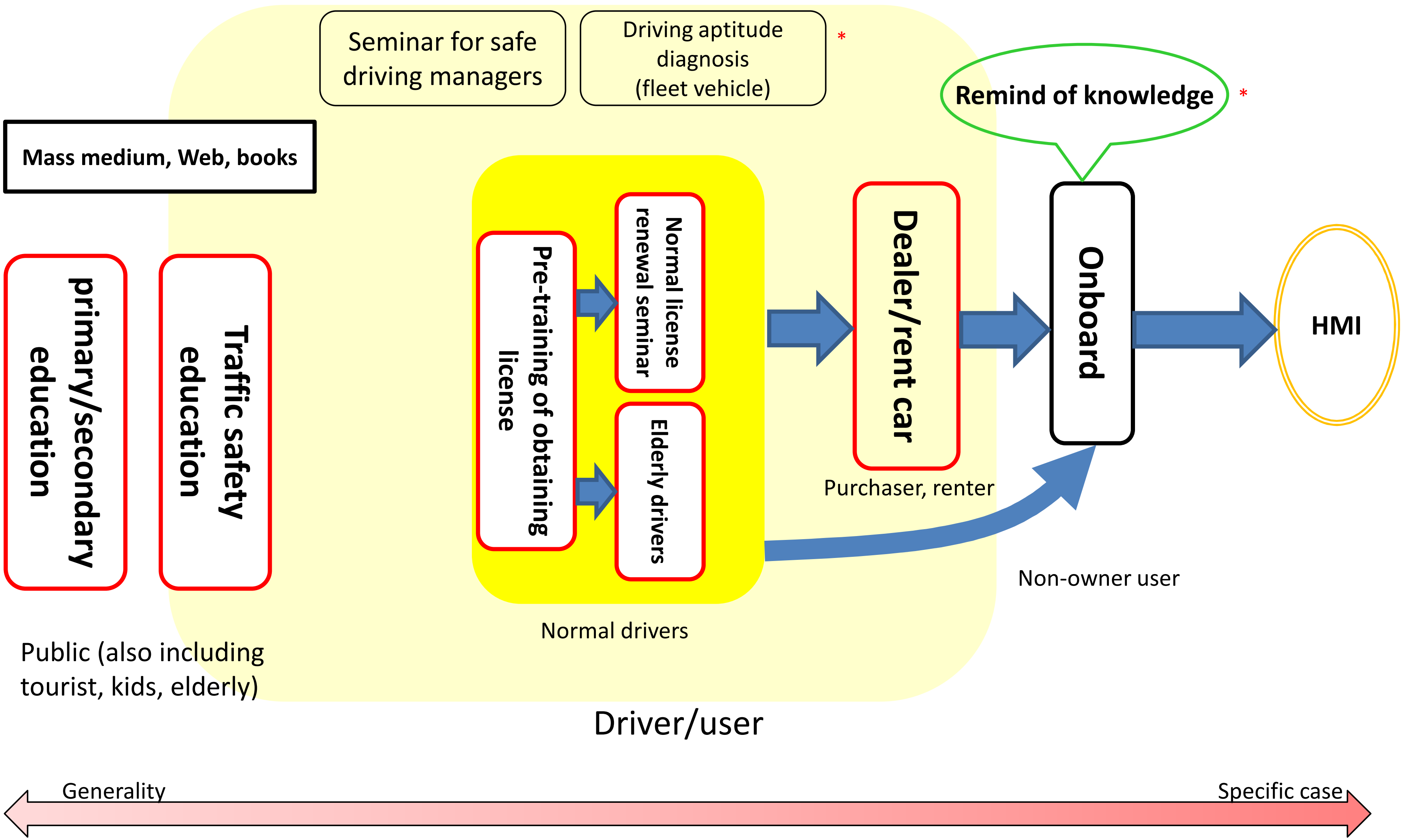
The takeover time tended to be shorter when dynamic HMI was used after risk occurrence. Meanwhile, no traffic light ignorance occurred with dynamic HMI and the number of times that a driver could stop in front of the stop line increased when dynamic HMI was used, compared to that when no HMI was used.

Task C

Education and Training for Users

University of Tsukuba

Framework of education/training & transferring knowledge about driving automation's usage and interaction



* That were pointed out at 20190918 system-application WG meeting

Concrete topics

1. Development of motivating method

- Opening video（for arousing user willingness to learn via a short video)
- Informal learning via group training
    - → It is still useful for promoting attitude of safely driving except for obligatory lectures

2. Education/training approach on a case-by-case

- i. General knowledge about driving automation
    - Is it necessary to educate general knowledge?
    - Is it possible to realize its education with limited time?
    - Effort on fixing user comprehension

- ii. Specific system's knowledge
    - Utilization of E-learning（learning-based training of experiencing intervention）

3. Coping with learners' diversity

- Adaptive learning of utilizing condensed version of learning style and career resilience

→ Individual differences have to be absorbed with limited time and resource

- On the other hand, approaches are also possible utilize the individual difference in terms of educational opportunities.

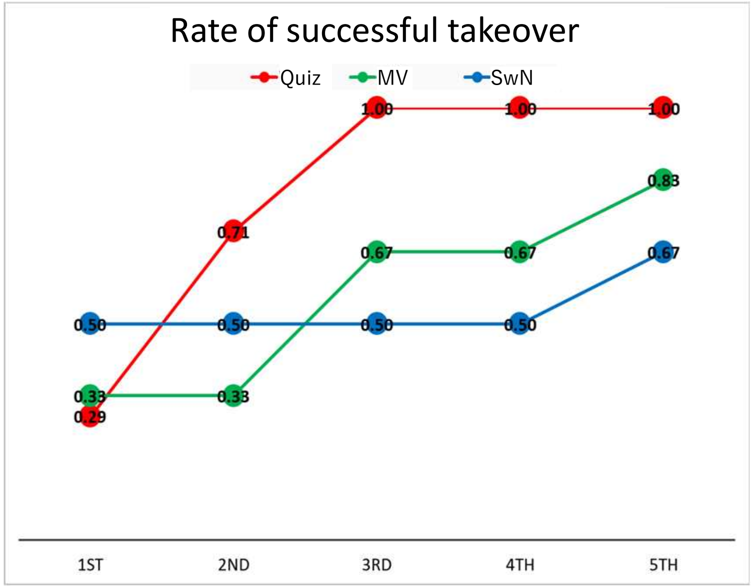
1. Development of opening video for motivation

(1) Video training material

- Opening video (OP)(story series, event series)
  - ARCS model: A (attention), R (Relevance)
    - OP1 story series：to imagine family driver
    - OP2 event series：for people who are good at learning from facts
  - Expert review, implement of formative assessment

(2) Web survey

- Independent variables
  - Opening video（story, event, none）
  - Training material format (text, quiz, slideshow with narration)
- Participants：total 1800 people
- Results：
  - Opening video might enhance understanding
  - Story series might be more effective for aged people and female



(3) DS-experiment verification

- Independent variables
  - Training material

  motivated video (MV) / quiz / slideshow with narration (SwN)
- Participants：16 people for each group (total 48)
- Results
  - Watching MV is helpful to improve motivation to learn, and makes participants to observe and learn events by themselves.
  - Via DS experiment one month later, driving performance is obtained under conditions of MV as same as SwN.

Conclusion：Developed motivated video is effective to improve user's motivation to learn.

（Developed training material is opened at SIP-adus: https://www.sip-adus.go.jp/showcase/d3.html）

1. Approach of developing motivated video: informal learning via group training
Training for aiming to achieve safe attitude on multi-level driving automation (1/2)

Learning objectives:

(1) that would explain driving automation's schema, such as levels, mechanism, driver role

(2) That would describe own opinion about necessary attitude to safe usage under traffic environment including different level automated vehicles.

Opening	Self-introduction of group members/sharing experience about traffic safety
[exp.] what is coexisting social of different level driving automation?	Know automated driving cars! (2-min opening video serial, 5-min driving automation's video material) Schema of driving automation, what is to use co-existing traffic with different level automated driving cars? (2-min outward communication video)
Discussion1: as a traffic user (pedestrian)	In order to use co-existing traffic with different level automated driving cars, arrange knowledge, emotion, and action as a traffic user
[exp.] Confirm D1's outcome	Confirm Miro's activities
[exp.] Mixture of different level automated driving cars	Confirm Miro's activities. Think about driver's safe attitude (2-min opening video serial)
Discussion2: as a driver	In order to use co-existing traffic with different level automated driving cars, arrange knowledge, emotion, and action as a traffic user
[exp.] Confirm other group's Miro result	Review own's output by referring others. Try to think of what kind of contribution to safe/relief/smooth traffic you can do.
[exp.] Confirm D2's outcome	Confirm Miro's activities
[exp.] Example of safety driving scale & conclusion	Lee see examples of safe driving's scale from viewpoint of items, safe attitude!

1. Approach of developing motivated video
Training for aiming to achieve safe attitude on multi-level driving automation (2/2)

Training method: 20 colleague students, synchronous online training

Effort for improving universal use:
- distinction of instructor and designer
- **Application of developed training material** (Modulized training material)

Result ・Conformation on improvement of knowledge and medication of safety attitude

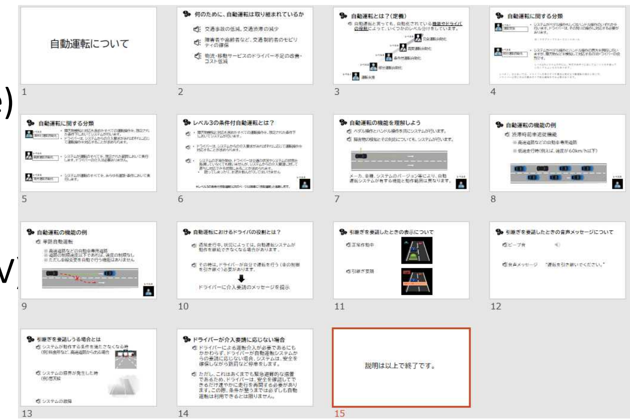
Paired Item (Post - Pre)	Paired Differences					t	df	Sig. (2-tailed)
	Mean	S.D.	Std. Error Mean	95% C.I.				
				Lower	Upper			
Post- Pre test total score	2.294	2.519	0.611	0.999	3.589	3.755	16	0.002
pst1. - pre1. I am preserving safety rule and decided procedure.	-0.059	0.243	0.059	-0.184	0.066	-1	16	0.332
pst2. - pre2. I would not preserve safety rule and decided procedure when I believe OKEY.	0.118	0.993	0.241	-0.393	0.628	0.489	16	0.632
pst3. - pre3. I am checking cautionary notes on safety rule and decided procedure before taking any action.	0.294	0.686	0.166	-0.059	0.647	1.768	16	0.096
pst4. - pre4. I am reflecting past-accidents or troubles before taking any action	0.529	0.8	0.194	0.118	0.941	2.729	16	0.015

2. Education/training approach on a case-by case

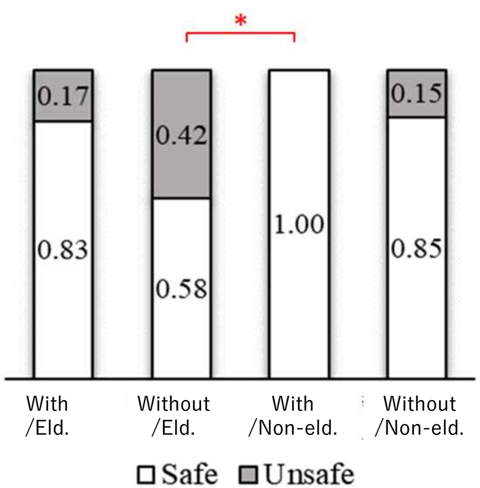
i. General knowledge about driving automation: "Is it really needed to do education about general knowledge?"

- **Purpose** to verify the effectiveness of the general knowledge on safe usage of automated driving system
- **Learning material** Slideshow with narration (SwN)
- **Independent variables**
  - Education (two-level, between subject): with/without
  - AGE: Elderly (Eld.) /Non-elderly (Non-eld.)
- **Participants** 12 people for each group (total 12×4 group＝48 people)
- **Dependent variables**
  - Takeover performance
  - Resuming performance (maximum steering angle velocity, Max-SAV)
- **Typical results**

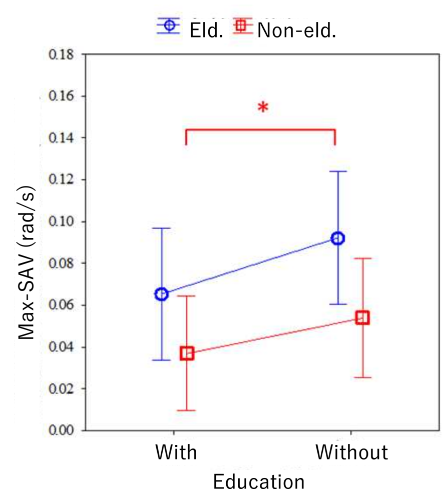
Group with education received instruction of general knowledge one month before DS verification



Rate of takeover performance @ construct site



Max-SAV @heavy rain



Conclusion

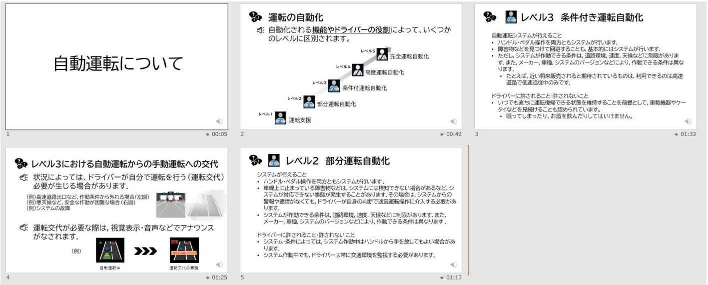
Education of general knowledge is effective for safe usage of automated driving system. Therefore, the education is important and necessary.

2. Education/training approach on a case-by-case

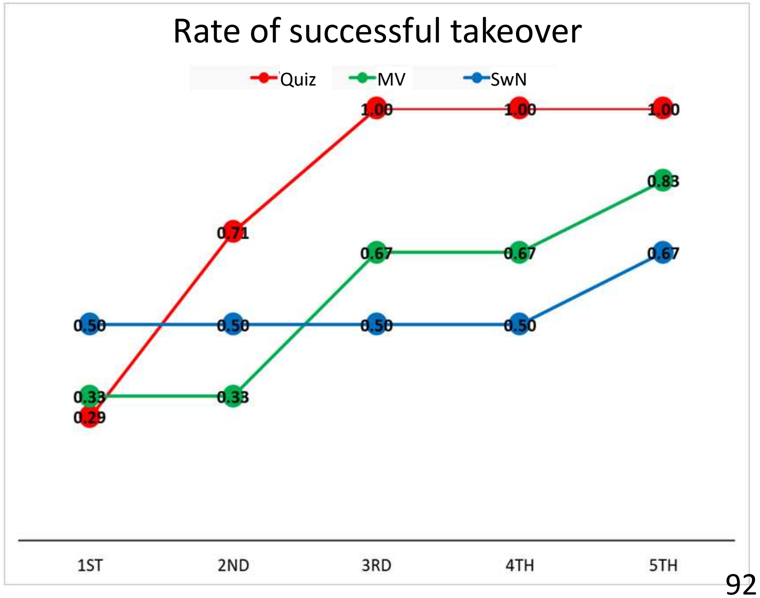
i. General knowledge about driving automation: "is it possible to realize its education with limited time?"

- **Purpose**：is it effective to shorten educating content when the lecture time is limited?
- **Independent variable**：Content (between subject)

Detailed	Content		
	SwN	Quiz	MV
Time length	4 min	8 min	2 min
Take-way material (handout)	No	No	Yes



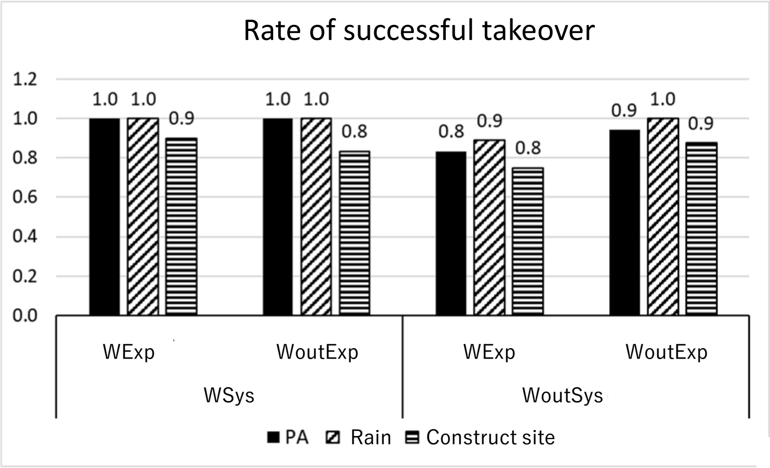
- **Participant** 16 people for each of 4 groups（total 48） （Age：43±14 years old）
- **Dependent variable** Rate of safe intervention before automated control is canceled
- **Procedure**
  - Day1 Instructions of GK＋system used for Day2
  - Day2 （more than 30 days interval）
    DS experiment
- **Main results**
  Lots of people forgot what they had been instructed about the system used on day2.
- **Discussion**
  It is necessary to investigate how to fix users' comprehension on what they have learned.



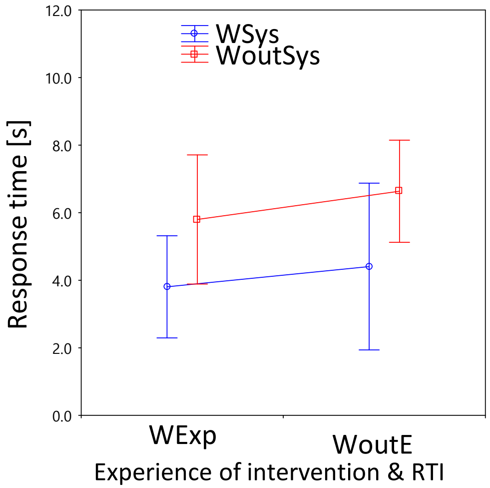
2. Education/training approach on a case-by case

i. General knowledge about driving automation: effort on fixing user comprehension

- **Purpose** to verify effectiveness of introducing specific system/experiencing intervention in cases of RtI
- **Learning material**
  13-min Slideshow with narration (SwN) (one month before DS experiment)
- **Independent variables**
  - Specific system (two-level, between subject): with (WSys)/without(WoutSys)
  - Experience of intervention & RtI (two-level, between subject) with (WExp) /without(WoutExp)
- **Participants** 10 people for each group (total 10×4 group=40 people)
- **Dependent variables**
  - Rate of successful takeover
  - Response time
- **Typical results**



Response time @ construct site

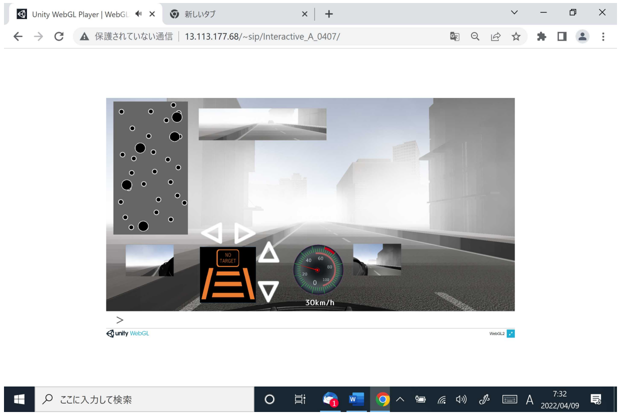


- **Conclusion**

Educating time of general knowledge is too short to improve user comprehension.

Adding specific samples is helpful to fix user comprehension.

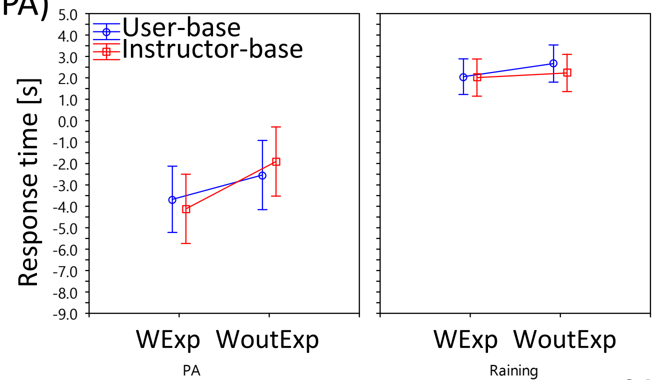
2. Education/training approach on a case-by case
ii. Knowledge for specific system: utilization of E-learning



- **Purpose** to verify effectiveness of user-based learning style, and experiencing intervention at practical scenes for specific system
- **Developing a web-based simplified driving simulator**
  - Intervention is operated via keyboard
- **Independent variables**
  - Instruction style (two-level, between subject):
    user-base (U)/Instructor-base (I)
  - Experience of intervention (two-level, between subject)
    with (WExp) /without(WoutExp)
- **Participants** 12 people for each group (total 12×4 group＝48 people)
- **Procedure**
  - Web-seminar
  - Verify experiment via DS (one-month later)
- **Typical results**
  - Most of user-base participants skipped the slides
  - WExp-Group operated better performance at planned scene (i.e., PA)

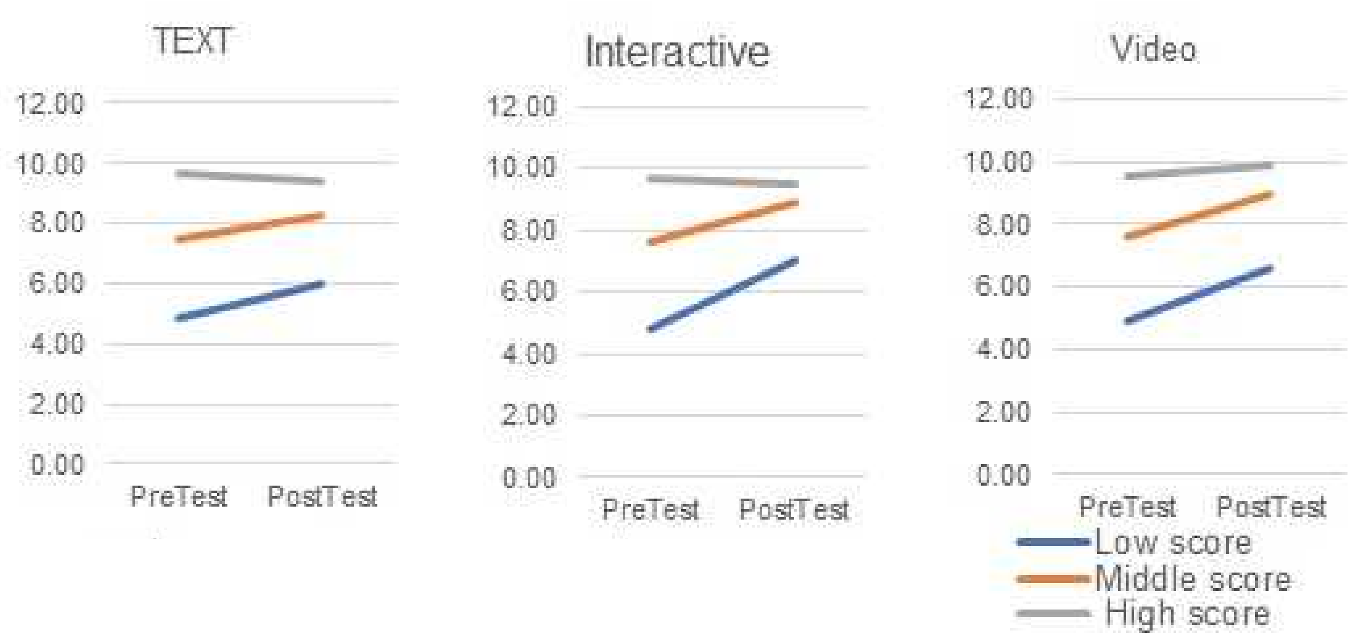
- **Conclusion**

On-demand E-learning is effective for supplying learning under limited time (e.g., dealer’s instruction) .
Experiencing practical scenes on a simplified DS (without handle/pedal) is meaningful.



3. Coping with learners’ diversity
adaptive learning of utilizing condensed version of learning style and carrier resilience

In cases of choosing material for remove individual difference



Rate-of-climb before-and after seminar based on web survey

Result: higher rate was obtained for interactive (quiz) and SwN (video) learning materials.

3. Coping with learners’ diversity

adaptive learning of utilizing condensed version of learning style and carrier resilience

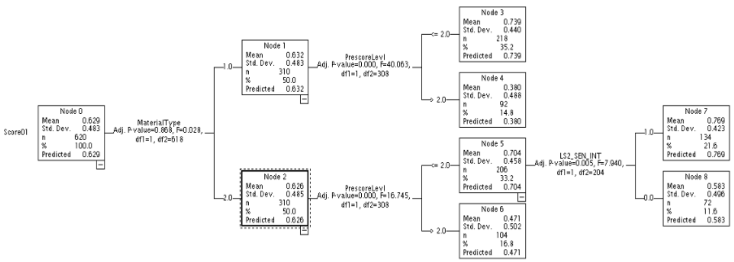
Developing condensed version of learning style and carrier resilience

→ to be easy to understand individual learner

	Item
	37. I am more likely to be considered
ACT_REF	25. I would rather first 33. When I have to work on a group project, I first want to
SEN_INT	22. I am more likely to be considered 38. I prefer courses that emphasize 30. When I have to perform a task, I prefer to 31. When someone is showing me data, I prefer
VIS_VER	11. In a book with lots of pictures and charts, I am likely to 19. I remember best 20. It is more important to me that an instructor
SEQ_GLO	36. When I am learning a new subject, I prefer to 32. When writing a paper, I am more likely to

Item
1. I think my future outlook is bright.
2. I have hope for my future.
3. I'm sure there is something good in my future.
4. I'm good at making people laugh.
5. I'm good at talking funny.
6. I'm not good at saying humor.
7. I want to know a lot.
8. I have a strong interest in things.
9. I like new things and unusual things.
10. I am a person who can flexibly respond to changes in the surroundings.
11. I am a person who can adapt to changes in the environment.
12. I can overcome any problems at work in my own way.
13. I treat people with compassion.
14. I am kind to others.

Decision Tree analysis



It is specified more effective learning material adapted to characteristics of learning style and carrier resilience (r).

compatibility				
	ACT-SEN 3	REF-SEN 2	ACT-INT 1	REF-INT 0
Low r < 2	Active	Interactive	Interactive	Interactive
Middle r = 3	Video	Interactive	Interactive	Video
Middle h >= 4	Video	Text	Video	text

Conclusion: it is suggested that more appropriate learning material could be made adapted education chance

Outcomes and applications

Assuming case

1. Motivated approach
   - Improvement of learning motivation via MV → compulsory training/lecture
   - Building safety attitude via informal learning → various chances of traffic safety education

2. Education/training approach on a case-by case
   i. General knowledge (GK) about driving automation
      - Educating GK is useful
      - Too simplified content might degrade education's effectiveness
      - Usefulness of particular cases

      → compulsory training/lecture

   ii. Specific system's knowledge
      - On-demand E-learning
      - Usefulness of experiencing the practical HMI

      → supplementary explanation to dealer's introduction

3. Coping with learners' diversity
   – SwN is effective for remove individual difference → compulsory training/lecture
   – Selectable/suitable training materials adapted to learning style and carrier resilience
     → various chances of traffic safety education

Outcomes and applications

Manual and video learning material are opened at SIP-adus website (https://www.sip-adus.go.jp/showcase/d3.html) for making learning material. With National Police Agency's cooperation, guidance would be noticed to companies for making learning material.

Manual

Index
1. Introduction
2. Necessity and role of education on driving automation/driving assistance
3. Education diversity
4. Importance of interactional design about educating approaches
5. Motivating learning driving automation/driving assistance
    5.1 Importance of motivation
    5.2 Motivation approach: video material
    5.3 Motivation approach: informal learn
6 learning approach about driving assistance : focusing on driver role
7 effort on deepening and fixing comprehension
    7.1 Expression
    7.2 Type of learning material (text, slideshow with narration, quiz)
    7.3 effort on fixing comprehension
8. Expanding chance of education
    8.1 remoted learning
    8.2 effectiveness of experience
9. Conclusion

Video learning material

Motivated video
Publica education video

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.