Submitted by the expert of Japan

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Results of the Study on Transition for level 3 Automated Driving system

National Traffic Safety and Environment Laboratory, Japan

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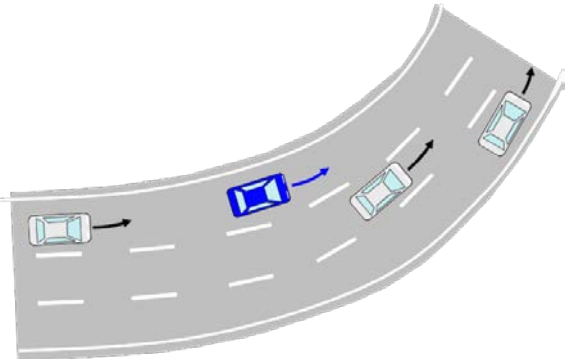
Objectives of the Study

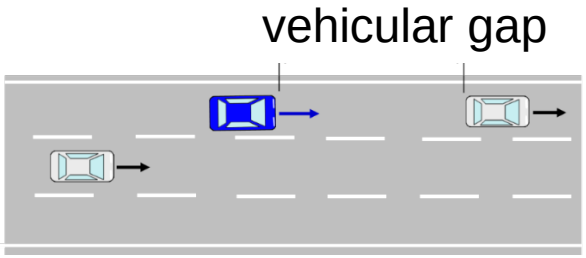
1. To study transition from Level 3 Automated Driving system to the driver using a driving simulator when the driver needs manual operation while using the system on a highway.
   (1) Transition time required for the driver to become aware of the transition demand and begin manual operation in a safe manner
   (2) Driving behavior in case that a driver encounters the traffic scene which requires higher driving workload after taking over to manual driving
2. To conduct experiments with the following scenarios in order to study what is described above:
   (1) Exit of the highway
   (2) A system malfunction, another vehicle cutting in and decelerating
   (3) Reduce of the lanes, and driver has to take over manual driving
3. To study differences in driver's response between when there is or is not a secondary activity.
4. To conduct experiments involving 20 subjects in their 30’s to early 80’s.
5. To propose a transition time and related items required for Level 3 Automated Driving system based on the results of the experiments mentioned above.

Experimental conditions

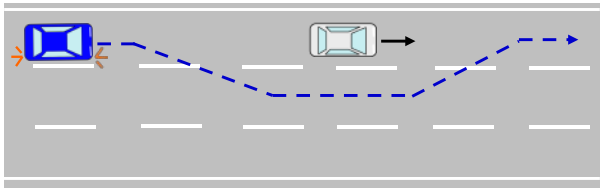
A driver can use the Automated driving system which has the functions of Lane Keeping, Adaptive Cruise Control and Lane Change (over taking) on the highway. While the system is working normally, the driver is not required to gaze the front. And also, no manual operations of accelerator pedal, brake pedal and steering wheel (he/she doesn't hold the steering wheel) are necessary.



Lane Keeping



ACC



Lane Change (over taking)

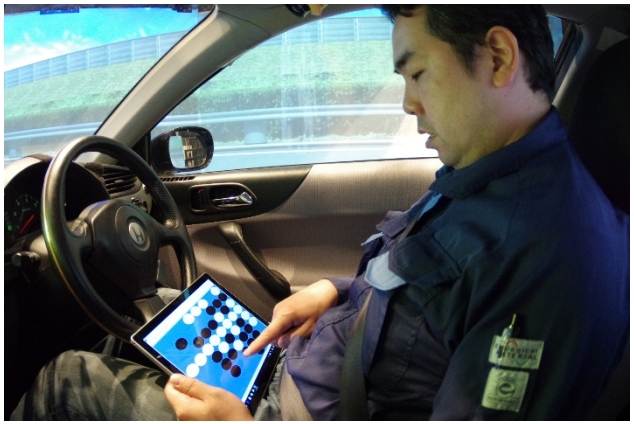
Experimental conditions

Two types of secondary activities which have possibilities being carried out by the driver while he/she is using the Automated driving system were taken into account as the experimental conditions.

type 1 : Through the monitor display of the vehicle infotainment system, he/she watches videos.

type 2 : The driver is holding a touch pad which is not linked to the vehicle infotainment system in his/her hands. And he/she plays a game (Othello game).

type 1

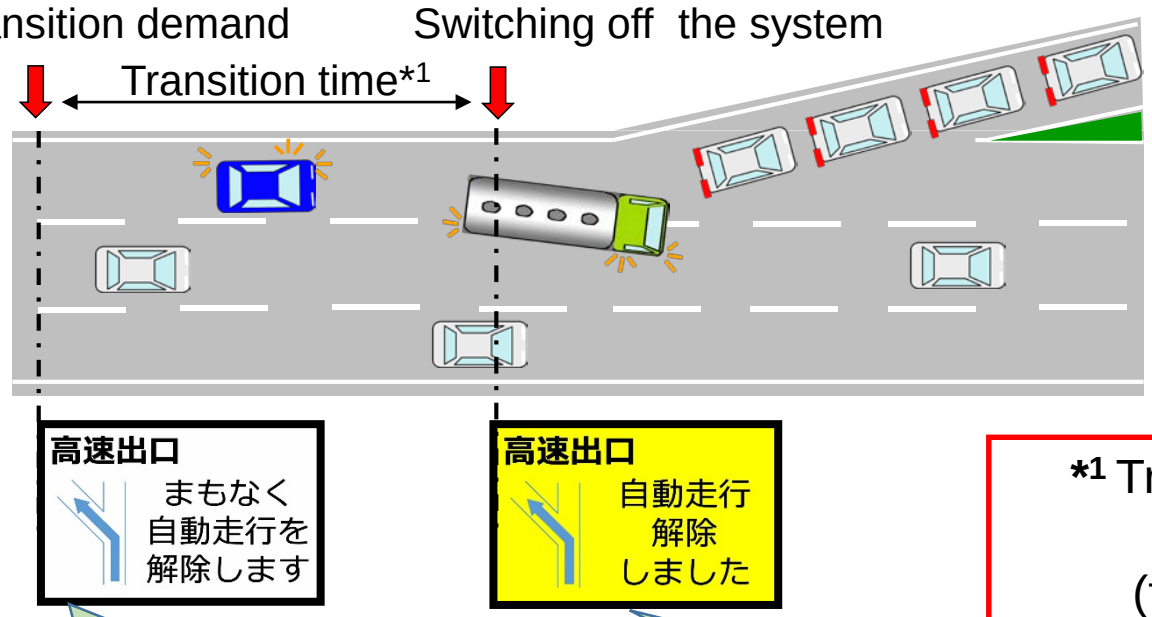


type 2

Experimental traffic scenes and transition demand

3 scenarios were created where the driver's manual operation is required.

Scene A : Exit of the highway (an example of planned transition)



Exit of the highway is congested, and the frontal vehicles are stopping.

*1 Transition time : 15sec. (fixed value)

Visual HMI

Audible HMI

「ピンポン！
高速出口、間もなく自動走行を解除します」

(Ping-pong!
Exit of the highway, the automated driving will be switched off soon.)

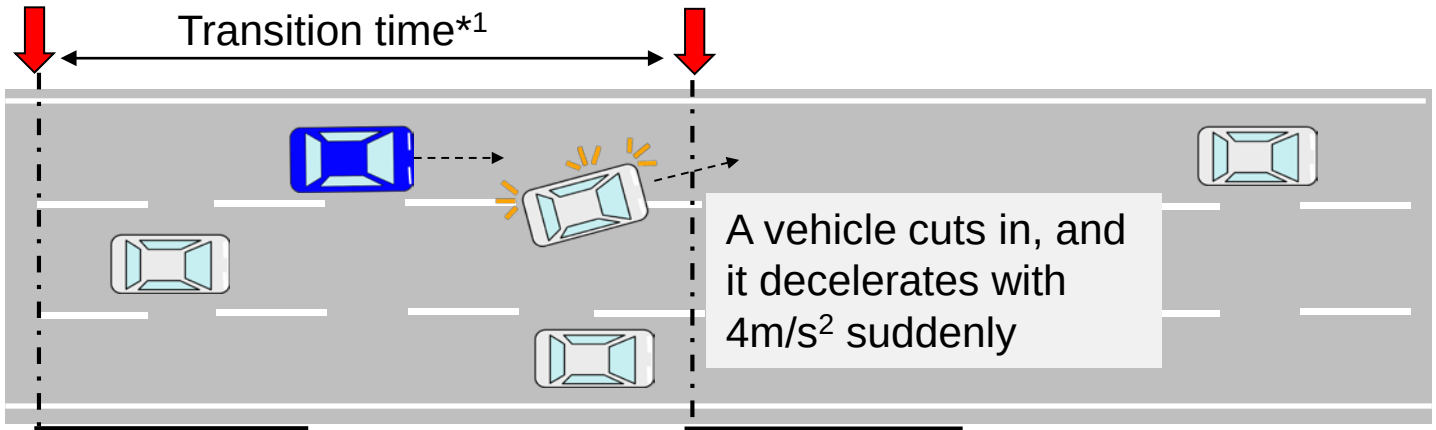
「ピピピ!ピ！
高速出口、自動走行を解除しました」

(Pi-pi-pi-pi!
Exit of the highway, the automated driving has been switched off.)

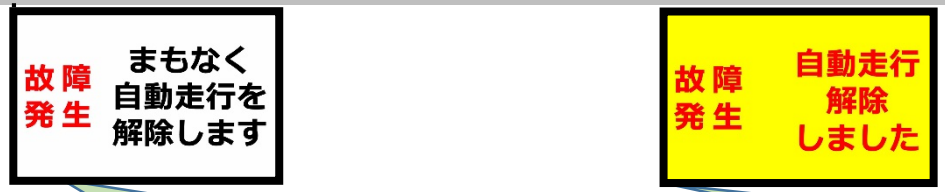
Experimental traffic scenes and transition demand

Scene B : A system malfunction, another vehicle cutting in and decelerating (an example of unplanned transition)

***1 Experimental variable**
Transition time :
5sec., 10sec., 15sec.



Visual HMI*2



*2 Visual HMI was displayed on the vehicle infotainment system

Audible HMI

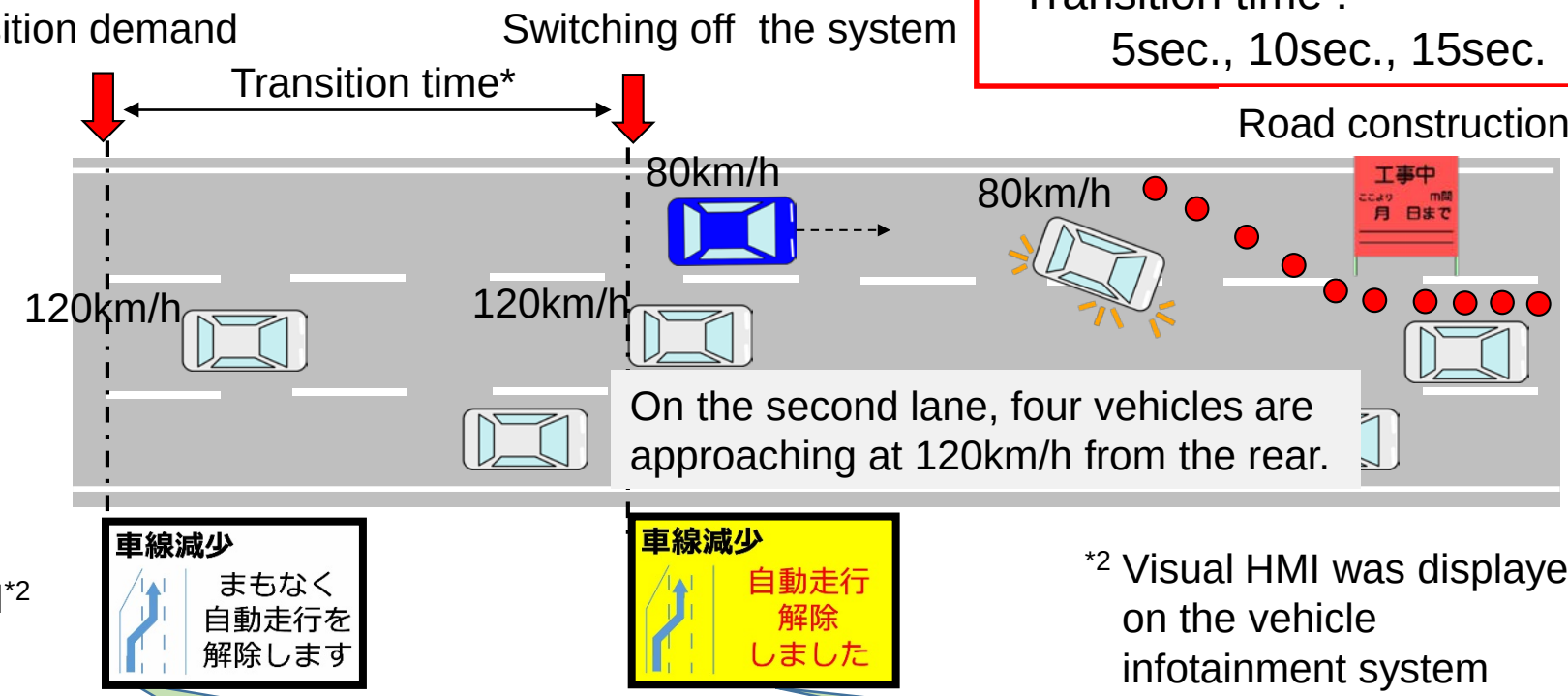
「ピンポン！
間もなく自動走行を解除します」
(Ping-pong!
The automated driving will be switched off soon.)

「ピピピ!ピ！
自動走行を解除しました」
(Pi-pi-pi-pi!
The automated driving has been switched off.)

Experimental traffic scenes and transition demand

Scene C : Reduce of the lanes due to a road construction
(an example of unplanned transition)

***Experimental variable**
Transition time :
5sec., 10sec., 15sec.



Visual HMI*2

Audible HMI

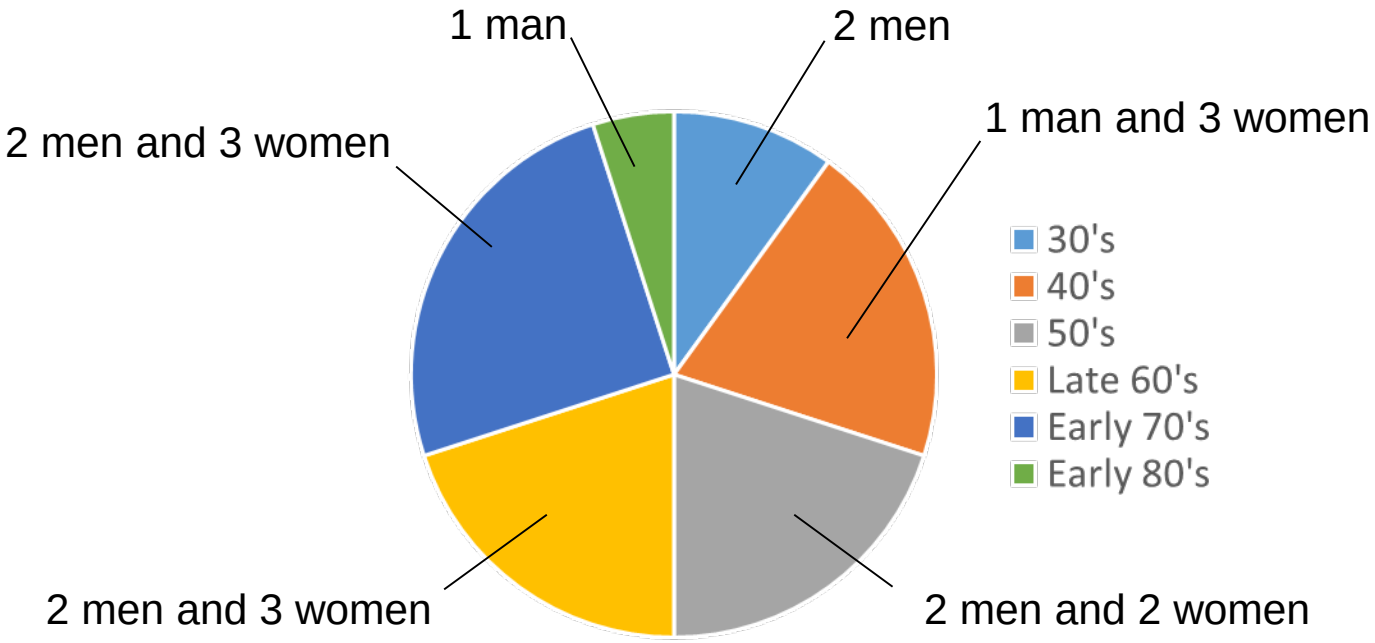
「ピンポン！
間もなく自動走行を解除します」
(Ping-pong!
The automated driving will be switched off soon.)

「ピピピ!ピ！
自動走行を解除しました」
(Pi-pi-pi-pi!
The automated driving has been switched off.)

*2 Visual HMI was displayed on the vehicle infotainment system

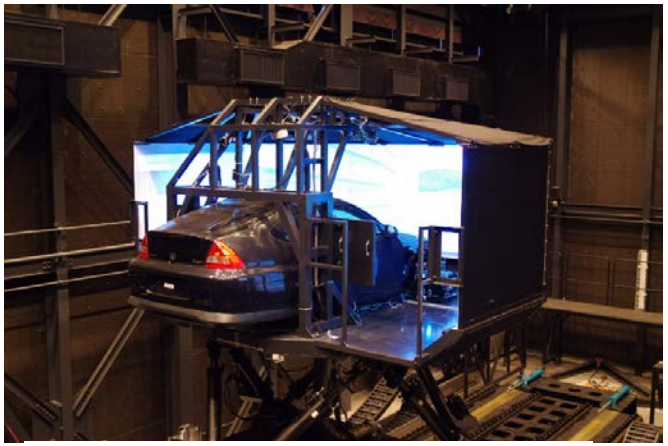
Subjects of the Experiments

- A total of 20 general drivers participated in the experiments (breakdown is shown below).
- Before the start of the experiment, the subjects fully learned how to drive when Automated Driving system works normally and how to drive manually with Automated Driving system off.



Breakdown of subjects

Driving Simulator used in the Experiments



External shape of DS

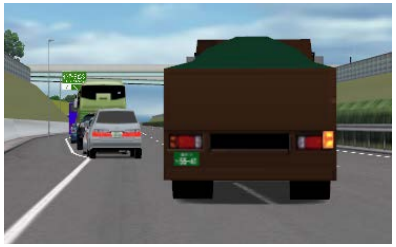
Surrounding of the driver's seat

- A driver can use the Automated Driving system on the highway.
- Both steering control and ACC can be overridden individually by the driver at any time. However, the drivers did not override before transition demand was shown from the system, because they were lectured not to hold the steering wheel and not to operate AB pedals while the system is operating normally.

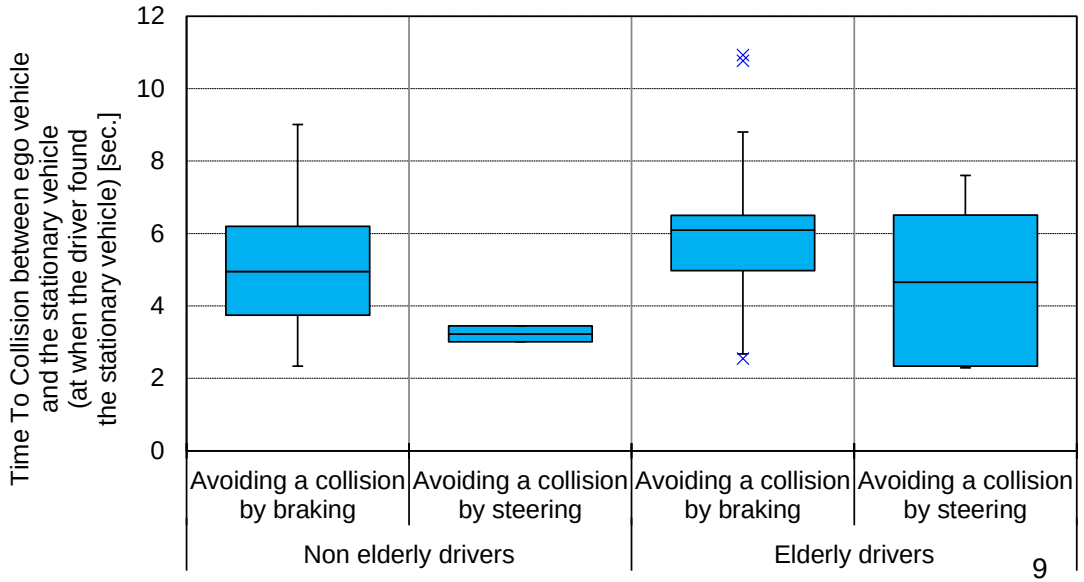
Results - Scene A -

Exit of the highway, frontal vehicles are stopping (an example of planned transition)

Time To Collision between ego vehicle and the stationary vehicle, and strategy of avoiding a collision



- In case of elderly drivers, the rate of avoiding a collision by steering is higher than that of non-elderly drivers.
- In case of non elderly drivers, TTC of avoiding a collision by steering shows smaller value than that of avoiding a collision by braking. On the other hand, in case of elderly drivers, data of TTC of avoiding a collision by steering is distributed over wider range.
- For the drivers who avoided a collision by steering, it is considered that it was extremely hard situation without enough safety margin.

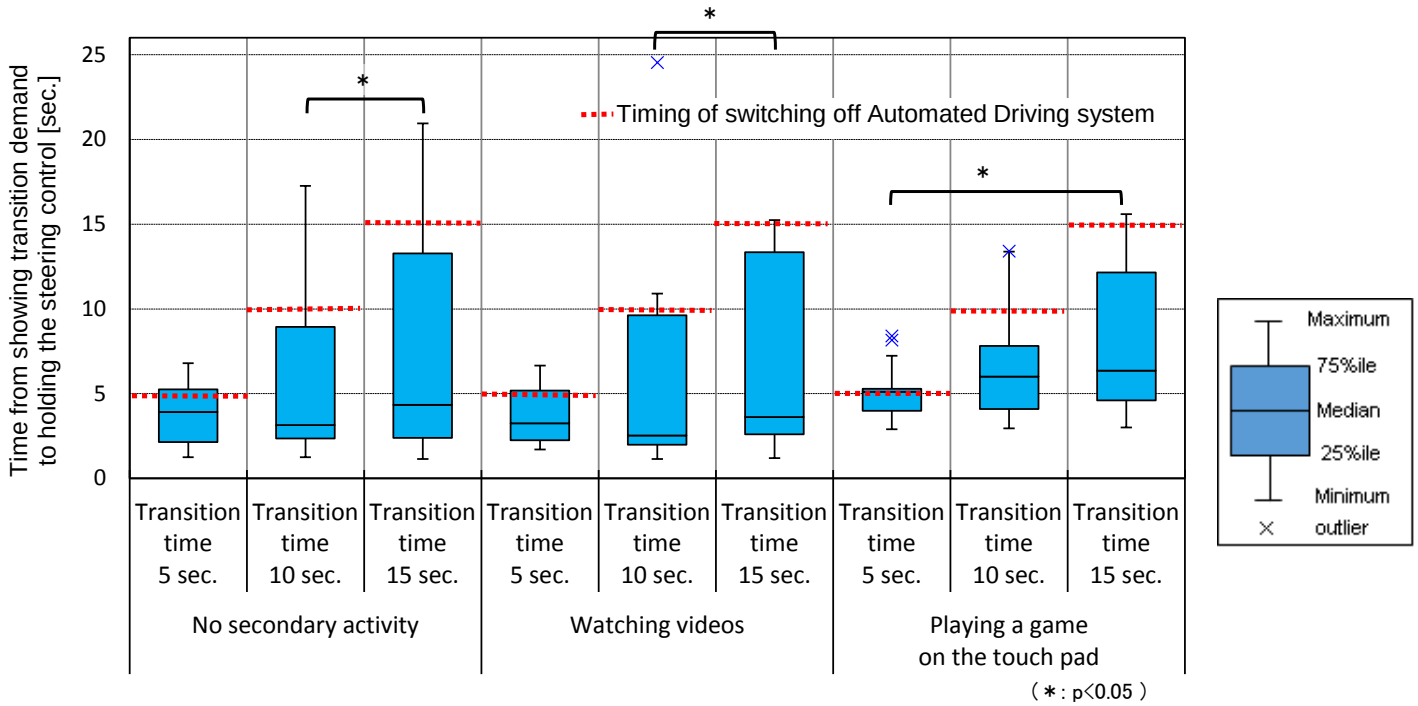


Results - Scene B -

A system malfunction occurs, another vehicle cutting in, and decelerating (an example of unplanned transition)

Time from showing transition demand to holding the steering control (all experimental conditions)

- Regardless of with/without secondary activity, as the transition time becomes longer, 75%ile data of the time from showing transition demand to holding the steering control increases. The above reason is that some of the drivers who understood that the control of the system was continued until the timing of switching off responded after looking at the situation for a while.
- One elderly person could not respond to transition demand in case of playing game.

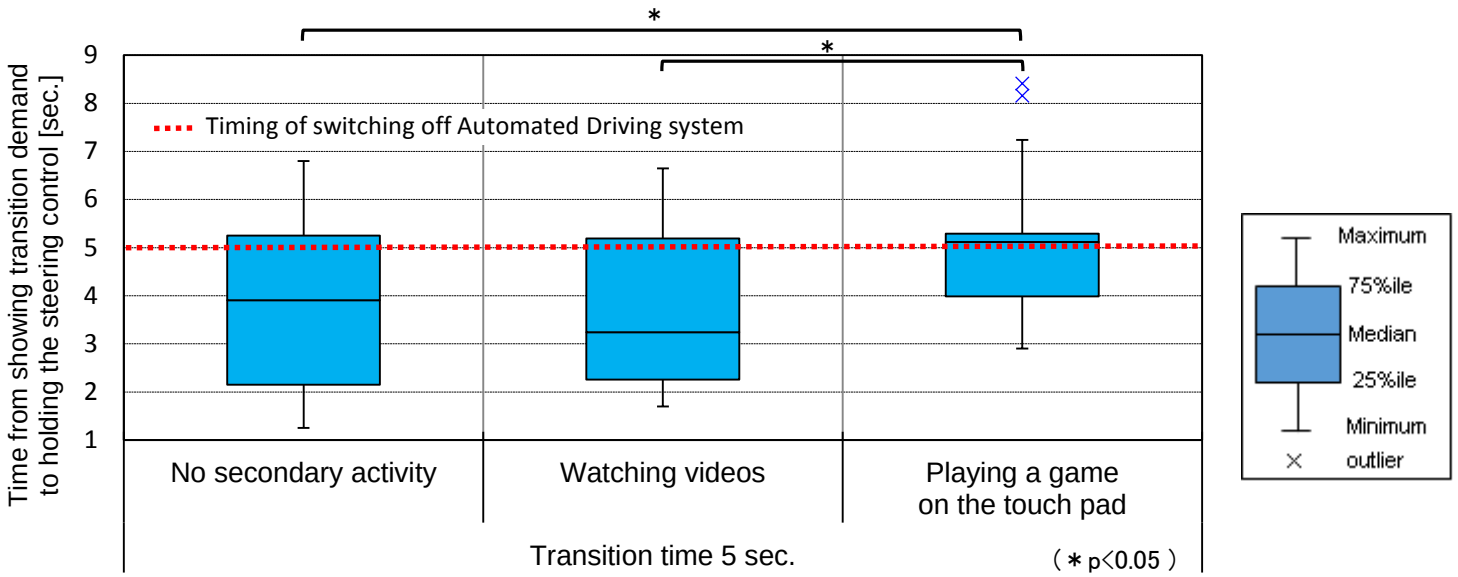


Results - Scene B –

A system malfunction occurs, another vehicle cutting in, and decelerating (an example of unplanned transition)

Time from showing transition demand to holding the steering control (In the conditions of transition time 5 sec.)

- In case of playing a game on the touch pad, median data of the time from showing transition demand to holding the steering control increases for around 1 sec. or 2 sec. compared to the other two cases. However, 75%ile data of the time is almost same.
- It is considered that for many drivers, they can hold the steering control within around 5 sec. after the transition demand regardless of with/without secondary activity.

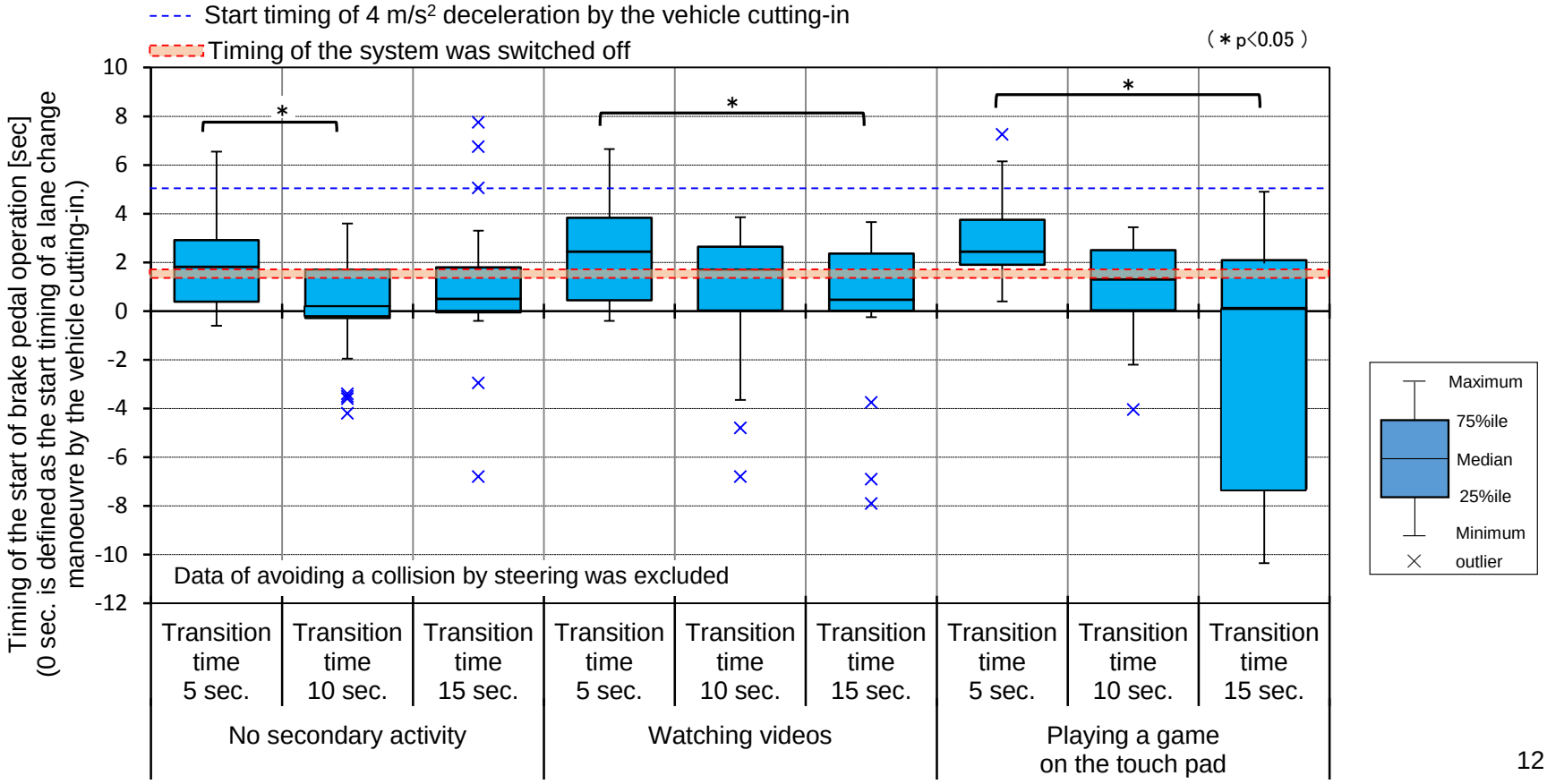


Results - Scene B –

A system malfunction occurs, another vehicle cutting in, and decelerating (an example of unplanned transition)

Timing of the start of brake pedal operation by the driver

- Many of the drivers started brake pedal operation to keep the safe distance to the vehicle cutting-in before it started 4m/s^2 deceleration.
- 50%ile data shows that in some of the cases of transition time 10 sec. and 15 sec., brake pedal operation started before the system switched off.

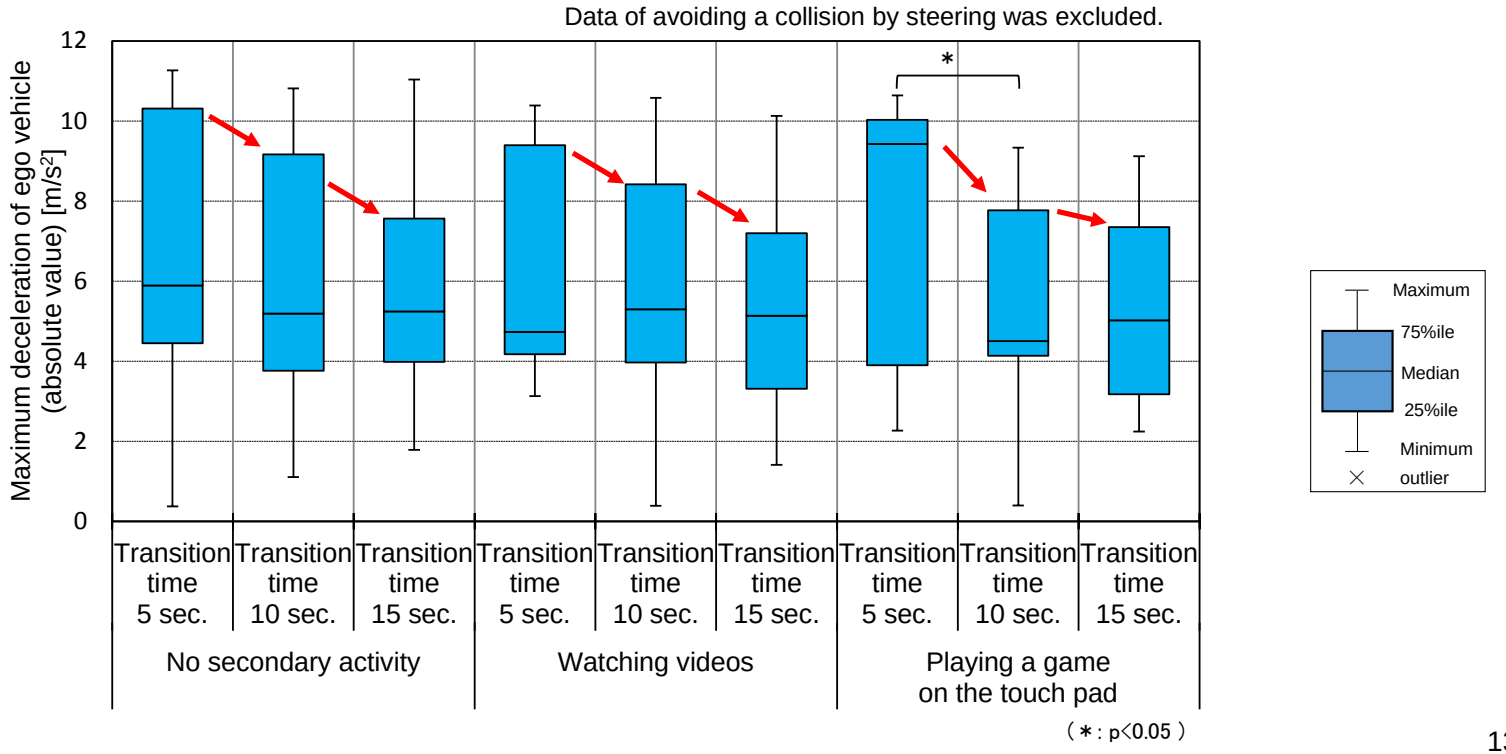


Results - Scene B –

A system malfunction occurs, another vehicle cutting in, and decelerating (an example of unplanned transition)

Maximum deceleration of ego vehicle by driver's brake pedal operation to avoid a collision

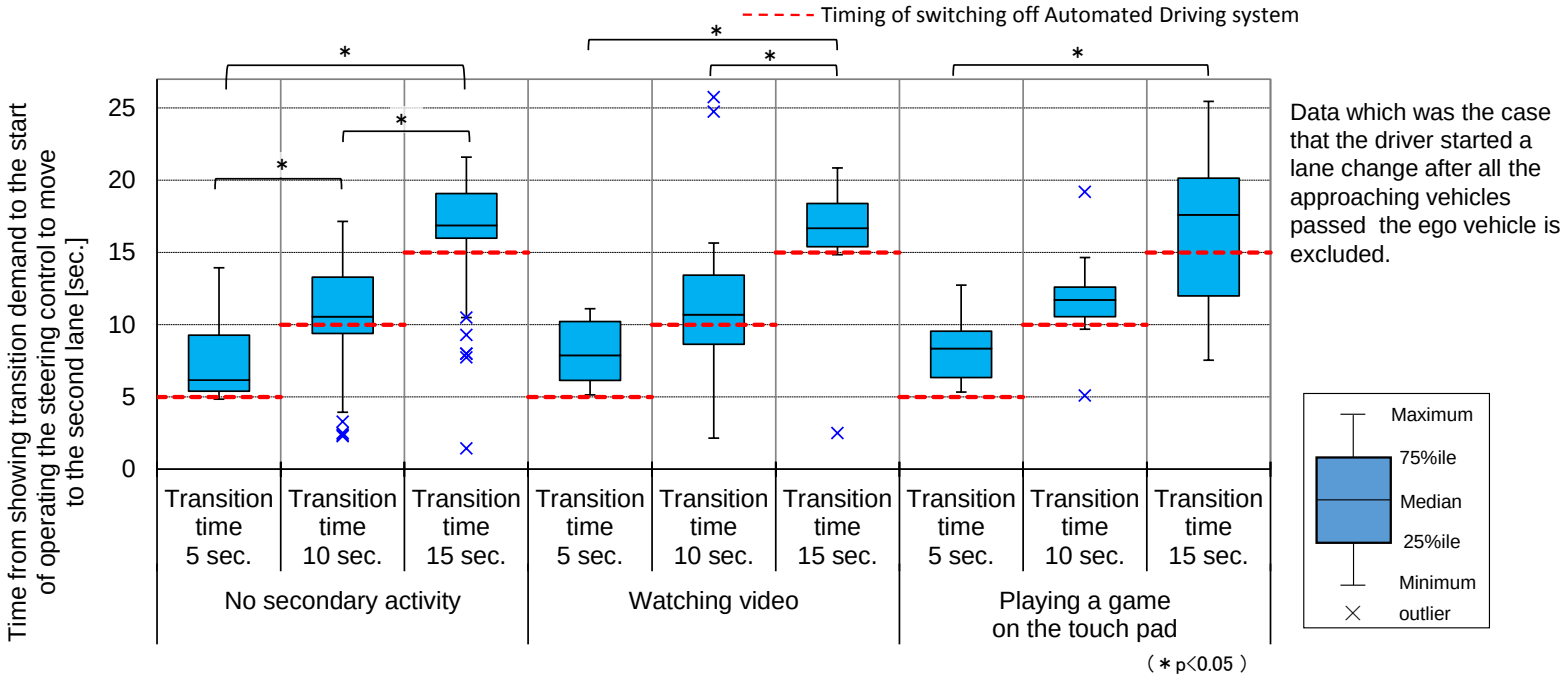
- 75%ile data shows that as the transition time becomes longer, maximum deceleration of ego vehicle is decreased. It is considered that in case of transition time 10 sec. and 15 sec., start timing of brake pedal operation becoming earlier leads to lower maximum deceleration .



Results - Scene C -
Reduce of the lane
(an example of unplanned transition)

Time from showing transition demand to the start of operating the steering control to move to the second lane

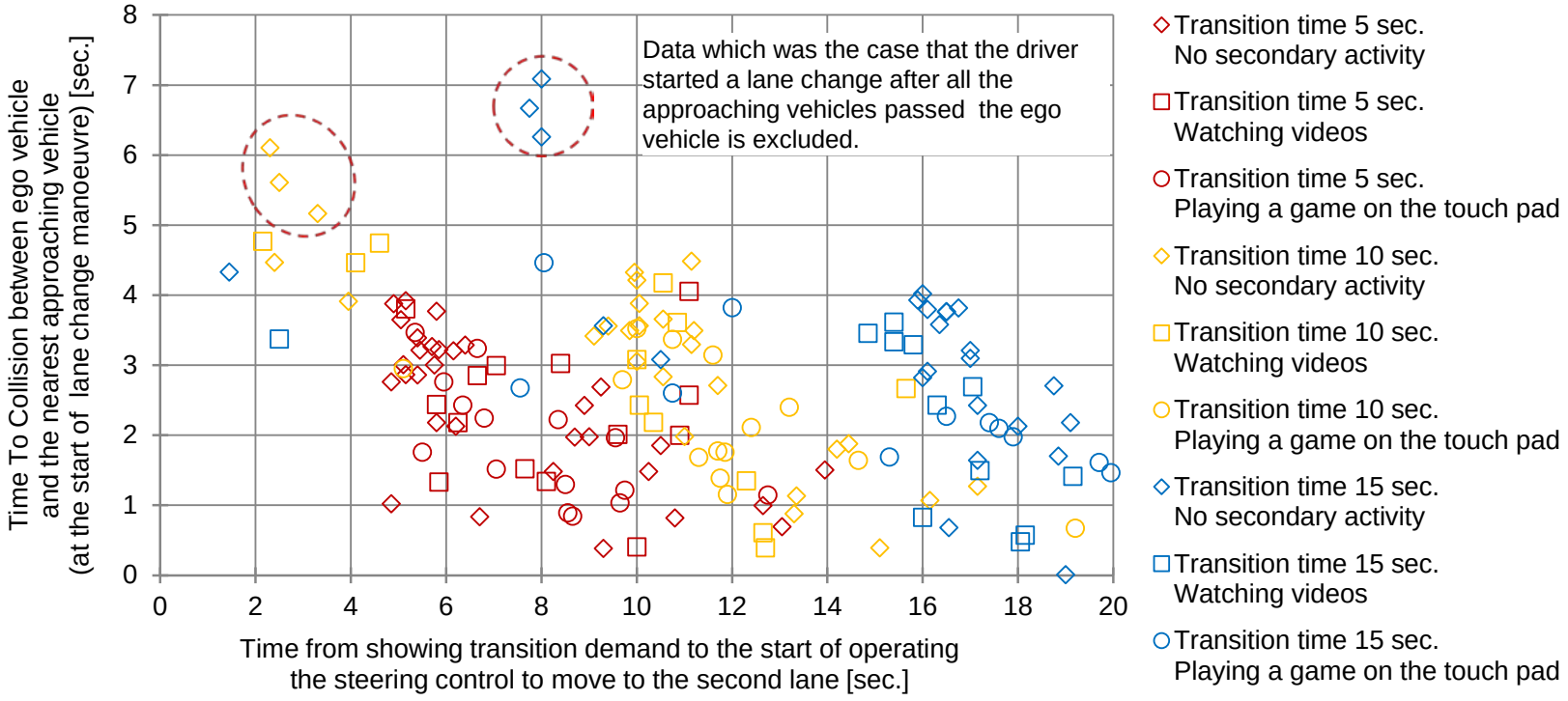
- Regardless of with/without secondary activity, as the transition time becomes longer, the time from showing transition demand to the start of operating the steering control to move to the lane increases. The reason is that it was difficult for the drivers to recognize the situation (reduce of the lane) before the system was switched off, because a vehicle was running in front of ego vehicle.
- In case of transition time 10 sec. and 15 sec., some of the drivers started to operate the steering control before the system was switched off



Results - Scene C -
Reduce of the lane
(an example of unplanned transition)

TTC between ego vehicle and the nearest approaching vehicle

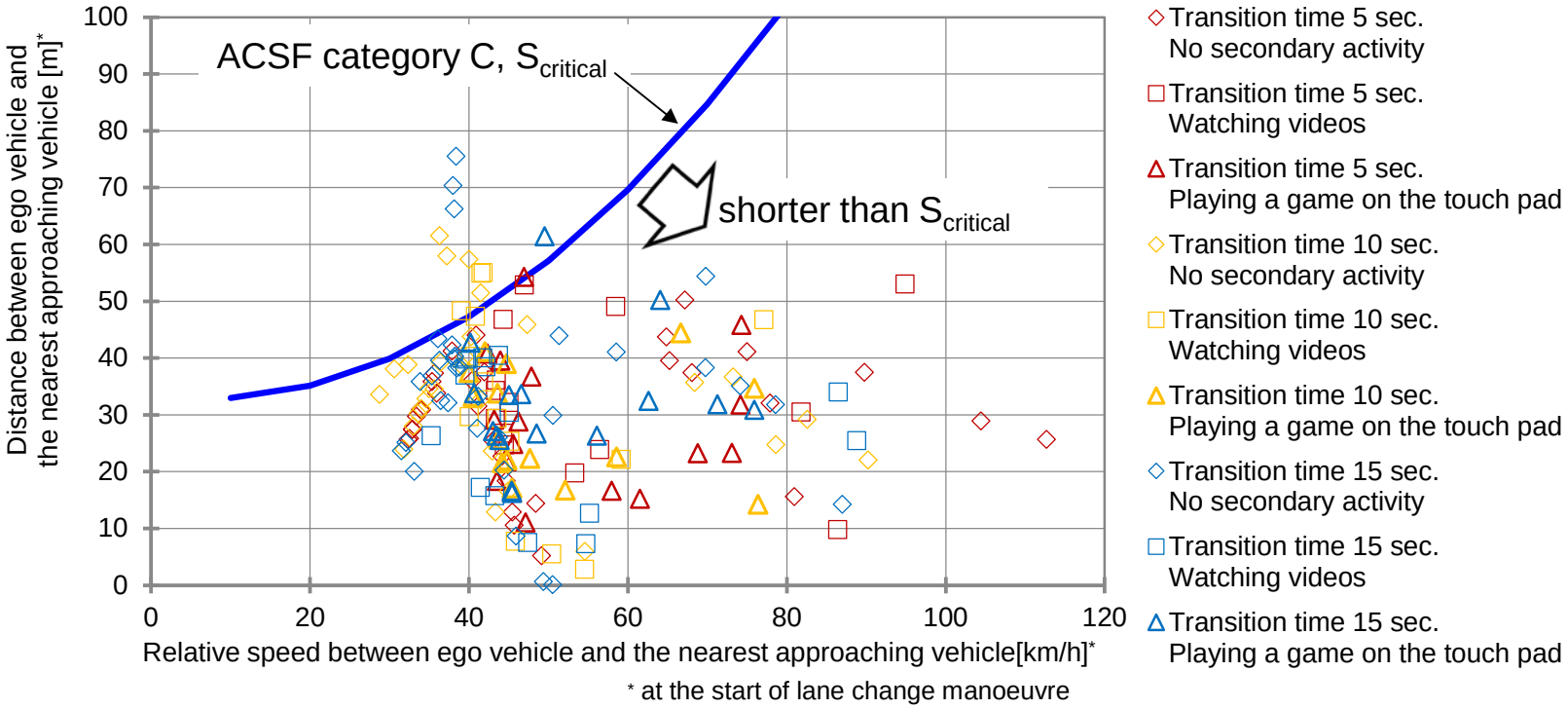
- In the condition of transition time 10 sec. and 15 sec., in many cases the drivers started the operation of the steering control to move to the 2nd lane after the system was switched off, and Time To Collision (TTC) was almost same as the cases of transition time 5 sec.. The longer transition time was not used effectively.
- On the other hand, in the condition of transition time 10 sec. and 15 sec., in some cases the drivers started the operation of the steering control several seconds before the system was switched off, and TTC became larger. (example)



Results - Scene C -
Reduce of the lane
(an example of unplanned transition)

Distance between ego vehicle and the nearest approaching vehicle

- In many of data including the condition of transition time 10 sec. and 15 sec., the distance between ego vehicle and the nearest approaching vehicle is shorter than $S_{critical}$. On the other hand, some of data in 10 and 15 sec. are longer than $S_{critical}$.
- For safer transition, it is considered to be important that the system takes into account not only longer transition time but also some kind of HMI which make the driver start manual operation more quickly.



Data which was the case that the driver started a lane change after all the approaching vehicles passed the ego vehicle is excluded.

Summary

- Many of the drivers can hold the steering control within around 5 sec. after the transition demand is shown. On the other hand, if we consider the time margin for the drivers in order to manage their vehicle more safely just after the transition, to keep around 10 sec. as the transition time is considered suitable.
- Many of drivers tend to respond more slowly in case of the longer transition time. In this experiments, the longer transition time was not always used effectively for the safer transition. Therefore, some requirements of HMI during the transition time to make the driver start manual operation more quickly will be necessary (for example, to inform the driver imminent situation by the audible HMI, etc.).
- It is considered that the system should manage the vehicle behavior during the transition time to reduce the risk after the transition time in both cases of planned and unplanned transition (for example, to reduce the vehicle speed, etc.).
- As the secondary activity, in case of watching videos on the vehicle infotainment system, no special concern was observed. On the other hand, in case of operating a touch pad which is not related to vehicle infotainment system, a concern was observed that a part of the drivers could not recognize transition demand.