TIME REQUIRED FOR TAKE-OVER FROM AUTOMATED TO MANUAL DRIVING WHEN EXITING THE HIGHWAY

Arata Takada and Toshio Ito

Graduate School of Engineering and Science, Shibaura Institute of Technology

Takeshi Enya and Yuuya Higuchi

DENSO CORPORATION

mf15049@shibaura-it.ac.jp

ABSTRACT

Automation of the vehicle can be expected to improve safety, comfortable and efficiency, and developed by every countries.

The SAE working group defined "On-roads Automated Vehicle Standards Committee" was established in 2011. Automated driving level is divided into six.

Level 0 : Systems cannot execute longitudinal or lateral control but may issue warmings to the driver. Level 1 : Systems execute parts of the dynamic driving task (steering, accelerating/braking). Level 2 : Systems execute the lateral and longitudinal control dynamic driving subtasks completely with the driver in the loop executing. Level 3 : Systems allow the driver to run his attention away from the complete dynamic driving task. Level 4 : Systems do not have those restrictions. Level 5 : Systems can accomplish the complete journey from origin to destination in a high automation, and human can legally drive a vehicle.

Currently, feasible automation level is Level3 and take-over from automated to manual driving is needed when the automated system overs at this level. In this situation, required time for take-over is an important issue.

In the level3 Automated system, for applying to the highway driving, a take-over from automated to manual driving at the entrance and exit of interchanges is needed. The issue here is that whether the take-over from automated to manual driving is operational while the driver is accustom to a long time, of automated driving.

1. INTRODUCTION

We can expect automation of vehicles to improve safety, comfort and efficiency, and developed various driver assistance systems are put to practical use. Automated driving is one form of the driver assistance systems which were developed further, and various countries are researching this actively. We progress automated driving in stages, and SAE classifies this into 6 stages from level 0 to level 5. The current stage is level 1: Driver assistance systems. By combining Full Speed Range Adaptive cruise control (FSRA) with Lane Keeping Assistance (LKA), one could achieve level 2 partial automated driving on the highway, and level 3 conditional automated driving. In this way, it is thought that automated driving will be first introduced on highways, and by automating driver pedal operation and steering operation at the same time, the system will also do status checking in level 3, so automated driving could fundamentally change driving tasks. That is, it is very possible that we will advance from level 2 with surroundings monitoring by the driver, to level 3 where inattention is allowed.

level 3, when the automated driving system controls the vehicle, due to system failure etc., manual driving is returned, and the driver takes over driving from this system. In take-over, the time required is an issue.

In level 3, an autonomous driving assistance system could be applied, so it would drive while maintaining a safe distance from vehicles driving nearby on the highway, but it has no automatic lane change function for stopped vehicles, and it could give a take-over request to the driver, so driving would shift from the system to the driver. At this time, assuming a take-over display ahead monitoring radar detection distance of 200 m, then at 100 km/h driving speed, TTC 7 seconds of detection performance can be expected. And at 140 m detection distance, this becomes TTC 5 seconds. Thus in this research, we used a driving simulator to evaluate whether take-over of 7 seconds or 5 seconds is feasible.

However, the driver must be a takeover with a margin than the above take-over, when exiting the highway. Below in this paper, we report the change in the operating characteristics of the driver, doe to the effect of changing the distance after a take-over. Present issues, how much driver needs the margin distance.

Table 1 Level of driving automation

Level	Name	Execution	Monitoring	Fallback
0	No	Driver	Driver	Driver
1	Driver	Driver &	Driver	Driver
2	Partial	System	Driver	Driver
3	Conditional	System	System	Driver
4	High	System	System	System
5	Full	System	System	System

2. TAKE-OVER

From level 0 to level 1, driving control is always with the driver. At level 4 and above, the system is always driving, so at these levels, take-over does not occur. At level 2, the system drives, but the driver monitors the surroundings, and when the situation exceeds the system's limits or when it fails, the driver must take over driving. At level 3, the system not only drives, it also monitors the surroundings, so the driver does not need to monitor the surroundings, but even in this case, when the system fails, the driver must take over.

In the take-over situation considered in this paper, the system foresees a situation that exceeds the limits of its performance, and for handing over driving control to the driver, there is a time-budget until the location where it exceeds the limits of its performance. As a specific scenario, we can consider a system which detects a stopped vehicle, but control is not done at all, and at the moment it is detected, the driver is presented a take-over request (TOR) which would cancel automated driving. At a driving speed of 100 km/h (27.8 m/s), TTC is about 7 seconds when a vehicle is detected 200 m ahead ($200 \div 27.8 \simeq 7.2$), and TTC is about 5 seconds when a vehicle is detected 140 m ahead ($140 \div 27.8 \simeq 5.0$). This situation is shown in Fig. 1.

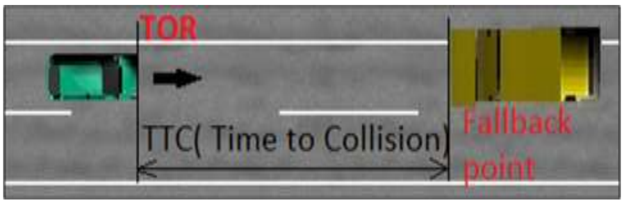

Figure 1. This figure shows a take-over situation for a fallback point. If this automation system doesn't perform a lane change operation, this system issues a take-over request to the driver for a construction vehicle like this.

The take-over process at this time could be as shown in Fig. 2. Thus a possible scenario is, until the TOR appears, the driver is outside the feedback loop of vehicle driving, but when the TOR appears, first his attention returns to driving operations, next is situational awareness, then he starts driving operations, and by manual driving completes the feedback loop of vehicle driving.

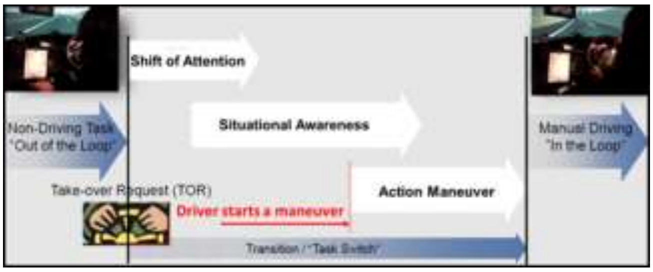

Figure 2. The take-over process can be considered like this. When the TOR is issued, a non-driving task ends and the driver begins to enter the driving loop. At first, the driver shifts his/her attention to this situation, and understands this. Then, the driver starts a maneuver for this situation and the Task Switch completes.

3. TAKE-OVER IN THE FALLBACK POINT

For TOR of TTC 7 seconds and 5 seconds, to investigate whether the driver can appropriately take over, we did the experiment described below. We considered reproducibility and the safety of subjects, etc., so this experiment used a 6 axis vibrating driving simulator, with 14 male and female Shibaura Institute of Technology students who held a regular driver's license as subjects. When doing the experiment, the subjects were only given the instruction "I'll explain TOR. There is a TOR warning sound (4 kHz intermittent sound), and after it sounds, the manual driving method is free". Also, to prevent artificial driving, subjects were not told the experiment's goals before the entire experiment ended. In doing the experiment, it underwent an ethics review on Shibaura Institute of Technology biotechnology research and was approved, and before the experiment, the experiment's details and personal information protection were explained, consent was obtained, then the experiment was done.

Figure 3. driving simulator with 6-axis swinging

The experiment's road was 2 lanes on one side of a highway, with a level 3 automated driving system operating. The subjects were experienced in manual driving on a driving simulator, and they had ability to freely drive on the subject road without special instructions. The TOR presentation was after at least 10 minutes of experiencing automated driving, and the timing and place occurred randomly on the course, and the situation was the vehicle was driving alone, with no other vehicles driving.

During automated driving, the subjects were subjected to the following 6 types of issues.

(1) Both hands on the steering wheel, monitoring ahead. Feet free
(2) Hands off the steering wheel, line of sight free. Feet also free
(3) Both hands on the steering wheel, attentive to movements on navigator screen. Feet free
(4) Hands off the steering wheel, attentive to movements on navigator screen. Feet free
(5) One hand on the steering wheel, doing an additional task. Feet free
(6) Hands off the steering wheel, doing an additional task. Feet free

The automated driving speed was 100 km/h, with a steering wheel that automatically steers in response to curves. The pedal operation does not move from the moment when it is off, then when it switches to manual driving, the driver can step on it. The navigator screen position is in the lower part of the center console, in a position where the driver does not see the situation ahead while looking at the navigator screen. In (3) and (4), video was streamed to this navigator screen, and it grabbed the attention of the subject. In (5) and (6), the additional task was: a paper on which meaningless multiple 4 digit numbers were printed was attached onto the center console's lower part; look at that paper, and continually input the numbers into the navigator screen, so it was a task they could not do if not concentrating.

Fig. 4 shows two examples of the vehicle path after TOR and take-over. Fig. 5, 6 and 7 show boxplots of how many seconds it took for the subject to start steering avoidance operation after TOR appeared, for TTC 7 seconds and TTC 5 seconds.

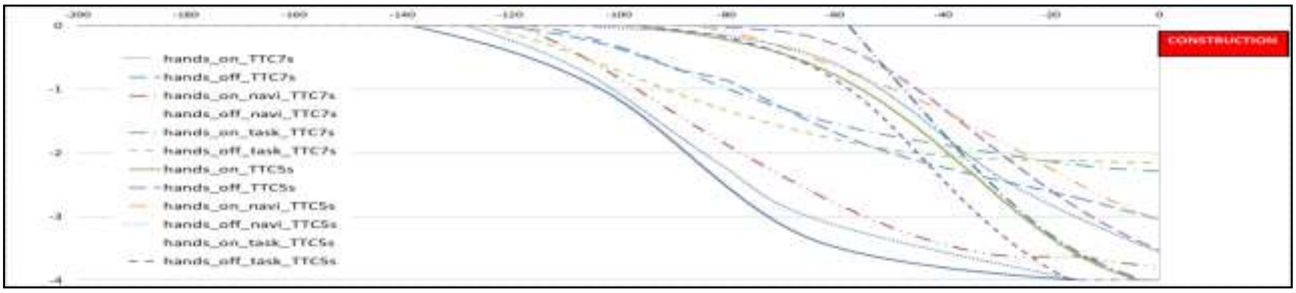

Figure 4 This figure shows trajectories after TOR of the subject No.1. From the driving paths of this subject, steering avoidance had different operations methods in the available distance until the stopped vehicle. That is, for TTC 7 seconds, when there was time available, this driver operated smoothly, but for TTC 5 seconds, there was little time available, and this driver operated suddenly.

For both TTC 7 seconds and TTC 5 seconds, none of the 14 subjects had a rear-end collision, as they used steering operation to avoid the stopped vehicle. After TOR presentation, automated driving was cancelled, so the vehicle speed started to slow, but 8 of the 14 subjects started to operate the accelerator pedal, and while maintaining the 100 km/h vehicle speed from when it was automated driving, they did steering operations; 6 of the 14 subjects first stepped on the brake pedal, then while slowing to about 80km/h, they started steering operations, then quickly switched to stepping on the accelerator pedal, and recovered vehicle speed. As a result, none of them completely stopped for the stopped vehicle, as finally all of them did steering avoidance operations and manually continued driving.

From the driving paths of 2 subjects in Fig. 4, steering avoidance had different operations methods in the available distance until the stopped vehicle. That is, for TTC 7 seconds, when there was time available, they operated smoothly, but for TTC 5 seconds, there was little time available, and they operated suddenly. This trend was unaffected by driving experience and ability, as it was seen to be common to all subjects.

4. LANE-CHANGE TAKE-OVER

Similarly, we used the experiment's road was 2 lanes on one side of the highway, with a level 3 automated driving system operating. When conducting the experiment, the subjects were only given the instruction "I'll explain TOR. There is a pylon when you hear TOR warning sound. After it sounds, the manual driving method is free along with the pylon. And, change the lane when the pylon is finished." In this experiment, we have changed the pylon section distance, at 0.5km intervals 0.5km to 2.0km, as the distance of the lane changes from the TOR generated point. This situation is shown in Fig.5. In addition, the subject's wakefulness is good in this experiment. Also, we did not give the task in automated driving to the subject, as they are looking at driving environment such as landscape.

Figure 5. Situation of take-over point

In this experiment, we presume that the driver's driving operation will change by the distance travelled after the take-over of the automated driving. Then, the vehicle path is observed.

Fig,6 shows two examples of the vehicle path after take-over and lane changing.

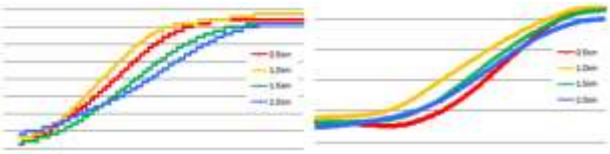

Figure 6(a). Trajectories after takeover (Subject A)

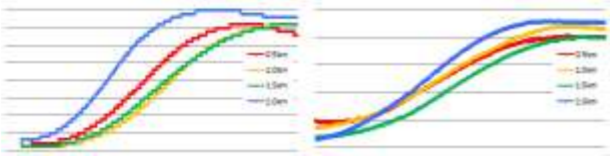

Figure 6(b). Trajectories after takeover (Subject B)

In these graphs, we focus on the driving operation when the subject makes a lane change. As can be observed, difficult margin distance produced different driving operation during the lane change.

Subject A has the most smooth lane change operation when the margin distance is 2.0km and this trend is seen to be common to all courses. However, in subject B, the tending like subject A is not observed. Subject B has the most steeps operation when the margin distance is at 2.0km.

5. DISCUSSION

From these results, we did not obtain common characteristics from all of the subjects. However, we were able to see the trend for each subject. Before the experiment, we already obtained the data that shows the usual lane change operation without take-over. Usually subject A will operate the lane change with the smooth trajectory, while subject B will operate in the steeper manner. Comparing these results, it is understood that the longer the distance, the closer the results of this times experiment with the subject’s usual lane change operation.

Moreover, in this experiment, while the course is randomly selected, during the second half of the course, the data that is close to the usual operation is obtained. From this, it can be understood that the longer the margin distance, or the higher the number of experiments conducted, the closer the trajectory of the subjects to their own usual operation since the subjects are not accustomed to the automated driving. So in order to obtain results close to the usual operation, we should consider the required distance margin.

6. CONCLUSION

In this paper, we examined the margin distance at the switching to manual driving from automated driving when exiting the highway. This experiment was performed using the driving simulator. The results of the experiment show differences in the driving behavior, after the take-over. However, we see the effect of how the drivers get used to the automated driving. Since these are only the tendency, it is necessary to analyze more. As for a future plan, we will increase the number of subjects, investigate the relevance of the driver state during the automated driving, and consider a method of estimating the appropriate margin distance required for each driver.

REFERENCES

Ian Riches, “The Implications of Fully Automated Driving for the Automotive Industry”, ITS World Congress 2014 Detroit (2014).

SAE, "Summary of levels of driving automation for on-road vehicles in Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems", SAE J3016,(2014)

Morita, K., Mashiko, J., Okada, T., “Delay in Response Time of Automobile Driver due to Gazing at an In-Vehicle Navigation Display Device”, Journal of Illuminating Engineering Institute of Japan, Vol. 82, No. 2, pp 121-130, 1998

Arata Takada received B.E. (2015), degrees in systems engineering and science from Shibaura Institute of Technology

He is a Student, Department of Machinery and Control Systems, Shibaura Institute of Technology His Current interest includes the driver behavior.

Toshio Ito received B.E.(1982) and D.E. (1995) degrees in system engineering from Kobe University.

He is a Professor, Department of Machinery and Control Systems, Shibaura Institute of Technology. His current interests include the driver behavior and machine vision for advanced driving support systems.

Takeshi Enya received his B.S. in applied physics engineering from Tokyo Denki University, in 1987. Since 1987, he has been a researcher at DENSO CORP. R&D Div. His current research activities are driver monitor system and HMI system.

Yuuya Higuchi received his M.S. in computer science and engineering from Nagoya Institute of Technology, in 2008.

Since 2008, he has been a engineer at DENSO CORP. His current research activities are human factor and takeover system