2018 IEEE Intelligent Vehicles Symposium (IV)
Changshu, Suzhou, China, June 26-30, 2018

The Impact of Explanation on Possibility of Hazard Detection Failure on Driver Intervention under Partial Driving Automation *

Tianwei Liu, Huiping Zhou, Makoto Itoh, and Satoshi Kitazaki.

Abstract— **The purpose of this study is to clarify how to explain the system limitations in terms of possibility of hazard detection failure under partial driving automation, which is the level 2 of driving automation defined by Society of Automotive Engineers (SAE). Different from level 3 of driving automation which is supposed to issue Request to Intervene (RTI) to the driver whenever system limitations, an RTI may not be issued by the level 2 system because it is possible that the level 2 system fails to detect a hazard or understand the situation accurately which system cannot deal with. Under level 2, a driver therefore needs to understand the situation accurately and intervene in driving operation when necessary. This study focuses on whether explanation on the traffic scenes where the driving automation system may fail to detect a hazard has an impact on driver intervention or not. An experiment is conducted with a driving simulator (DS) in which the host vehicle is equipped with a driving automation system at level 2. A between-participants design is employed in our experiment. We have 30 participants, half of them are explained the possible traffic scenes and the other half are not. The participants are expected to find out the hazard which the system cannot detect a hazard by itself and to intervene in driving operation. The results show that drivers who were explained the possible scenes can deal well when the automation fails. According to the results, it may be claimed that it is necessary for car makers/dealers to explain to drivers on possible scenes where the driving automation system may fail to detect a hazard.**

I. Introduction

Automated driving technology is expected to reduce traffic accidents and to increase drive safety and comfort. Countries around the world are working on automated driving development. However, there is a concern about the new types of accidents due to driving automation. For example, a fatal crash when using a level 2 driving automation system occurred on May 7, 2016 in Williston, Florida. It was considered that a probable cause of the accident was that the car driver's inattention due to overreliance on driving automation system by National Transportation Safety Board (NTSB) [1]. Referring to this case, human factors issues [2] such as safety, acceptance and usability in automated driving need to be considered. Therefore, an appropriate design of the roles of the driver and the driving automation system is necessary. Contributing to that, many projects around the world are working on human factors issues in automated driving to solve this problem (see, e.g., [3][4]).

A. Issues in Level 2 Driving Automation

SAE [5] proposed the definition of levels of driving automation from 0 to 5 according to the roles of the system and the driver. The level 2 is called Partial Driving Automation, Where the system executes both the lateral and longitudinal vehicle motion control and the driver is expected to monitor the system, find and respond to the event when system limitations [6]. However, humans are not good at monitoring [7]. Compared to manual driving, it is suggested that the driver tend to feel drowsy. Furthermore, non-driving-related tasks could be easily observed [8]. As a result, the intervention behavior would be worse [9], the reaction time would be long [10], the attention to driving tasks would be declining [11] and misunderstanding of system states might occur [12]. In fact, Gold et al. [13] pointed out that drivers who did not attend to the road needed 5 to 7 seconds to resume driving operation. Ito et al. [14] claimed that it took at least 5 seconds to go back to control the vehicle from driving automation system.

Even if drivers can maintain their situation awareness while a level 2 driving automation system is working, still there is a critical issue. Drivers are expected to find hazards when using a level 2 driving automation system, because it is possible that system fails to detect hazards or understand the situation accurately that the system cannot deal with under level 2. Accordingly, drivers need to understand the situation accurately and intervene in driving operation in a limited time. Therefore, it becomes a topic to clarify the system design to support drivers monitoring and intervening safely and smoothly in a limited time.

B. Role of prior education

Let us think about a model of human information processing when using a level 2 driving automation system as shown in Fig. 1. The driver needs to acquire information from the system and the surrounding environment to know whether he/she needs to intervene in the system. Therefore, it is necessary for the driver to comprehend their roles and system functions. The driver would be distracted if he/she lacks the knowledge about the driving automation system, especially on the limitation of the functions. As a result, in that case, the driver would not be able to intervene in the system in time so that an accident may occur. Therefore, it is important to educate drivers about knowledge of system functions and driver's roles. It is important to clarify the required knowledge

*Resrach supported by SIP-adus Project entitled "Human Factors and HMI Research for Automated Driving".

T.W. Liu is with the Graduate School of Systems and Information Engineering, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki, 305-8573, JAPAN. (phone: 029-853-5011; fax 029-853-5011; e-mail: liutw@css.risk.tsukuba.ac.jp).

H. Zhou is with TOKYO BUSINESS SERVICE, 6-14-1 Nishishinjuku, Shinjuku, Tokyo, 160-0023, JAPAN.(e-mail: hzhou@tokyotobs.co.jp)

M. Itoh is with Faculty of Engineering, Information and Systems, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki, 305-8573, JAPAN. (e-mail: itoh.makoto.ge@u.tsukuba.ac.jp).

S. Kitazaki is with Automotive Human Factors Research Center, National Institute of Advanced Industrial Science and Technology, 1-1-1 Umezono, Tsukuba, Ibaraki, 305-8560, JAPAN.(e-mail: satoshi-kitazaki@aist.go.jp).

978-1-5386-4451-5/18/$31.00 ©2018 IEEE

about system functions for the driver to take over safely and smoothly. However, compared to human machine interface (HMI) design studies, there is little research on education about knowledge of the driving automation system.

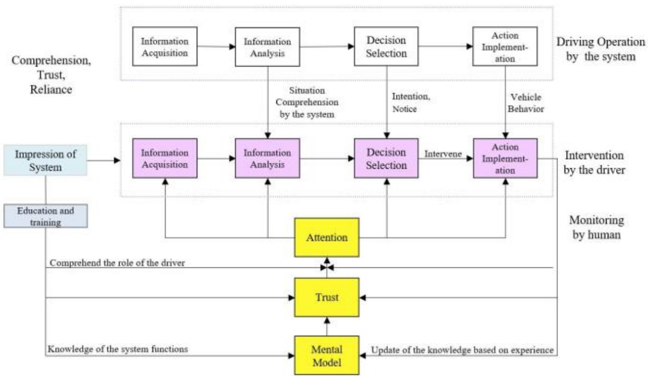


Figure 1. The Model of Human Information Processing when using a level 2 driving automation system

C. Purpose

This study focused on the required knowledge about system functions and limitations for drivers and how to give this knowledge to drivers for taking over safely and smoothly in the situations which hazard detection failure at level 2. The results of the SIP-adus Project, task A [15], which to understand effects of driver's knowledge about the system functions and limitations on driver's behavior in taking-over from automated, said that the possibility which the hazard detection failure will occur needs to be explained to drivers. Based on the results, the purpose of this paper is to clarify that whether explanation on possible scenes where the system might fail to detect hazards had an impact on driving intervention or not, and whether it is necessary to explain all possible scenes.

II. METHODS

A. Driving Automation System

This study was conducted in the D^{3}Sim driving simulator from Mitsubishi Precision, five 50-inch displays ahead of the driver's seat (Fig. 2), and Control Loading system (steering, accelerator, brake) from MOOG to simulate the motion of control devises. The driving automation system could act automatically when the vehicle started. The driver could use steering and brake pedals to override the automated control. The system will be canceled once the driver intervened the driving operation. The driving automation system manipulates the longitudinal (e.g. cruise control) and lateral (e.g. lane keeping) direction during automated driving but did not have automatic lane changing function.

Participants can release their hands from the steering wheel and remove their feet from the accelerator pedal and brake pedal when the automated driving is active. However, the vehicle will decelerate, and automated driving will be cancelled 5 seconds later after a notice is issued, the driver should resume the driving task otherwise a traffic accident will occur. The notice may not issue in some scenarios because of hazard detection failure.

Figure 2. The D^{3}Sim Driving Simulator and Five 50-inch Displays

B. Participants

30 participants in age from 61 to 79 years old (mean = 68.4, SD = 5.2) were recruited from via a local society after receiving approval from University of Tsukuba Research Ethics Committee. Each participant possessed a valid driving license and drove daily and did not have professional knowledge of driving automation system. After receiving an explanation of the data collection process, all the participants gave written informed consent for their participation.

C. HMI

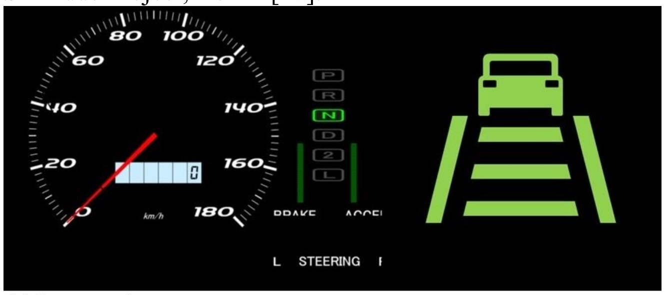
It is necessary to limit the content which conveyed from the system to the driver to examine the effect of explanation on scenes where hazard detection failure occurred. To grasp how to convey information to drivers, Otani et al. [16] investigated the driving behavior after system limitations occurred at level 2. As a result, it was confirmed that there was negative influence on driving behavior if not using audiovisual display to inform drivers of system limitations. Therefore, we used human-machine interface which present the system state by audio-visual display.

The driving automation system is active as shown in Fig.3(a), and the icon changes to black when the system is not active. When a notice is issued, the icon changes to orange and blinks at 5 Hz simultaneously with an audible "beeping" signal, as shown in Fig. 3(b), the driver is expected to intervene driving operation in 5 seconds.

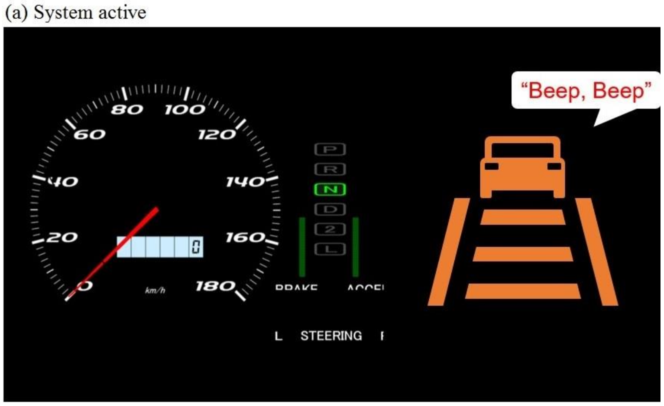
D. Experimental Design

In this study, a between-participants design was employed, with two levels of explanation on traffic scenes where hazard detection failure occurred. Group A was explained the possibility that a notice would be not issued and partially traffic scenes where a notice would be not issued. That is "The notice may not be issued even if the driving automation system cannot continue controlling. For example, a small falling object on the road such as pylon cannot be detected by the system. There is a possibility of collision if you do not do anything. You need to control the vehicle and avoid obstacles by yourself". And group B was only explained the possibility that a notice would be not issued.

We did not establish control group based on the results of the SIP-adus Project, task A [15].



(a) System active



(b) A notice is issued

Figure 3. HMI when active (a) and notice issued (b)

E. Procedure and Scenarios

Participants were explained of the experiment after obtained the signature on the consent form. Each participant was explained (1) The function and usage of the driving automation system; (2) Necessity of driving intervention from driving automation system; (3) The meaning of HMI; (4) Traffic scenes where a notice would issue because of system limitations; (5) Responsibility for safe driving; (6) Monitor the driving automation system conditions and the surrounding environment; (7) Knowledge of hazard detection failure as described in the section of experimental design. The experimenter was not allowed to provide supplementary explanation to the reading material for eliminating potential effects from variations in the experimenters' subjective opinions.

Participants performed exercises of manual driving and intervention when automated driving was active until proficient. After that, the formal experiment began. There was a two-lane highway and the automated driving speed of the vehicle is 80 km/h. Drivers must always abide by Japan traffic law. Each driver participated in nine events, there were three events which a notice was not issued because of hazard detection failure, four events which a notice was issued and two dummy events which system could deal with the situation automatically in the same order from S1 to S9 (Table I). Participants received a five-minute break after four events.

After the experiment, all participants were interviewed and filled in the questionnaire about the comprehension of intervention because of system limitations and system failures before and after experiment.

TABLE I. EXPERIMENTAL EVENTS AND SYSTEM RESPONSES

Event	System Responses
Pylon(S2)	No response because the system failed to detect hazards
Cardboard(S5)	
Vehicle stopping on the shoulder(S8)	
Construction site(S1)	A notice would be issued because of system limitations
Fog(S4)	
Interchange(S6)	
Vehicle cutting off(S7)	
Dummy 1(S3)	The system acted accurately and avoided hazards automatically
Dummy 2(S9)	

F. Hypotheses

- The driver does not comprehend of hazard detection failure if the driver is not explained scenes where the system fails to detect hazards. Therefore, the driver intervenes in driving operation delayed, changes the lane suddenly and an accident is likely to occur
- The driver can gain knowledge and experience from other explained scenes and deal well with the scenes where are not explained. Therefore, it is not necessary to explain all scenes for drivers.
- To comprehend intervention because of system limitations and system failures, it is necessary for drivers to experience some scenes, not just explanations.

G. Measures

We used the reaction time and whether an accident occurred when manual to analyze the driving behavior about intervention. The reaction time referred to the time when the driver performed the initial intervention (steering intervention or braking intervention). We used steering wheel torque larger than 0.5 (N·m) to detect steering intervention and braking pedal stroke larger than 0.1 (N·m) to detect braking intervention. The maximum steering angle when lane changing was also collected to analyze the driving behavior about lane changing. Furthermore, we used subjective evaluation which was visual analog scale from 1 to 10 to measure the comprehension of intervention before and after the experiment. The question is described as "Do you understand the intervention when driving automation".

III. RESULTS

A. Accident

We analyze driving behaviors from the 30 participants. Table II shows the number of accidents in events which a notice issued. There are only one traffic accidents occurred on group A and three traffic accidents occurred on group B of all events. There is no statistically significant difference between group A and group B. It shows that driving behavior is good when scenes are explained. See Table III, the result of

Pearson's chi-square test shows that there is a significant difference between group A and B in total. ($\chi^2(1) = 6.05$, $p < 0.05$*). The results show that the number of accidents will increase if traffic scenes where the system fails to detect hazards are not explained to drivers.

TABLE II. THE NUMBER OF ACCIDENTS IN EVENTS WHICH A NOTICE ISSUED

Event	Group A (15)	Group B (15)
Construction site(S1)	0/15	3/15
Fog(S4)	0/15	0/15
Interchange(S6)	1/15	0/15
Vehicle cutting off(S7)	0/15	0/15
Total	1/60	3/60

TABLE III. THE NUMBER OF ACCIDENTS IN EVENTS WHICH THE SYSTEM FAILS TO DETECT HAZARDS

Event	Group A (15)	Group B (15)
Pylon(S2)	1/15	4/15
Cardboard(S5)	0/15	4/15
Vehicle stopping on the shoulder(S8)	0/15	0/15
Total	1/60	8/60

B. *Reaction Time*

Kaplan-Meier survival curves for the reaction time of group A and B in events which the system fails to detect hazards are shown in Fig.4. According to the survival analysis, there is a significant difference between group A and B in S5($\chi2= 6.792$, df = 1, $p < 0.01$**), but for S2 and S8 there are no statistically significant differences between groups A and B. According to the graphs, however, for group A it decreases faster than B on S2 and S8. It suggests that the driver who is explained scenes comprehends the situation quickly. It shows that it is necessary for drivers to provide explanation on scenes where the system fails to detect hazards.

Among all nine cases of failed interventions, seven cases which do not intervene the vehicle before the collision occurred all belong to group B. The reason is that drivers think the system can deal with the situation or wait for the notice from interview after the experiment. Therefore, the driver that may not comprehend situations which hazard detection failure and driver's intervention is necessary. Furthermore, drivers in group A can also deal well with scenes where are not explained (S5, S8). It shows that it is not necessary to provide explanation on all scenes where hazard detection failure occurred because the driver can gain knowledge and experience from other explained scenes.

C. *Correlation between reaction time and maximum steering angle when lane changing*

We use correlation analysis to find the correlation between maximum steering angle when lane changing and reaction time in all events which the system fails to detect hazards. As a result, there is a positive correlation between maximum steering angle and reaction time (r=0.47, Fig.5). And there is a significant difference between maximum steering angle and reaction time. ($p<0.01$**). It suggests that the driver who intervenes delayed performs steering operation steeply in a hurry.

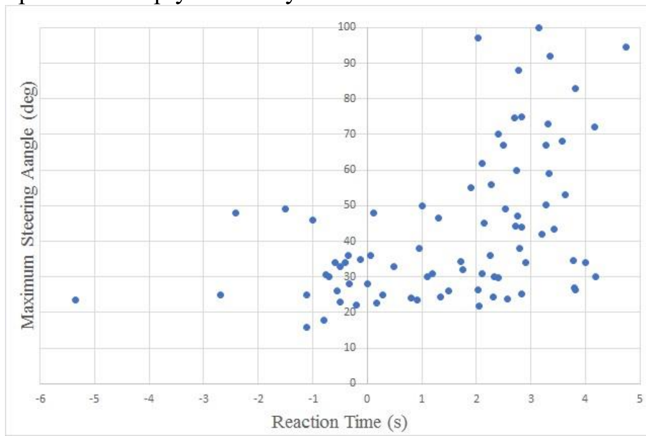


Figure 5. Scatter plot between Reaction Time and Maximum Steering Angle

IV. DISCUSSION

According to questionnaires, there is no statistically significant difference in the comprehension of intervention because of system limitations before and after experiment (Fig.6). A probable cause is overvaluation that some of drivers insist they have comprehended the intervention even if a traffic accident occurred in their driving. However, the comprehension after the experiment is higher than the comprehension before the experiment. It suggests that the actual experience may contribute to driver's comprehension. Therefore, it may be necessary for people to experience scenes where system limitations, not just explanation before they buy an automated driving car in the future.

Observed drivers' driving behavior, we also found that some of drivers (9/30), concretely speaking, five in group A and four in group B intervened in scenes where unexpected (such as dummy events). It suggests that drivers distrust the driving automation system because of the possibility of driving automation system fails to detect hazards. It is undesirable for the designer because drivers become to refuse to use the system. It is important to improve the driver confidence in the system. However, we should avoid overtrust because it may occur such as negligence of monitoring and abuse in highly driving automation system [17] and an accident may occur. Therefore, it is important for designing to establish appropriate trust which commission the system control when appropriate and intervene when necessary [18]. Therefore, it becomes a topic in designing of driving automation system.

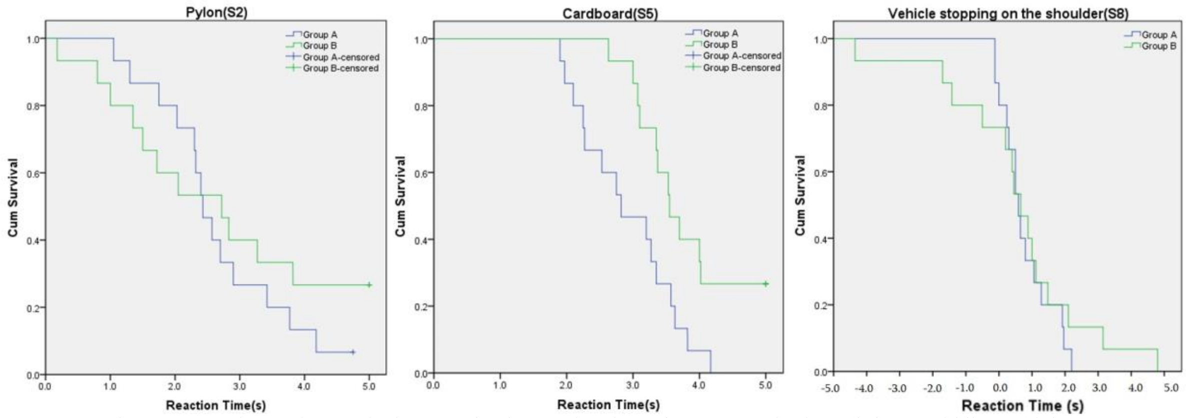


Figure 4. Kaplan-Meier Survival Curves for the reaction time of group A and B in S2(left),S5(middle),S8(right)

In our study, we provide the hazard which is a small falling object, that cannot be detected by the driving automation system to drivers. There may be countless potential hazards which cannot be detected by the system. It may be impossible to find out them in advance by some opinions. However, the standard of automotive functional safety is defined by ISO 26262[19]. To some extent, hazards which cannot be detected by the system can be predicted for designers. Then it is also possible to provide them to drivers. In the experimental design, the ratio of detection failure may affect the driving behavior. Therefore, we will experiment other ratio to figure out in the future.

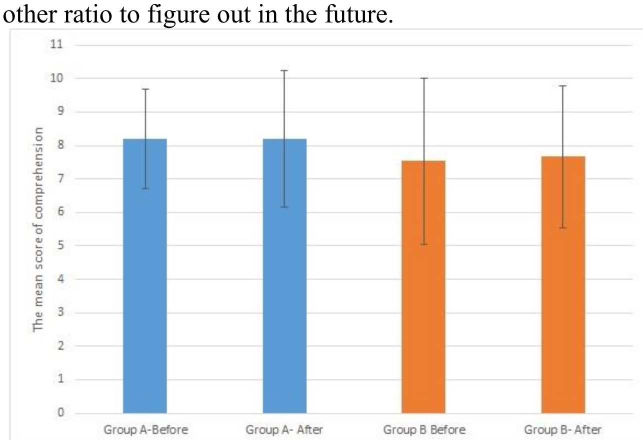


Figure 6. The Mean Score of Comprehension of Intervention before and after experiment

V. Conclusion

This study investigated that the impact of explanation on possibility of hazard detection failure on driver intervention under level 2. The results showed that some drivers who were not explained scenes where the system failed to detect hazards could not comprehend the situations and then an accident was likely to occur. Compared to drivers who were explained, drivers intervened the vehicle delayed and might perform steering operation steeply in a hurry. Therefore, it was necessary for drivers to provide explanation on possible scenes where the system failed to detect hazards to take-over from driving automation system safely and smoothly in a limited time.

Furthermore, the results showed that it may be not necessary to provide explanation on all scenes because drivers could gain knowledge and experience from other explained scenes. However, it is also important for taking-over to provide the information from the system about system status and limitation when automated driving. As our future works it is necessary to figure out the information which is required and how to convey the information to drivers for taking-over safely and smoothly. For that reason, the designing of human machine interface that as a mean of “human know the machine” [20] is essential.

Acknowledgment

This work was supported by Council for Science, Technology and Innovation (CSTI), Cross-ministerial Strategic Innovation Promotion Program (SIP), entitled “Human Factors and HMI Research for Automated Driving”. The authors would like to thank Y. Noguchi, N. Kashiwazaki, Y. Ishitsuka, and members of laboratory for their help in advice and data collection.

References

[1] National Transportation Safety Board(NTSB) News, Driver Errors, Overreliance on Automation, Lack of Safeguards, Led to Fatal Tesla Crash, 2017

[2] Neale, V. L., & Dingus, T. A, Commentaries in: Human Factor Issues for Automated Highway Systems (AHS). Intelligent Transportation Systems Journal: Technology, Planning, and Operations, 4, 111–119, 1998

[3] Trimble, T. E., Bishop, R., Morgan, J. F., & Blanco, M. Human factors evaluation of level 2 and level 3 automated driving concepts: Past research, state of automation technology, and emerging system concepts. (Report No. DOT HS 812 043). Washington, DC: NHTSA, 2014.

[4] Flemisch, F. O., Bengler, K., Bubb, H., Winner, H. & Bruder, R., Towards cooperative guidance and control of highly automated vehicles: H-Mode and Conduct-by-Wire. Ergonomics, 57(3), 343–360, 2014.

[5] SAE International, “Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles,” J3016, SAE International, 2016.

[6] D. Abbink, M. Mulder, and E. R. Boer, “Haptic shared control: Smoothly shifting control authority?” Cognition, Technology & Work, vol. 14, no. 1, pp. 19-28, 2012.

[7] Brookhuis, K. A., De Waard, D., & Janssen, W. H., Behavioural impacts of advanced driver assistance systems–An overview. European Journal of Transport and Infrastructure Research, 1(3), 245–253, 2001.

[8] Ryohei Homma, Takashi Wakasugi, Kenji Kodaka, Basic Study on Transition to Manual from Highly Automated Driving (First Report)-Effects of Drowsiness and Non-Driving-Related-Tasks and Driver Behavior When Take-Over-Requests Were Provided-, International Journal of Automotive Engineering (IJAE), Vol.47, No.2, p.537-542, 2016.

[9] K. Zeeb, A. Buchner and M. Schrauf, "What determines the take-over time? An integrated model approach of driver take-over after auto-mated driving," Accident Analysis & Prevention, vol. 78, pp. 212–221, 2015.

[10] Larsson, A. F. L., Kircher, K., & Hultgren, J. Andersson., Learning from experience: Familiarity with ACC and responding to a cut-in situation in automated driving. Transportation Research Part F: Traffic Psychology and Behaviour, 27(Part B), 229–237, 2014.

[11] Farrell, S., & Lewandowsky, S. A connectionist model of complacency and adaptive recovery under automation. Journal of Experimental Psychology. Learning, Memory, and Cognition, 26(2), 395, 2000.

[12] Martens, M. H., Pauwelussen, Schieben, Flemisch, F., Merat, Jamson, & Caci. Human factors' aspects in automated and semi-automatic transport systems: State of the art, 2008.

[13] Gold, C., Damböck, D., Lorenz, L., & Bengler, K., ''Take over!" How long does it take to get the driver back into the loop? In Paper presented at the proceedings of the human factors and ergonomics society annual meeting, 2013

[14] Toshio Ito, Kenta Osawa, Required time for take-over from automated to manual driving. Society of Automotive Engineers of Japan, 2015.

[15] Cabinet Office, Government of Japan. SIP-adus Project, Human Factors and HMI Research for Automated Driving, 2016

[16] Akira Ohtani, Yoshinori Egami, Kenji Sato, Kazushi Mitsui, Masaaki Abe, Human Machine Interface with Driver in Automated Driving (First Report) ―Driver's Behaviors under Lower Levels of Vehicle Automation. Society of Automotive Engineers of Japan, 2015.

[17] Sheridan, T. B., Supervisory Control. Handbook of Human Factors and Ergonomics, pp. 1025–1052, 2006.

[18] Lee, J. D., & See, K. A, Trust in Automation: Designing for Appropriate Reliance. Human Factors: The Journal of the Human Factors and Ergonomics Society,46(1), 50–80, 2004

[19] International Organization for Standardization (ISO), "26262: Road Vehicles-Functional safety." International Standard ISO/FDIS 26262, 2011.

[20] Toshiyuki Inagaki, Safety and Peace of Mind in Human-Machine Collaborations - Discussions from Human-Centered Automation Points of View -, Journal of the Japanese Council of Traffic Science, vol.9, No.1, pp. 11-20, 2010.