Human Factors Research in Automated Driving

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1. Toyota's Approach to Automated Driving

Recently, automated driving technology is being developed remarkably fast, and you can see it in many news outlets. Expectations for automated driving are increasing. For example, automated driving may eliminate or reduce traffic jams, reduce crashes, reduce environmental impact, improve mobility for older drivers and increase driving comfort. In order to resolve important societal problems and realize new and comfortable transportation in the future, national projects in the US, EU and Japan have been making progress.

Since the 1990s, Toyota has confronted the challenge of automated driving research. From the beginning of the research, we continue to think that the synchronization between the vehicle and the driver is essential in order to sustainably realize and expand automated driving technology. We have used the Mobility Teammate Concept as the basic framework to support human and system integration. This concept shows our aim of automated driving technology development, "Aim to achieve a society that all people can move safely, Efficiency and with Freedom." (Figure 1)

Figure 1. The Mobility Teammate Concept

2. Research into the Interaction between Automated Driving and Humans

2.1 Vehicle↔Driver Interaction

SAE defined the 6 different levels for automated driving systems (Figure 2). In this presentation, we clarify the problems in each automation level and propose the direction of necessary next steps. Especially for the level 2 and 3 automation, the driver may be confused about his responsibility for monitoring roadways and performing safe operations. The analysis of situations of take over requests (TOR) and driver behaviors at TOR is an urgent topic, which the automotive industry must address. HMI with driver-system coordination is being studied in each field.

Figure 2. SAE International's Levels of Driving Automation (Ref: <http://articles.sae.org/15021/>)

The figure 3 shows the process of the driver's recognition and action when the system transitions from automated driving to manual driving due to urgent system errors. In order for the driver to exchange the controls from the vehicle to the driver,

The driver needs to respond to the exchange after a system prompt, understand the situation and perform an appropriate action. This requires some time. After this, a slightly longer time will be required for the driver to take over driving while reaching stability with the driving controls. It is a substantial challenge in automated driving to transfer control during abrupt state

changes with limited transition time.

Figure 3. Transition from Automated to Manual Driving

From HMI point of view, we can see two issues here regarding a responsibility transition in Level 2 and 3 automated driving. One is that the lower level of readiness requires a longer time to regain control. The other is that Level 3, compared to Level 2, is more difficult for the driver to maintain readiness when needed and results in a longer time to regain control.

For these issues of “transition of responsibility”, the challenges for HMI are; What type of HMI can maintain high enough driver readiness? What type of HMI can reduce the time of a driver state transition? (Figure 4)

Ref. : Concept image from SIP automated driving system result report of HMI task force (Apr/2016)

Figure 4. Challenges of HMI

2.1.1. HMI to maintain driver readiness.

In a steady condition of automated driving, the driver is required to maintain some level of readiness. In such a condition of automated driving, the HMI needs not only to improve and maintain readiness, but also to minimize annoyance and distraction for the driver. Multiple subconscious stimuli has been studied in various research projects (Figure 5).

Figure 5. Maintaining Driver State: User-Centered HMI

2.1.2. HMI to improve a driver state transition.

A successful driver state transition will be achieved with HMI which is intuitive and easy to understand. “Reduction of reaction time” and “Accurate comprehension and decision” will be important factors to realize appropriate HMI (Figure 6).

Reaction time consists of Perception time reacting to a warning, Recognition time including eye movements and visual accommodation, and Decision and Expectation time of information processing.

HMI such as a display is required to have intuitiveness, and reduce each time component and promote more accurate comprehension and decision.

Various concepts of multi-modal information have been proposed recently. We are expecting research outcomes in the near future.

Figure 6. Driver State Transition: Intuitive Interface

Toyota’s HMI goal is creating HMI that can synchronize the system with the human and resolve driving operation problems by using the HMI technology mentioned before.

We aim to provide an HMI that encourages the driver to maintain the balanced point. With this, we believe we

can provide safe and comfortable automated driving for our customers.

2.2 Vehicle⇌Society Interaction

When we think about the evolution of automated driving, there are two approaches. The first one is enhancement of automation technology from only the system side. And the other one is a human-centric method to improve advanced driving support systems while maintaining social acceptance.

The goal of both approaches is no crashes, and Toyota continues to develop technologies in both ways. However, we are striving for the Teammate concept to provide better harmonization with society.

2.2.1 Communication between Automated Driving and Surrounding Society

We believe that automated vehicles must be sociable because there is communication between “Me” and “You” (Figure 7). This sociable vehicle behavior is necessary to create a trust relationship which is built on understanding the intent of each other. For example, if the automated driving has contrary movement to the social behavior in a traffic flow, it cannot construct a trust relationship, and cannot be accepted easily into society.

Figure 7. Communication between Automated Driving and Surrounding Society

2.2.2. Challenges of Traffic Communication in an Aging Society

We are facing unique prevalence of older drivers in certain types of crashes and the concerning rates of mild cognitive impairment. This suggests that the increasingly large number of aging society members may integrate poorly into traffic society in the future.

Based on cognitive impairment increasing in the future, we can use automated driving technologies to help older drivers harmonize with traffic and avoid crashes by predicting risky driving and providing proactive assistance for drivers. Additionally, we expect to mitigate the negative social and physical impacts of aging by maintaining driving independence. Automated driving will play a significant role while maintaining mobility across the lifespan (Figure 8).

Supporting Drivers to Harmonize Driving Behavior

Figure 8. Maintaining Mobility Across the Lifespan

3. Synchronization Between the Driver and the Vehicle in High Level Automated Driving

When fully automated driving is available, a driver’s in-vehicle activity will change significantly. HMI needs to consider totally different interactions from the current assumptions. New HMI will need to play a role not only as the function of driving support information, but also as communication partner of the driver.

Toyota aims towards “teammate concept”: The AI vehicle shares the common goal with the driver, communicates closely with the driver through HMI, and creates safe driving by adapting to the driver.

When there is an emergency, the AI system assists the driver intelligently. The driver understands the AI subconsciously, and then the driver subtly gets benefits from AI system.

Toyota’s HMI supports the “teammate concept” from these two aspects; One is the intelligence of the driving agent and the other is kindness of the communication. What this means is that the AI partner supports driving and develops a partnership like a close friend. The AI partner will change the method for a particular assistance level and a communication method. And the AI will select the best interaction case by case in real time.

3.1. Utilize the Big Data for AI Partner

For the evolution of HMI technology, we need to consider it's link with BIG DATA for the future. The basic technology of HMI in the vehicle consists of 3 components. One is the detection of external information such as driver monitoring information and in-vehicle sensor information. Two is the estimation of the internal state of the driver by extracting characteristics of state. And three is the component to prompt the human through the AI partnership. We would like to evolve the HMI technology by using BIG DATA for the detection, and AI for the state estimation and prompting the human (Figure 9).

Figure 9. Utilize the Big Data for AI Partner

3.2. AI Adjusts to Human Cognitive Development

Driving skill and driving style change over time.

AI also will change the driver model to adjust to the driver over time. It means that the AI subconsciously develops a cognitive model of the driver when the driver also develops the control model of AI.

This is that: The AI will support the driver's learning as the driver wants to improve him/herself. The AI develops "a cognitive model of the human" and the human subconsciously develops "a control model of the AI". So that over time the human and AI develop a deeper understanding of each other, adapt mutually, and then become teammates.

When the harmonization between the driver and the vehicle works well, And the driver develops a deeper understanding of the process that the vehicle uses to understand the driver,

The vehicle will become a personalized vehicle that understands the driving style and skill to react appropriately (Figure 10).

Figure 10. The new relationship driver and vehicle

4. Conclusion

With the evolution of driving AI, We believe that automated driving technology can realize both of the goals of "Mobility freedom" and "Driving enjoyment". "Mobility freedom" means that there are No crashes, and that Everyone can move safely and comfortably and "Driving enjoyment" means that drivers can Drive as they intend, Can improve driving skills, Can have fun, and Can Maintain an active life (Figure 11).

Automated driving is a big innovation incorporating AI, Big-data and connected technology. This would change the interaction not only between the driver and vehicle, but the interaction with surrounding road users such as pedestrians, and expand finally the interaction at the society level. The problems of automated driving will be more diverse along with social change. Toyota would like to create a future society with automated driving with a new approach and collaboration with the other fields. We appreciate comments from all academic society members.

Figure 11. Create New Value with Automated Driving Technology