A Simulator-Based Approach to Assess Take-over Performance in a Conditionally Automated Vehicle

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Abstract. The interaction between the driver and the automated driving systems (ADS) will remain a key element of automated driving because drivers are expected to be available to take over control for the case of system failure or limitation in a conditionally automated vehicle, i.e. SAE level 3. A number of studies reported that various factors such as the time budget, the traffic complexity, and the driver's inattention may influence take-over time and quality. Therefore, the driver's take-over performance must be carefully analyzed to ensure a safe transition. This study aims to propose a take-over performance assessment method using a driving simulator. A systematic review was conducted to design a driving scenario for unintended take-over events. As a result, a take-over performance test protocol with four take-over situations such as missing lines on a straight and a curved road, road construction, and system failure was designed. Visual and cognitive non-driving related tasks, which influence a driver's situation awareness and take-over performance, were also considered. It will be proposed as Korean Traffic Safety Regulation to assess the safety of the take-over control in a conditionally automated vehicle from the perspective of the driver.

Keywords: Take-over performance · Conditionally automated vehicle Simulator-based assessment

1 Introduction

Improvement of the automation level frees drivers from the primary driving tasks and allows to perform non-driving related tasks by shifting attentional resources to other tasks during driving [1]. However, the existing automated driving systems (ADS) are still considering a driver as a fallback-ready user who is receptive to the ADS-issued requests to take-over [1, 2]. Previous studies on automation and human factors found that a high level of automation can cause out-of-the-loop problems [3] and humans are

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not good at tasks that require vigilance for prolonged periods of time [4]. Thus, the driver's take-over performance must be carefully investigated to ensure a safe transition in a conditionally automated vehicle. This paper aims to propose a harmonized experimental protocol to assess drivers' take-over performance in a driving simulator and compare the results around the world.

2 Research Frameworks

In order to design an experimental protocol, we adopted a framework for human factors of transitions in automated driving [1, 5] and categorized the factors for the simulator-based take-over experiment design (Table 1). The factors are assigned to four simulation design elements such as participants, driving contexts, control contexts and ADS design. Among the simulation design elements, the participants and the ADS design were not considered because the recruitment of participants is dependent on the size and budget of the experiment and the ADS design are related to the individual design philosophy. The driving contexts was further investigated to propose a harmonized experimental scenario and summarized in Table 2. Except the system failure, most of the driving context factors were used in the previous studies. Although the system failure may affect the participant's perceived reliability and safety, it is worth considering as a safety-critical event.

Table 1. The factors of transitions in automated driving

Factors				Conditions	Simulation Design
Initiator of the transition (From)				Driver Car	Control Contexts (Apparatus Support)
Control after transition (To)				Driver Car	Control Contexts (Apparatus Support)
Situation Awareness	Situation Variables	Traffic Complexity	Roadway Type	Number of lanes Geometry (Straight/Curved)	Driving Contexts
			Events	System Failure / Limitation External Object	Driving Contexts
			Traffic Density	Number of vehicles per km	Driving Contexts
		HMI	Informing Interface	Visual Vocal Acoustic Tactile	ADS Design (Apparatus Support)
			Deactivation Interface	Button / Lever Steering wheel Pedals	ADS Design (Apparatus Support)
		Non-Driving Related Task		Visual Manual Cognitive	Control Contexts (Apparatus Support)
	Driver Variables	Age		Younger Older	Participants
		Gender		Male Female	Participants
		Driving skill		Experienced Novice	Participants
		Knowledge of ADS		Low High	Participants
		Take-over Readiness		Low High	Control Contexts (by NDRT)

Table 2. Summary of driving contexts in previous studies

Previous studies	Traffic complexity					
	Roadway	Take-over events			Traffic density	
	Geometry	Missing lane mark	External objects	System failure	Surrounding car	Defined density
Zeeb et al. [6]	S[a], C[a]	O	–	–	O	–
Zeeb et al. [7]	S, C	O	O	–	O	O
Zeeb et al. [8]	S	–	O	–	O	–
Chae et al. [9]	S, C	–	O	–	O	–
Melcher et al. [10]	S	–	O	–	–	–
Kuehn et al. [11]	S	O	–	–	–	O
Lorenz et al. [12]	S, C	–	O	–	O	–
Hergeth et al. [13]	S	–	O	–	–	–
Forster et al. [14]	S	–	–	–	O	–
Naujoks et al. [15]	S, C	O	–	–	O	–
Radlmayr et al. [16]	S	–	O	–	O	–
Happee et al. [17]	S	–	–	–	O	–
Gold et al. [18]	S	–	–	–	O	O
Clark and Feng [19]	S	–	O	–	O	–
Braunagel et al. [20]	S, C	–	–	–	O	O
Gibson et al. [21]	S, C	–	O	–	–	–
Korber et al. [22]	S, C	O	–	–	–	–

[a]S: straight, C: curved

3 Proposed Experimental Protocol

3.1 Experimental Design

In this study, the factors including 'take-over events', 'traffic density' and 'NDRT' were selected as independent variables. They are expected to affect situation awareness and drivers' readiness. As mentioned in the previous section, age, gender, and experience are considered as latent variables that can influence the take-over quality and take-over performance. Therefore, it is worth to note to recruit participants considering the proportion of sample size.

3.2 Take-over Situations in Driving Contexts

Based on the literature survey of the previous studies, this study proposes the driving contexts of four representative situations such as "Lane marking is missing on a straight road (S1)", "Lane marking is missing on a curved road (S2)", "Roadwork appears during driving a straight road (S3)", and "An automated system is deactivated due to system failure on a straight road (S4)". As shown in Table 3, S1 is the scenario with the lowest complexity and S4 is the highest.

Table 3. Take-over situations in the driving contexts

	S1	S2	S3	S4
Roadway	Straight	Curved	Straight	Straight
Lane marking	Missing	Missing	Visible	Visible
Roadwork	X	X	O	X
System failure	X	X	X	O
Surrounding cars	O	O	O	O
Traffic density (vehicles/km)	10	10	10, 30	10, 30

3.3 Take-over Performance Measures

Reaction time, take-over time and take-over quality measures are typical dependent variables in take-over related studies. The potential measures to assess take-over performance are summarized in Table 4.

Table 4. Summary of take-over performance measures

Measures	Description
Reaction times	
Time to eyes on (s)	First gaze at road (video labelling) [6]
Time to hand on (s)	First gaze at road (video labelling) [6]
Time to driver intervention (s)	Steering: steering wheel angle velocity $\geq$ 10/s [6]
	Braking: standardized brake pedal travel $\geq$ 10% [6]
Take-over time	
Time to disengage automation	[7, 8]
Steering response time (RT_{steer})	the point in time where the steering wheel angle exceeded 2° in the direction of the lane change [6]
Brake response time (RT_{brake})	the first point in time where the brake pedal was depressed more than 10% of the available stroke [6]
Take-over quality	
Maximum accelerations	[8, 13, 23]
Minimum time headway to an obstacle	[24–26]
Reaction type	Steering only, braking only, steering and braking [6]
Lateral maneuver	
Max. deviation from lane center (m)	Max. deviation of the ego-vehicle from the center of the ego-lane [6]
Min. Time to lane crossing (TLC)	Min. time to lane crossing (as measured by half of the ego-vehicle crossing the lane marking) [6]
Longitudinal maneuver	
Min. Distance (m)	Min. distance to leading vehicle [6]
Min. Time gap (s)	Min. time gap to leading vehicle [6]
Time to collision (TTC)	The time required for two vehicles to collide if they continue at their present speed and on the same path

4 Summary and Concluding Remarks

This paper proposed a simulator-based method to evaluate the take-over performance of the conditionally automated vehicle. In this study, we categorized a driving simulator experimental protocol into four components, i.e., driving contexts, control contexts, ADS design and participants. Then the driving context related parameters were selected based on the previous studies. Finally, four take-over events and performance measures were proposed. The result of this study may contribute to establish a guideline for take-over experiments. A pilot test will be conducted based on this experimental design.

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