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# Situation Awareness and Transitions in Highly Automated Driving: A Framework and Mini Review

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## Abstract

The human factors of transition in highly automated driving is becoming crucial, because transitions between the driver and the automation will remain a key element of automated driving until fully automated driving replace manual operation. This paper aims to suggest the framework to investigate human factors in transition of highly automated driving. The framework classifies transitions according to the transition initiator, control after transition, and situation awareness. Based on the framework, we retrieved previous studies and categorized their experimental designs. The inclusion criteria for the review were transitions which involved SAE level 3 automated driving and the research topics on driver behavior and/or performance during a transition. Finally, we interpreted the empirical studies on transitions using the proposed framework, and suggested areas for future research.

**Keywords:** Automated driving; Human factors; Transitions; Situation awareness

## Introduction

Automated driving vehicles have the potential to reduce the number of traffic accidents [1] and improve road safety, because most of accidents are attributed to human error [2,3]. They also contribute to improve fuel economy, reduce emissions, increase efficiency of land use for city planning, and increase driving possibilities for the physically impaired [4].

The existing automated driving systems function as supportive automation and some advanced systems allow the driver to be out-of-the-loop for extended periods, but the systems still expect that the driver stays in the loop to monitor the environment and control part of the driving task [5]. Thus, the interaction between the driver and the automated driving system must be considered until the fully automated vehicle will be able to drive on the public road. The results from an interview study also suggested that human factors perspective on automated driving need to be considered by researchers, designers, and policy makers because the driver's role in automated driving is changed from manual driving [6].

Previous studies on automation and human factors have found that a high level of automation can cause out-of-the-loop problems [7,8] and suggested the effect of vehicle automation on driver behavior, including complacency [9], mental workload [10-12], driver state [5], and situation awareness [13]. A recent study on partially automated driving argued that intermediate levels of automation in which the human driver is expected to monitor the automated driving system, may be hazardous because humans are not good at tasks that require vigilance for prolonged periods of time [14]. Empirical studies also confirmed the out-of-loop problem in driving automation by showing that accidents are likely to occur in situations where drivers suddenly have to resume manual control from an automated driving system [15-17].

However, the driver's vigilance is a key component in the definition of automated driving systems developed by three authorities, namely the Society of Automotive Engineers [18,19], and the United States National Highway Traffic Safety Administration [20,21], the German Federal Highway Research Institute [22]. Due to the fact that the SAE, NHTSA, BASt conflated required behavior with actual behavior for vigilance [5], the definition of driving automation level may still have limitation.

In order to understand the driver behavior in a highly automated driving vehicle, this paper proposes a framework that incorporates situation awareness into transitions between the driver and automated driving.

## Driving Automation and Situation Awareness

### Driving task

Driving is a complex visuomotor task that requires good coordination of cognitive, sensory and psychomotor skill as well as attention and concentration of the driver. Michon identified a three-level model that included strategic, tactical, and operational levels [23]. We may also consider driving as three primary driving tasks including lateral control, longitudinal control, and monitoring, which are present in the definition of levels of automated driving [5].

### Automated driving system

The SAE and NHTSA defines six different levels of automated driving system, ranging from level 0 (no driving automation) to level 5 (full driving automation) based on what extent of the primary driving task are performed by the human driver or the system [19,21]. As the level of automation increases, the role of the human driver shifts from a primary operator to a passive supervisor. However, the SAE explicitly impose responsibility for monitoring the driving task and the road environment to the driver for the lower levels (level 0, level 1, and level 2), and the system for the higher levels (level 3, level, 4, and level 5) [24]. The mixed categorization between the hierarchy of the technology and the expected driver behavior, i.e., the amount of human supervision, may create false expectations among policymakers and the public [25]. For example, SAE level 2 (Partial Automation) and level 3 (Conditional Automation) depend on the driver's monitoring task. The driver must monitor the driving task in level 2 but monitoring is not expected in level 3. In the both level, however, drivers are expected to be available to take over control for the case of system failure or limitation. In other words, drivers have no responsibility to monitor the driving task but must have a certain level of situation awareness. As mentioned, the supervisory role in higher automation level takes drivers out-of-the-loop and impairs their ability to manage critical situations such as automation failure and limitations.

### Situation awareness in automated driving

A common definition of situation awareness (SA) is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future [26]. Endsley also conceptualized three levels of SA including perception (level 1), comprehension (level 2), and projection (level 3) [13].

There is a close relationship between automated driving and SA. Drivers in highly automated driving gaze on the road less often than when in manual control, which therefore could result in lower workload, but also poor situation awareness [27].

### Transitions in automated driving

A transition in automated driving can be defined as a process during which the driver-automation system changes from one driving state to another driving state [5]. For example, from SAE level 3 driving state to level 0 driving state means that the driver resumes manual driving with sufficient SA. Marten et al. classified the possible control transitions between the driver and the automation based on three questions, including 1) "Who has it?" 2) "Who should get it?" and 3) "Who initiates transition?" [28]. The results provided four types of transitions: 1) driver-initiated, from the driver to the automation control (DiAc), 2) automation-initiated, from the driver to the automation control (AiAc), 3) driver-initiated, from the automation to the driver control (DiDc), and 4) automation-initiated, from the automation to the driver control (AiDc).

Among four types of transitions, an AiDc transition which known as a 'take over', may be caused by a failure or exceedance of the automation's operational limits. It may cause serious accidents if the driver is not able to manage the situation due to loss of situation awareness or temporal inability to drive. Thus, the time to resume manual control after automated driving has attracted growing attention in recent years [17]. The temporal sequence of a take-over process after highly automated driving is illustrated in Figure 1. The take-over time is specific for a particular set of situation variables such as traffic complexity, Human-Machine Interface (HMI) concept, and level of driver distraction, and driver variables, including age and driving skill [17].

### A framework for transitions in highly automated driving

By integrating transitions in automated driving with situation awareness, we can generate a classification tree of transitions in highly automated driving in Figure 2. The first dimension is the initiator of the transition, i.e., driver or automation. The second dimension is who is in control after transition. The third level is situation awareness related variables, including level of distraction, traffic complexity, HMI concept, age and driving skill.

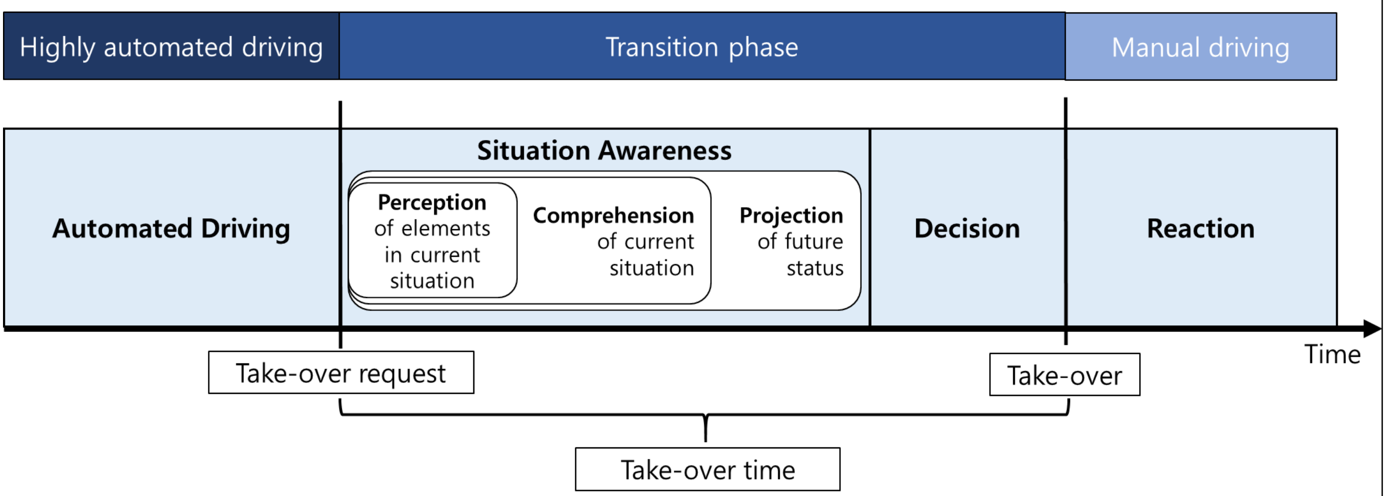


**Figure 1:** The take-over process from highly automated to manual driving.

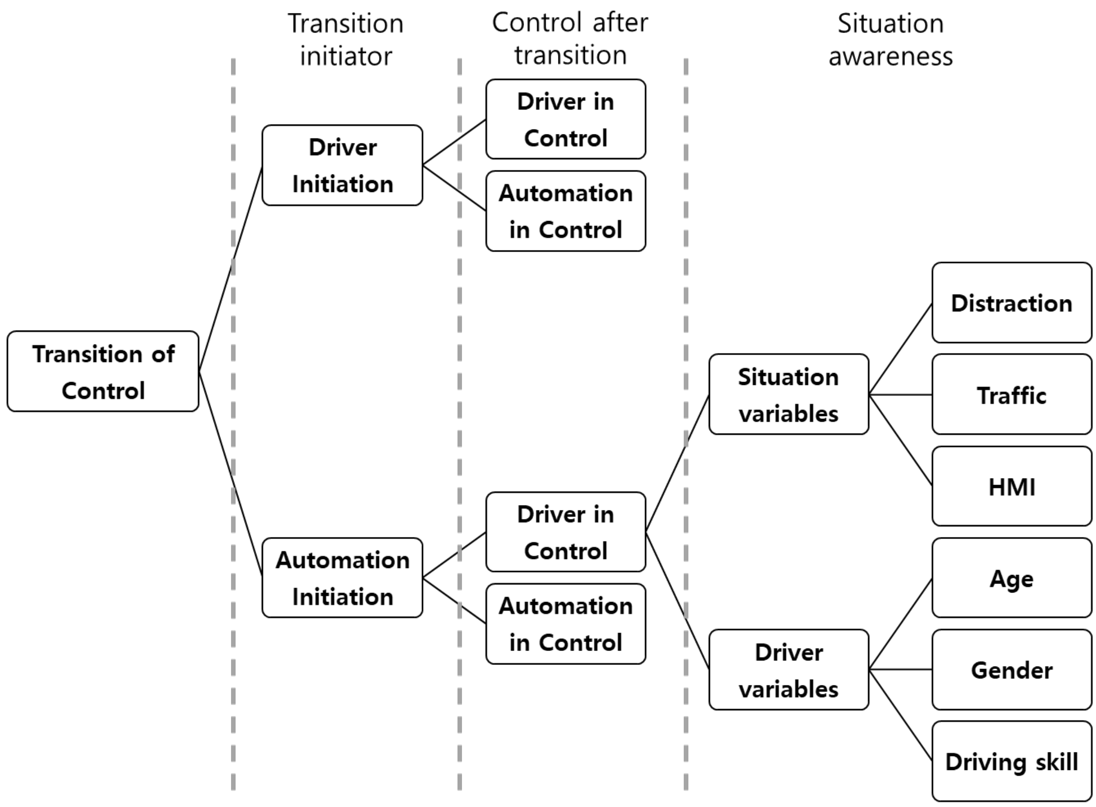


**Figure 2:** Classification tree of transitions in highly automated driving.

## Survey of Human Factors Research on Transitions in Automated Driving

### Methods

In this section, we review previous experimental studies using above framework of transition and situation awareness to understand the empirical literature systematically and recommend further research. We focus on transitions where the driving state changed from SAE level 3 to level 0. A meta-analysis showed that driver that drivers' overall workload while driving in SAE level 3 is substantially lower than while driving with level 1, and this low-workload situation may be challenging in a high-workload safety-critical AiDc transition [27].

We reviewed empirical research based on the following inclusion criteria: (1) The control transition should involve driving SAE level 3, (2) The study should focus on driver behavior and/or performance during a transition, and (3) The paper should be in English.

### Results

Results from our literature review found that the experimental studies on transitions in highly automated driving focused on driver's behavior, cognitive states, and take-over performance. The results are summarized in Table 1.

In general, the experiments have attempted to find an effective method for increasing the driver's situation awareness and yielding shorter reaction times. Telpaz et al. and Petermeijer et al. suggested that tactile feedback leads to a faster response time compared to no tactile feedback [29,30]. Naujoks et al. found that visual-auditory warnings were more efficient to reduce drivers' reaction times compared to a visual-only [31].

A number of studies which assessed driver behavior after transition from highly automated driving, found that the shorter time budget decreased the take-over quality, including percent of accidents and maximum longitudinal/lateral acceleration [32,33]. They also found that the higher complexity of the traffic increased the take-over time due to longer situation awareness regaining. Several studies used secondary tasks to reduce the driver's situation awareness while highly automated driving, and found that higher levels of situation awareness are beneficial for safety, improving driving performance after the transition.

## Discussion and Concluding Remarks

In this paper, we suggested a framework that incorporates situation awareness into transitions between the driver and automated driving, and reviewed previous studies for understanding the driver behavior in a highly automated driving vehicle, especially at the moment of transition from automation to the driver. A number of well-designed experiments have already been conducted, but there is still a lot of room to fill.

Regarding the types of transition, most previous studies focused on AiDc transition (Table 1), but the driver's behavior in AiAc transition to manage safety critical event situation regardless of the driver's state, e.g., automatic emergency braking (AEB), may be considered.

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| **Paper** | | | | | **Toffetti et al. [34]** | **Van den Beukel and Van der Voort [33]** | **Kerschbaum et al. [35]** | **Merat et al. [16]** | **Naujoks et al. [31]** | **Radlmayr et al. [32]** | **Telpaz et al. [29]** | **Zeeb et al. [17]** | **Petermeijer et al. [30]** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SAE level before transition** | | | | | **L3** | **L3** | **L3** | **L3** | **L3** | **L3** | **L3** | **L3** | **L3** |
| Initiator of the transition | | | | Driver | | | | | | | | | |
| | | | | Car | * | * | * | * | * | * | * | * | * |
| Control after transition | | | | Driver | * | * | * | * | * | * | * | * | * |
| | | | | Car | | | | * | | | * | | |
| Situation Awareness Factors | Situation on variables | Traffic complexity before transition | Roadway | Uninterrupted Flow | * | * | * | * | * | * | * | * | * |
| | | | | Interrupted Flow | | | | | | | | | |
| | | | Driving Scenario | In Lane | * | * | * (Curved) | * | * | * | * | * | * |
| | | | | Changing Lane | | | | | | * | | | |
| | | | Event | System Failure/ Limitation | | | | | * (missing lines) | | | | |
| | | | | External Object | * | * | * | | * | * | * | * | * |
| | | Distraction | | Visual | * | * | | * (reading) | * | | | | |
| | | | | Cognitive | | | | | * | | | | * (n- back) |
| | | HMI | Informing interface | Visual | * | | * | * | * | * | * | * | |
| | | | | Vocal | * | | | | | | | | |
| | | | | Acoustic | * | * | * | | * | * | * | * | |
| | | | | Tactile | | | | | | | * | | * |
| | | | Deactivation interface | Button/Lever | * | | * | | * | | | * | |
| | | | | Steering wheel | * | * | * | * | * | * | * | * | * |
| | | | | Pedals | * | * | * | * | | * | * | * | * |
| | Driver variables | Age | | Non-older | * | * | * | * | * | * | * | * | * |
| | | | | Older | | | | * | | | * | | * |
| | | Gender | | Male | * | n/a | * | * | n/a | * | * | * | * |
| | | | | Female | * | n/a | * | * | n/a | * | * | * | * |
| | | Driving skill | | Experienced | * | * | * | * | * | * | * | * | * |
| | | | | Novice | | | | | | | | | |

**Table 1:** Experimental studies on transitions in highly automated driving.

For the transition scenarios, the situation variables and the driver variables need to be considering designing experimental scenarios. The situation variable may be manipulated by adding more complex situations, including interrupted flow (e.g., urban traffic), take-over request during lane change, and secondary tasks (e.g., SuRT [36] and N-back [11]). In the driver variable, the older and novice drivers are not carefully considered yet. Especially, it is known that the older driver showed different performance at the moment of high workload [11]. The effect of age on transition in highly automated driving need to be considered.

In summary, the paper suggests the framework to investigate the driver behavior in transition of highly automated driving by considering situation awareness. The literature review overviewed the state of the art of human factors research in automated driving, and suggested that human factors engineering is crucial when introducing automation to a human-machine system, because transitions between the driver and the automation will remain a key element of automated driving until the driving task is wholly automated and humans are prohibited from driving manually [5].

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