Designing An Informative Interface for Transfer of Control in Level 2 Automated Driving System

SAFETY RESEARCH USING SIMULATION

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A Report on Research Sponsored by

SAFER-SIM University Transportation Center

Federal Grant No: 69A3551747131

August 2019

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. UM-4-Y2	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Designing An Informative Interface for Transfer of Control in Level 2 Automated Driving System		**5. Report Date** August 2019 **6. Performing Organization Code**
7. Author(s) Shannon C. Roberts, Ph.D., PI https://orcid.org/0000-0002-0052-7801 Yalda Ebadi https://orcid.org/0000-0002-0871-5225		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Roberts Research Group Mechanical and Industrial Engineering Department 160 Governors Drive Amherst, MA 01003		**10. Work Unit No.** **11. Contract or Grant No.** Safety Research Using Simulation (SAFER-SIM) University Transportation Center (Federal Grant #: 69A3551747131)
12. Sponsoring Agency Name and Address Safety Research Using Simulation University Transportation Center Office of the Secretary of Transportation (OST) U.S. Department of Transportation (US DOT)		**13. Type of Report and Period Covered** Final Research Report (June 2018 – August 2019) **14. Sponsoring Agency Code**
15. Supplementary Notes This project was funded by Safety Research Using Simulation (SAFER-SIM) University Transportation Center, a grant from the U.S. Department of Transportation – Office of the Assistant Secretary for Research and Technology, University Transportation Centers Program. *The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated in the interest of information exchange. The report is funded, partially or entirely, by a grant from the U.S. Department of Transportation's University Transportation Centers Program. However, the U.S. government assumes no liability for the contents or use thereof.*		
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17. Key Words		18. Distribution Statement	
Design; Highways; Safety and Human Factors; Vehicles and Equipment;		No restrictions. This document is available through the SAFER-SIM website, as well as the National Transportation Library	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 44	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Abstract

Although automated driving systems have made significant progress over the past few years, human involvement is still vital, especially for Level 2 (L2) systems. One of the challenges of L2 systems is transfer of control between drivers and systems. The objective of this study was to design and evaluate an in-vehicle interface for an L2 automated vehicle to increase situation awareness and help drivers identify and understand critical situations that require transfer of control. A comprehensive study was conducted in three Phases. In the first Phase, drivers' behavior in simulated drives was analyzed using video recordings, interviews, and questionnaires. Three different road geometries were considered: curves, intersections, and merges. Following this Phase, four design iterations were developed in the second Phase of the study. The final prototype was applied to the dashboard of the driving simulator cab. The third Phase included a between-design experimental study to test efficiency of new dashboard designs. Forty-two participants were recruited and assigned randomly to three different groups based on dashboard design (Advanced, Basic, Original) and all participants in each group drove through seven scenarios. Results showed that providing take back control feedback (combination of visual and audio) helps drivers to be more situationally aware while driving L2 vehicles. Additional feedback regarding road geometry can also improve drivers' take back control performance. The method and results of this study can help both researchers and manufacturers to gain more insight towards future designs of feedback systems in L2 vehicles.

1 Introduction

Driver support features (DSF) and automated driving features (ADF) have progressed rapidly in the past decade (NHTSA, 2018). These systems have the potential to cause a major shift in terms of how drivers interact with their vehicles (Milakis et al, 2017). Generally, DSF and ADF equipped vehicles are expected to reduce crashes, increase driver' comfort, reduce traffic congestion, and help decrease carbon emissions (Van den Beukel et al, 2016). However, most systems that are available to the motoring public, all DSF, are still dependent on human supervision. To remain safe, drivers cannot over-rely on the systems. Additionally, drivers need to remain situationally aware to understand the complex operational design domain (ODD) of each DSF feature and to know the status of automation. Only then can the driver be prepared to take over control when the system is no longer capable.

In 2014, SAE introduced a six-level classification system for automation which ranged from fully manual (Level 0) to fully automated systems (Level 5). At Level 0, drivers needs to perform all driving tasks while at the other end (Level 5), system has full vehicle control. Levels 0 through 2 are referred to as DSF systems where the human monitors the driving environment. In Level 2 systems, two of the primary driving functions (i.e., longitudinal and lateral control) are performed by the system, but drivers are responsible for monitoring the system and must be ready to intervene and take back control from system at any moment. Level 3 to level 5 are referred to as ADF system where automated driving system monitors the driving environment (SAE, 2014).

1.1 Challenges of Level 2 Automated Vehicles

There are several concerns with Level 2 (L2) vehicles and most are related to over-reliance on automation and a subsequent failure to take over control (Buckley et al, 2018; Parasuraman & Riley, 1997). First, and perhaps most importantly, in DSF vehicles, drivers get confused regarding whether they need to intervene or whether the system has primary responsibility of driving (Gibson et al., 2016). In part, this is because drivers do not understand the ODD of DSF features and assume that automation will function in a much broader domain than what it was intended. Second, it is challenging for drivers to maintain their vigilance (Merat & Lee, 2012) and consequently, drivers may fail to detect uncommon, complex situations that otherwise they would normally detect (Jones, 2015). However, activating vehicle automation means that drivers need to be responsible for maintaining situation awareness at all points in time. Third, some studies show that drivers confusion regarding whether DSF has been engaged is a common issue in human-vehicle interaction, especially in case of L1 and L2 systems (Degani & Kirlik, 1995; Sarter & Woods, 1997).

1.2 Transfer of Control

One particular issue while using L2 is transfer of control between system and driver. Transition in L2 is defined as the process where the primary control mechanism in human-machine interaction system changes from one state to another (Lu et al, 2016).Transition is particularly challenging for L2 vehicles since the system is not able to function during all roadway situations (Norman, 1990). Prior research has indicated that the response to critical road events by drivers in highly automated vehicles was slower than their response in manual vehicles (Young & Stanton, 2007). Previous research also showed that the Telsa Model S interface was inadequate at providing drivers with information they need to understand that it will be necessary for them to reassume control soon. A thematic analysis of video data in an on-road study featuring drivers in a L2 vehicle showed that drivers did not receive appropriate support from the system to fulfill their monitoring duties to efficiently take back control from DSF (Banks et al, 2018) . There may even be a case where humans and systems miscommunicate, resulting in false expectations from both sides. This can either be over-reliance by drivers on system capabilities or misconception by system about what drivers have noticed. Both cases can have disastrous consequences (Carsten & Martens, 2019).

1.3 Human- Machine Interface

To facilitate safe and smooth collaboration between drivers and driving automation systems, designing an effective Human-Machine interface (HMI) is essential, especially since no vehicle has reached level 5 automation. It is very likely that drivers of DSF equipped vehicles may not be aware that these systems cannot operate in all situations and they might need to take back control. A well-designed HMI will support drivers in their monitoring role and aid them in safely retrieving control (Hoc et al, 2009). Van del Buekel (2016) describe 'support for supervision' as helping drivers to improve their cognitive understanding of system capabilities in different conditions. They also describe support for intervention as assisting drivers with sufficient information to react fast and adequately when facing critical events (van den Beukel & van der Voort, 2017).

There has been much focus on designing an effective HMI for L2 vehicles, which considers both driving with automation engaged and the transition where drivers take back control from the system (Rezvani et al., 2016). Three challenges have been identified in previous studies with regards to designing of an interface for L2 vehicles: (1) how to present information about system's status to avoid mode confusion (Kyriakidis et al., 2017); (2) how to deliver take-over requests to drivers; and (3) how to get drivers to place their attention back on-road (Blanco et al., 2015). Providing a feedback system may help in resolving these challenges. Visual, auditory, and tactile are three feedback types that can be incorporated separately or as combinations (Bengler et al, 2012).

The most basic visual feedback system in a L2 vehicle would show whether automation is engaged or not and it will only require a short glance from a driver to acquire such information (Carsten & Martens, 2019). A more advanced feedback system for L2 vehicles would include transfer of control information when vehicles reach their ODD limit. Some DSFs may have more sensitivity to complex road designs, may not recognize lane markings in poor visibility, or may be restricted in the amount of force needed to initiate an action (e.g., braking or steering). As such, when DSF reaches its ODD limitations, drivers may experience unexpected DSF behavior (Seppelt & Victor, 2016).

To sum up, an efficient design for an automation system is one that predicts its limitations and requests drivers to takeover control (Carsten & Martens, 2019). Previous studies have tested different interface designs to adequately support drivers during takeover. Van den Beukel et al. (2016) tested three in-vehicle interface designs that require drivers to take back control from the system. They recommended a combination of auditory, visual, and tactile feedback to support the driver while taking back control. Although van den Beukel et al. suggested an interface that assisted drivers in knowing *when* to take back control, their design did not provide any information about *why* drivers needed to take back control. This is similar to real-world cases wherein actual DSFs, such as Cadillac Super Cruise, informs drivers to take back control, but does not provide any additional reasoning or information prior to the critical situation (Cadillac, 2018). This raises a question as to whether incorporating clues or additional information about critical situations would improve drivers' reaction time in takeover requests. Additionally, presenting appropriate clues and information prior to takeover requests may increase drivers' situation awareness. This is important since situational awareness is likely reduced since DSF do not require continuous driver involvement (Hirose et al, 2015; Merat & Jamson, 2009).

Another question surrounds identification of information and cues presented in HMI that helps drivers take back control from L2 systems. Previous literature mentioned different situations where drivers need to be aware and take control from L2 systems. For example, drivers may need to put in additional steering torque at curves when using lane centering systems and need to take back control when lane markings are lost due to unexpected roadway conditions such as at merged sections (Seppelt & Victor, 2016). Another example is over-reliance on automation and passive road monitoring, which may lead to a failure to detect safety-critical zones such as pedestrian crosswalks at intersections (Gold et al, 2013). This can be dangerous since drivers might need to take back control due to the sudden appearance of pedestrians or a vehicle at intersections. Despite the importance of these situations, there is no literature about whether providing additional information along with takeover request through an HMI can assist drivers in taking back control.

1.4 Objective and Phases of the study

The objective of this study is to develop and test an in-vehicle interface for use in DSF contexts, with a focus on delivering feedback and alerts when drivers need to make a manual transition between L2 (combination of Cruise Control and Lane Centering System) and manual (Level 0) mode. The study has been conducted in three experimental Phases according to the human-centered design process, wherein users and designers are jointly responsible for system development (François et al, 2017). The first Phase focuses on iterative development and in-vehicle interface design through an observational study conducted on a driving simulator followed by an interview. Results from the first Phase were used to conceptualize and design a prototype interface for the second experiment. In the second Phase, another group of participants were provided with prototypes in a co-design session. Results from this experiment were aggregated to prepare a second prototype and apply it to the simulator cab's dashboard. This was followed by a heuristic evaluation, carried out by four human factors specialists, to improve the design. Prior to the third Phase, a pilot session was conducted to finalize the design. In the third Phase, 42 participants were recruited to test the effectiveness of the newly designed interface. Each of these Phases and their corresponding hypothesis will be explained in detail in the following sections.

2 PHASE I: OBSERVATION

The objective of this Phase is to determine if drivers over-rely on automation in scenarios where transfer of control is critical to road user safety and, if so, what interface might better support transfer of control. Previous research has identified the general effects of over-reliance (e.g., longer response times), but not specific details of those scenarios in which these effects are most problematic. As such, we chose three different roadway geometries where drivers need to resume control. We asked whether and how drivers transferred control when it was critical. We focused on naïve drivers (drivers who were not told about the ODD) because of numerous studies that indicate that drivers generally understand little about these systems (McDonald et al, 2017).

2.1 Method

Participants drove twice through a virtual world containing four scenarios. In one drive, participants engaged the L2 system, while in the other, they drove the car manually. Thus, all participants drove both L2 and manual drives. To observe drivers' transfer of control behavior, drivers' foot movements were recorded. To gain insight about drivers' experience with L2 features, a set of interview questions focused on transfer of control, road design, and interface were designed based on twelve principles of transparency (Debernard et al, 2016). For instance, participants were asked questions such as, "Did you get surprised by the movement of your own vehicle near the curve?" , "What would you do differently if faced with this scenario in future?" and "What information do you think would be useful to present to the driver in that situation?". The interview took place right after each scenario. After all drives, a final set of interview questions focused on the need for feedback. Also, to assess drivers' situation awareness, participants completed the Situation Awareness Rating Technique (SART) questionnaire (Selcon & Taylor, 1990) after each L2 drive. SART measures how aware participants perceived themselves to be during their driving performance based on ratings of understanding, supply, and demand.

2.2 Participants

A total of 10 participants aged 20 – 54 years old (5 females and 5 males) were recruited from the University of Massachusetts Amherst campus and Amherst town using flyers and email advertisements. The average age of the participants was 27.4 years (SD = 3.07). Only individuals with a valid United States driving license who did not wear eyeglasses were included in the study.

2.3 Equipment

Driving Simulator. A fixed-based RTI (Realtime Technologies Inc.) driving simulator consisting of a fully equipped 2013 Ford Fusion surrounded by six screens with a 330-degree field of view was used for the current study (Figure 1). The cab features two dynamic side-mirrors which provide realistic side and rear views of the scenarios for participants. The car's interior has a fully customizable virtual dashboard and center stack. The simulator system is capable of simulating L2 drives by integrating a lane centering control system along with adaptive cruise control.

Eye tracker & Video Camera. An ASL (Applied Science Lab) Mobile-Eye XG head-mounted eye tracker consisting of a scene camera, eye camera, and a small reflective non-obtrusive monocle was utilized to monitor and record eye movements (Figure 2). Foot movement was recorded using a JVC HM40 video camera.

Figure 1. RTI Fixed-Based Driving Simulator

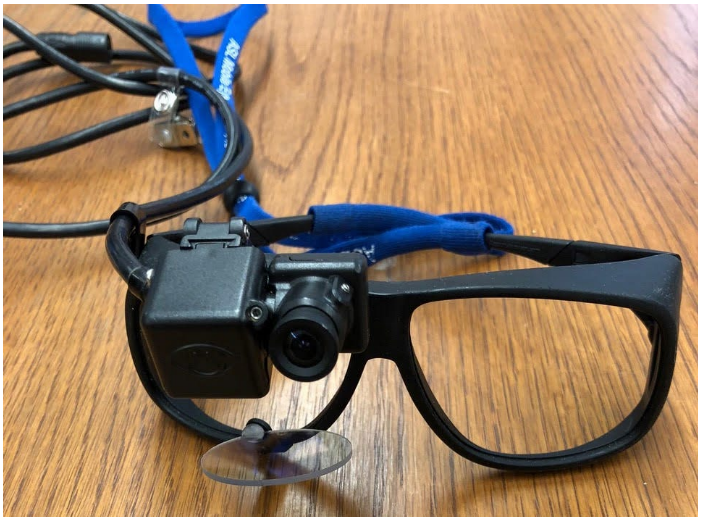


Figure 2. ASL MobileEye

2.4 Scenarios

Four scenarios were used to collect information regarding drivers' behavior and reactions to transfer-of-control situations. Table 1 describes scenarios where three types of road geometry (Curve, Merge, Intersection) were considered based on previous literature (Gold et al., 2013; Seppelt & Victor, 2016). All scenarios represent situations where L2 disengaged because it reached its ODD limit and a crash could occur.

Table 1. Scenario Descriptions (Phase I)

Scenario Description	**Driver View**
Merge- The driver reaches the end of a four-lane road (two travel lanes in either direction). A car is also going straight in the left lane at a constant speed.	

Curve- The driver is traveling along a curved road section (one travel lane in either direction), where a truck is parked on the right side of the curved road. A car is approaching in the opposite lane.	
Intersection- The driver is approaching a traffic signal-controlled intersection and the driver has a green light in his travel lane. A block of buildings obscures a pedestrian who is running to cross the street at the crosswalk.	
Baseline- This is a scenario in a suburban setting with no hazards.	

2.5 Experimental Design

Participants drove through four scenarios (Table 1) two times: Once while engaging the L2 system and once without the L2 system. The ordering of the drives was counterbalanced across participants: half of the participants drove automated drives first, while the other half drove manual drives first. Each participant experienced a different order of drives in the set with automation and in the set without automation.

2.6 Dependent Variable

One dependent variable was takeover reaction of drivers, which was binary coded (Successful takeover was ‘1’ and unsuccessful takeover was ‘0’). Another dependent variable was the overall SART score, which was derived using the following formula: Situation Awareness (SA) = U - (D - S), where U refers to summed understanding, D refers to summed demand and S refers to summed supply (Selcon & Taylor, 1990).

2.7 Procedure

After participants gave consent, they were given basic instructions and were seated in the simulator. The eye-tracker was mounted on participants' head and their pupil position was calibrated. Next, participants were introduced to the L2 system and were shown how to engage and disengage the system. Participants then drove a practice drive and were permitted to continue when confident. Drivers were not instructed on how to behave when L2 was engaged. Participants then navigated twice through all scenarios, once with DSF engaged and once without DSF engaged. In L2 scenarios, participants drove the vehicle in manual mode for approximately one minute, prior to being alerted to engage the L2 system by pressing a button on the steering wheel. A small blue LED icon on the dashboard would light up each time system was engaged (Figure 3). The participants could regain manual control of the vehicle by applying the brake or pressing the button on steering wheel. After each L2 drive, participants completed the SART (Selcon & Taylor, 1990) and were briefly interviewed. In this interview, we asked participants questions such as: “What information do you think would be useful to know about the situation on the road?”. At the end, they were interviewed again, completed a questionnaire regarding demographics and driving history, and were compensated.

One of the objectives of the study was to observe participants takeover reaction in critical situations. Therefore, there was no visual or audio feedback provided to participants regarding takeover control situations. Also, in order to observe whether participants were aware of the importance of knowing system's status, we used a simple blue LED icon on the dashboard, which turned on to signify that automation was engaged. In this way, we prevented bias in participants' interview responses by not providing a preconceived design.

Figure 3. Original Dashboard Interface

2.8 Results

2.8.1 Over-reliance

A three-second window before the hazard was used to observe participants' takeover reaction, similar to previous research in hazard mitigation training (Muttart, 2013). Within this window, drivers' takeover reaction was characterized by foot movement towards the brake pedal or by pressing the automation button. Results show that seven drivers took back control for the merge and intersection scenarios and only four drivers took back control in the curve scenario.

Results from the SART showed that drivers' overall SART scores for curve, merge, intersection and baseline scenarios were 14.7, 19.4, 19.3 and 20.8, respectively. SART results also showed that the score at curves was less than other scenarios, while merge and intersection scores were similar. These results further support participants' takeover reaction results which show that they over-rely on automation (did not take back control) at curves compared to merge and intersections.

Additionally, participants' interview responses after each automated drive were gathered and categorized. Seven participants responded 'Yes' as to whether they were surprised by the car movement in curve scenario. In their responses, they expressed their expectation for the car to slow down when approaching the curve. Regarding the question on what they think would be useful information to present to drivers, three types of responses were extracted from their statements: (1) need to take back control, (2) need for feedback about L2 functions, and (3) need for feedback about road geometry. Table 2 shows differences between the three scenarios in terms of participants' interview responses.

Table 2. Responses from each scenario's interview

	Number of participants (out of ten) who declared the following statements during the interview				
	Surprised by the car movement	Would take control sooner on second chance	Need feedback about taking back control	Need feedback about the L2 functionality	Need information about road geometry
Curve	7	5	4	0	5
Merge	6	6	4	6	9
Intersection	6	6	9	2	9

2.8.2 System Feedback

In the final interview, drivers were asked several questions about what information they needed regarding the road and automation system. For example, they were asked: "What information do you think would be useful to know about the on-road situation?". In response to this question, a participant replied: " It would be helpful to see the road's layout such as intersection, merge, etc. in advance". Another participant said "feedback about when it is not safe to use automation would be nice". In total, seven participants were interested in receiving feedback about the presence of pedestrians and objects on the road and nine participants preferred feedback about the road structure in advance.

In response to the question "How should information be presented (auditory/visual/tactile)?", they replied," Auditory feedback would be very helpful in a dangerous situation and visual feedback can help in minor situations". Another participant mentioned, "I would like a combination of visual and auditory, but I think tactile feedback would make me more nervous and distracted". Regarding type of feedback, nine participants preferred to receive visual feedback, while eight preferred auditory and only two preferred tactile.

Participants were asked if they knew about the vehicle mode at all times during their drives and if yes, how they recognize the correct mode. An example response was "Yes, I knew that car was on automation mode by the vehicle's steady movement". Another person responded by saying "I know that automation was engaged since the car's speed was constant ". However, they also mentioned that they did not notice the blue LED light on dashboard. Eye tracker data showed that seven participants fixated their glance on the dashboard right after the "engage automation feature" pop-up image appeared on-screen at least once during their driving session. However, only four participants declared that they saw the blue LED light during their final interview.

To understand participants' knowledge regarding L2 vehicles, they were asked if they know how these vehicles monitor the road and why this information was necessary. Only half of the participants indicated familiarity with how automation systems monitor the road and among them, only two participants mentioned weather impairing automation system functions. None of the participants mentioned system limitations regarding road design or when lane marking is not available (e.g., at merges). In total, eight participants declared that they needed information about automation system's capability. For example, one participant said, "It would be great if I could get such information so that I could analyze oncoming situations and make a better decision regarding automation disengagement".

2.9 Discussion

The results from first Phase indicated that participants over-relied on automation for the curve scenario. This might be due to drivers' failure to understand DSF functionalities at curves. Note that none of the drivers believed that they needed to know more about DSF functionalities at curves (Table 2). In general, their SART responses indicate that drivers were less situation aware at curves compared to other scenarios. Recall that in this scenario, there was a truck parked on the right and a car approaching in the opposing lane, which required drivers to thread their car between the car on the left and truck on the right. All drivers in the manual condition slowed as they approached the truck. But DSF does not slow the driver at the curve as drivers approach the truck.

As mentioned before, participant interview responses right after each drive showed that more than half of participants were surprised by the car's movement and they expected something different from the system. They also declared that they would take control sooner on a second chance. This shows the mode confusion experienced by most of the participants, especially in the curve scenario where only four drivers took back control. On the other hand, in the final interview, seven participants declared that they need feedback about the presence of pedestrians and objects on the road and nine participants were interested in receiving feedback about the road structure ahead of time. Based these all responses, we can conclude that it might be helpful to alert drivers regarding take back control situations.

This can be achieved in two steps: First, drivers need to be alerted that a transfer of control is required. This can be done by giving feedback to drivers to take back control in the form of visual, auditory, and/or tactile feedback. Second, drivers need to understand why they need to take control to become fully situation aware. This understanding could be provided by a diagram depicting alerts about changes in road geometry and objects detected on the road.

Results also show that only four participants noticed the blue LED light on the dashboard (which indicated status of automation), despite having glanced at the dashboard. It has been recommended that automation systems up to Level 4 should inform drivers about the system's status and limitations (Kyriakidis et al, 2017). This information can be provided by designing a more attention-grabbing display based on drivers' mental model.

To sum up, designing an appropriate interface that provides crucial information regarding safe transfer of control could be helpful to support drivers in their supervision and intervention role in DSF (Van den Beukel et al., 2016). This raises an argument to redesign the feedback for automation system status and also provide appropriate feedback regarding taking back control when the system has reached its ODD limitations. These concerns will be considered during our prototyping and re-designing in Phase II.

3 PHASE II: PROTOTYPING

The objective of this Phase is to design a new interface for an L2 system based on the Phase I results. Interview responses from Phase I indicated that the feedback system should be designed for takeover control situations along with related information such as road geometry and automation system status. To achieve this, four design iterations have been conducted and will be explained in following sections.

3.1 First Design Iteration

An initial prototype was made using the dashboard interface from Phase I, as seen in Figure 3. Participants responses from Phase I were extracted and aggregated to create new elements that could be featured on the initial prototype of the dashboard interface. In this process, two factors were considered: design of current vehicles, and visibility and color of display icons. The first element added was an icon depicting the automation system status. In order to design a proper LED icon similar to the design found in commercial vehicles (Cadillac, 2018; Tesla, 2019), an illustration of a car between two lanes was hand-drawn (Figure 4). When switched on, this would give drivers an indication that the automation system had been engaged and it will keep the car between the two lanes. The second element added was a ‘take over control’ icon. An LED shaped like a steering wheel helps develop a mental model that corresponds to the control mode of the vehicle (Figure 4). These two designs were chosen based on the design of current HMIs in commercially available vehicles such as Cadillac CT6 (Cadillac, 2018) and Tesla X (Tesla, 2019)(Tesla, 2019)(Tesla, 2019)(Tesla, 2019)(Tesla, 2019)(Tesla, 2019). The third element added was roadway geometry icon(s). Curved sections were considered due to two reasons: due to the importance of curves as mentioned in previous studies (Seppelt & Victor, 2016) and due to the observed over-reliance of participants at the curve scenario in Phase one. Merges and intersections were also considered based on participants’ responses in Phase 1 where all but one participant stated their need for feedback regarding these sections of the roadway. Three different roadway geometry icons for curve, intersection, and merge were considered based on their respective road signage (Figure 4). The fourth element added was an empty box to be filled with a text alert. For all elements, visibility, placement, and color of icons were decided in the next design iteration.

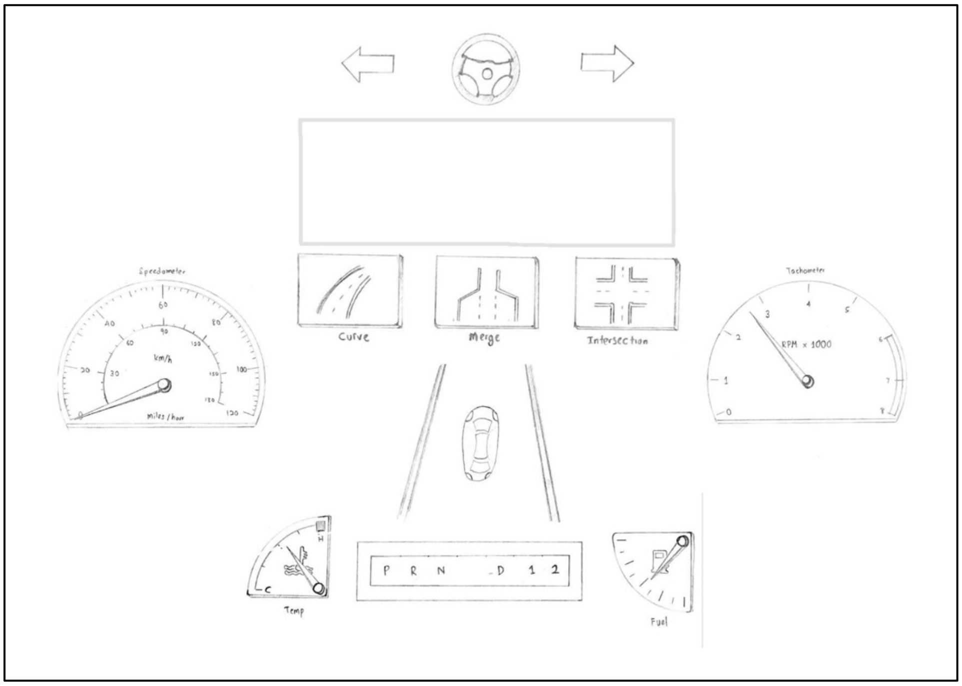


Figure 4. First Design Iteration

3.2 Second Design Iteration

In this iteration, the design of the prototype dashboard interface was modified based on the results of individual co-design sessions with 10 participants.

3.2.1 Participants

Ten participants (aged 20 – 54) were recruited from the same area as Phase I. The average age of participants was 27.4 years. Only individuals with a valid United States driving license were included in these sessions.

3.2.2 Equipment

A JVC HM40 video camera was used to record the discussion with participants as well as their prototyping suggestions, such as the placement or redesign of icons. The camera was positioned in a bird's eye view to capture the prototype in full view.

3.2.3 Procedure

All participants completed a 45-minute individual session. In these sessions, after participants gave their consent, they were interviewed with a series of questions targeting takeover request, automation system status, road geometries, and objects detected on the road. For example, for takeover request, they were asked “Do you need informative visual feedback on dashboard to take over control from the system?” and “Do you need labeling in addition to visual feedback?”

Following their responses, they were presented with a cut out of the steering wheel icon and asked the following question: “If this object’s shape lights up, what would that indicate in your opinion?”. The purpose of the icon was then explained, and the next question was asked: “What color do you prefer for this item? ”. They were then asked to relocate the item to their preferred location and asked for suggestions for better feedback regarding a takeover request, for which they were given the opportunity to hand-draw their suggestions or ideas.

A similar procedure was followed for ‘automation system status’, ‘road geometries’ and ‘objects detected on the road’. Figure 5-6 shows an example of a participant’s’ final design sheet indicating their preference for location and design.

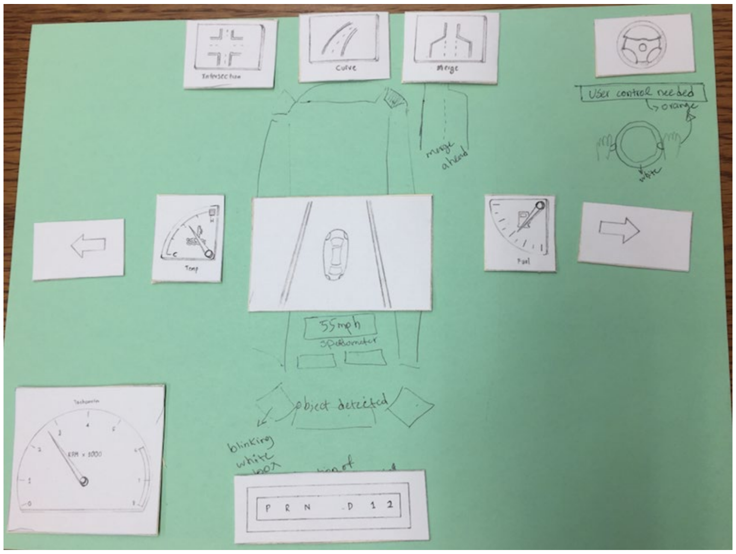


Figure 5. An example of a participant’s final design sheet

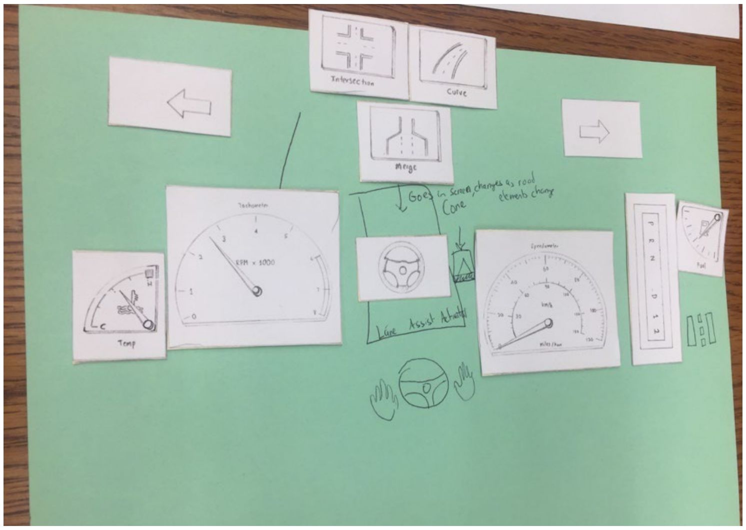


Figure 6. An example of a participant’s final design sheet

3.2.4 Results

Participants responses during co-design sessions and interview were aggregated. Participant responses to questions regarding automation system status show that all participants were in agreement about their need to know about vehicle’s status. They all understood the purpose of the display icon correctly (automation engaged when LED icon lights up and automation disengaged when icon is not lit). Also, they were all in agreement that “car between two lanes” icon is suitable to understand lane centering system. Seven out of ten participants indicated that there was no need for icon labeling.

In response to the question “Do you need informative visual feedback on dashboard to take over control from the system?”, one participant replied, “Yes, I would very much prefer audio feedback, but combining it with visual feedback may be most helpful if I’m listening to music”. In total, based on their responses, eight participants indicated that they needed visual feedback. Five participants indicated that they required a combination of auditory feedback and visual feedback. As a follow-up question, they were asked if they preferred labeling for the takeover control icon on dashboard. In response, half of the participants said that they preferred the icon with a text label. When asked for redesign suggestions, several participants mentioned that the steering wheel icon alone did not signify a taking back control action. There was a common redesign suggestion by half of the participants to redesign the icon by adding hands hovering over steering wheel.

For questions about road geometry, participants responses showed that all understood the purpose of display icon correctly. Most participants declared that “when LED icon lights up, the displayed road geometry is coming up ahead”. When they were asked about their preference for feedback type, nine participants indicated that they preferred visual feedback for information regarding roadway geometry. When asked “Do you need a label for any roadway icons?”, seven of the participants indicated that there was no need to label the icon, saying that icons were informative on their own. For example, one participant replied saying “I think the icon is easy to understand and adding a label would make my dashboard crowded”. As a common suggestion, half of the participants preferred that the three roadway geometry icons appear in the same location on the dashboard (above the ‘automation system status’ icon) when prompted. Two participants pointed out that they preferred the merge icon to be more consistent with its road sign i.e., one-sided merge.

Finally, for questions regarding ‘object detected on the road’, responses showed that nine participants needed visual feedback while only two preferred auditory feedback as well. This was followed by asking participants to suggest icon shapes, to which four participants drew a traffic cone-shaped icon to depict ‘object detected’. Other participants also drew similar stationary objects such as a large rock or a cube. When asked if they need icon labeling, one participant mentioned, “Yes, I think having a label saves me time to recall the icon's meaning”. In total, eight participants preferred the text label ‘object detected’. One participant suggested to have two types of icon for object on the road, one dynamic icon and one static icon, saying “I prefer if the icon can also show me if the object detected is stationary or moving, so it would make sense to have two types of the icon, one dynamic and the other static”. The first iteration design was updated based on results from all co-design sessions. Figure 7 shows the design after the second iteration.

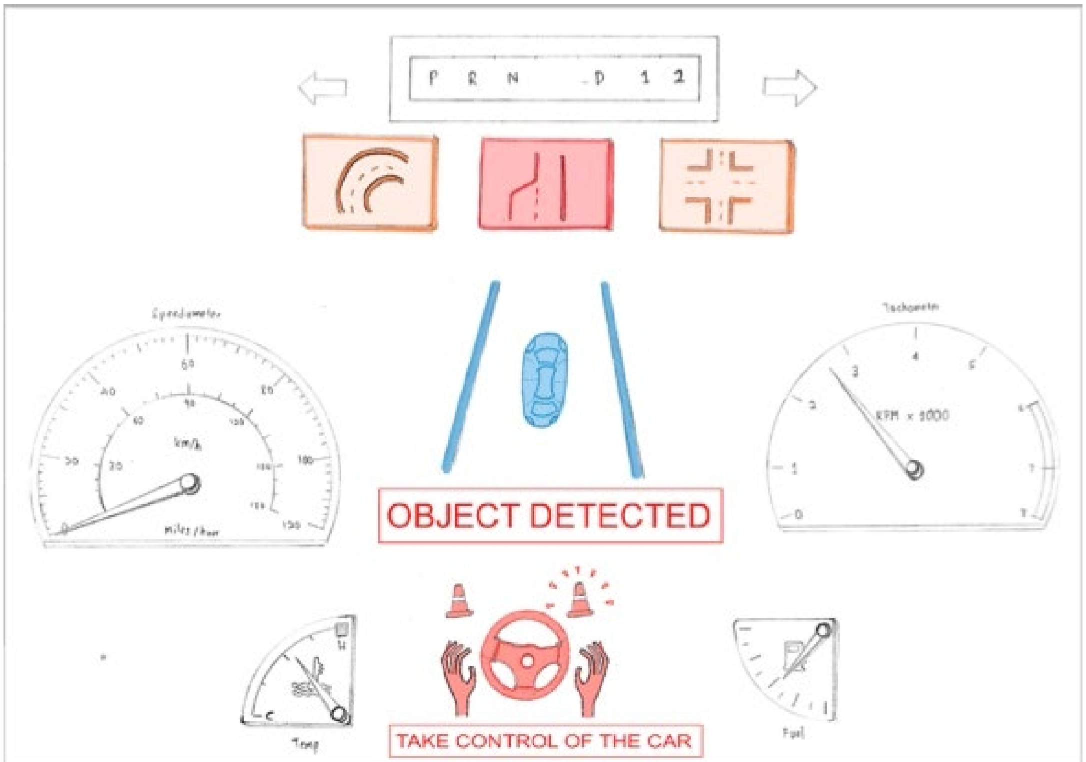


Figure 7. Second Design Iteration

3.3 Third Design Iteration

In this iteration, the prototype from the second iteration was applied to dashboard of the simulator cab (Figure 8, 9, 10). This was followed by a heuristic evaluation by four human factors specialists. The analyses were performed in isolation to suppress bias across users as well as to increase the number of independent heuristic violations discovered as suggested by previous studies (Nielsen, 1993). The heuristic evaluation was conducted for three dashboard interface designs:

1) Original Dashboard: Dashboard interface used in Phase 1 (Figure 3)
2) Basic Dashboard: Simpler version of new dashboard design from second iteration, excluding road geometry and object detected icons (Figure 8)
3) Advanced Dashboard: Dashboard design from second iteration (Figure 9-10)

The difference between the basic and advanced dashboard is that the basic dashboard only provides feedback such as take back control request and system status, similar to HMI designs of commercially available vehicles such as Cadillac Super Cruise (Cadillac, 2018). The advanced dashboard provides additional feedback along with the ones featured in the Basic dashboard, where information regarding take back control situations are presented prior to take back control requests. We decided to present these two interfaces separately to investigate the issues concerning the Basic dashboard (available in commercial vehicles) as well as Advanced dashboard (conceptualized and designed in this study).

3.3.1 Participants

Four human factors specialists (two female and two male) were selected. One was an assistant professor (9 years of experience in Human Factors) and other three were doctoral students (3 years of experience in Human Factors). All were from the Mechanical and Industrial Engineering Department at University of Massachusetts Amherst.

3.3.2 Procedure

At the beginning of heuristic evaluation, four participants were introduced to usability heuristics as introduced in Nielsen (1993). The purpose of three dashboard interface designs (Figure 3, 8, 9, 10) were explained to them. They were asked to individually provide a list of issues for each dashboard interface design in isolation. Their individual responses for each interface were collected, duplicate issues were removed, and a final master list of issues was created for each dashboard interface. Each participant then received a copy of the master list and asked to allocate a severity rating to each issue.

Figure 8. Basic Dashboard (Second iteration)

Figure 9. Advanced Dashboard for object detected on the road (second iteration)

Figure 10. Advanced Dashboard for road geometry (Second iteration)

3.3.3 Results

The average severity rating was calculated for each issue based on all participants response. Table 3, 4 and 5 shows the most severe issues for each of the dashboard interface designs.

Table 3. The heuristics, violations, and severity ratings for Original Dashboard Interface

Heuristics	**Issues**	**Average severity rating**
Visibility of the system	The interface does not provide enough information about the automation features (lane keeping system, cruise control,..)	4.25

Match between System and Real world	The blue light is a very ambiguous way to show the status of the automation (on/off). It might be hard for the drivers to connect a simple LED light to the automation system	4.5
Recognition and Recall	There is no information to help the drivers recall to take control from the car (as specified in the owner's manual)	4.5
Error Prevention	There are no error messages (to help the drivers recognize or prevent the errors)	4.25

Table 4. The heuristics, violations, and severity ratings for Basic Dashboard Interface

Heuristic	**Issues**	**Average severity rating**
Visibility of the system	The interface does not provide any reasoning or information about why the drivers need to take control of the car	4.25
Match between System and Real world	The important 'take control' message is not placed in the center of the display (where the most important information is), but rather appears at the bottom of the display	4
Recognition and Recall	The dashboard in itself may not be sufficient to engage the driver and may require audio cues for the take back control feedback.	4.5

Table 5. The heuristics, violations, and severity ratings for Advanced Dashboard Interface

Heuristic	**Issues**	**Average severity rating**
Match between System and Real world	The important 'take control' message is not placed in the center of the display (where the most important information is), but rather appears at the bottom of the display	4
Recognition and Recall	The dashboard in itself may not be sufficient to engage the driver and may require audio cues for the take back control feedback.	4.5

Results from heuristic evaluation for Original Dashboard shows that blue LED light does not have appropriate visibility and does not provide effective feedback about system features. The issue regarding the blue LED light has been resolved in the Basic and Advanced dashboard designs.

For the Basic Dashboard, the first issue was related to the system visibility with regards to the reasoning behind the take back control request. This issue has been addressed in the Advanced Dashboard for four different types of situations, three regarding road geometry and one regarding objects detected on the road. The second issue for Basic Dashboard was related to placement of the take back control feedback. This issue was addressed in the final design iteration, by placing take back control feedback in the center of the dashboard. The third issue for Basic Dashboard was regarding the recognition of the feedback system. It was suggested to provide audio beeps in addition to the visual feedback for the take back control request. The second and third issues were similar for the Advanced Dashboard as well. Both of these issues were addressed in the final design iteration. The Original dashboard was not modified in order to be used as a baseline for testing the Basic and Advanced dashboard in the third Phase of the study.

3.4 Fourth Design Iteration

In this iteration, five human factors specialists drove through the same scenarios, following the same procedure as in Phase 1, but with both Basic and Advanced dashboard interfaces. Their feedback regarding the interface design was collected and roadway geometry elements were modified to increase their visibility on the dashboard. One specialist also pointed out that the automation status icon (blue car between two lines) was only half visible, obscured by the steering wheel. Hence, the placement of icons was also modified to accommodate anthropometric factors. Moreover, another specialist suggested adding an additional beep to all of the object detected and road geometry related to visual feedback. Their argument was that an auditory beep would serve as redundancy for drivers to get information provided on dashboard. The beep for take back control feedback was replaced to an audio message with a female voice. This was done to distinguish both types of audio feedback and emphasize importance of take back control feedback. The final Basic Dashboard design is shown in Figure 11. The advanced dashboard interface design is shown in Figure 12-Figure 15.

Figure 11. Basic Dashboard (Fourth iteration)

Figure 12. Advanced dashboard showing the object detected icon (Fourth iteration)

Figure 13. Advanced Dashboard showing a curve ahead (Fourth iteration)

Figure 14. Advanced Dashboard showing an intersection ahead (Fourth iteration)

Figure 15. Advanced Dashboard a merge ahead(Fourth iteration)

4 PHASE III: Testing Dashboard Interfaces

The objective of this Phase was to test the interfaces designed in Phase II for a L2 system. To achieve this, seven scenarios were designed, and three participant groups drove through all scenarios. One group was exposed to the Original Dashboard, a second group to the Basic Dashboard design a third group to the Advanced Dashboard. All participants drove six scenarios in L2 mode and one drive in manual mode.

4.1 <u>Method</u>

4.1.1 Participants

Forty-two participants (aged 20 – 54) were recruited from the same area as previous Phases. The average age of participants was 25.73 years (SD=4.37). Only individuals with a valid United States driving license, who did not wear eyeglasses were included.

4.1.2 Equipment

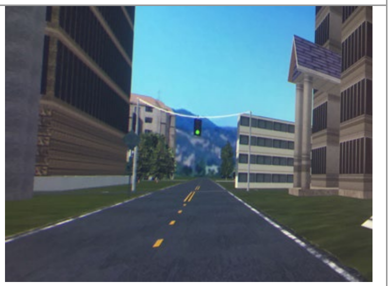
The equipment used in this Phase was similar to those from Phase I.

4.1.3 Scenarios

Seven scenarios were designed to investigate drivers' behavior and take back control reactions in three groups (Original Dashboard, Basic Dashboard, and Advanced Dashboard). Table 6 describes scenarios which were designed based on common human-automated vehicle conflict situations reported in past literature (Seppelt & Victor, 2016).

Table 6. Scenario Descriptions (Phase III)

Scenario No.	**Scenario Description**	**Image**
1	The driver reaches the end of a four-lane road (two travel lanes in either direction) which merges onto a two-lane road (one travel lane in either direction). There is a car following behind the driver into the merge.	
2	The driver is traveling along a curved road section (one travel lane in either direction), where a truck is parked on right side of the curved road section before a crosswalk. The truck is partly jutting onto the road obscuring a pedestrian.	

3	The driver is approaching towards traffic signal-controlled intersection (two travel lanes in either direction) with a green light in the travel lane. A block of buildings obscures a pedestrian who is running to cross the street at the crosswalk.	
4	The driver is approaching towards a traffic signal-controlled intersection (one travel lane in either direction) with a green light in the travel lane. There are no vehicles or pedestrians in the vicinity.	
5	The driver is approaching a stop sign controlled intersection (one travel lane in either direction) while following a car. The following car abruptly stops at the stop sign and proceeds to turn right.	
6	This is a scenario within a suburban setting with no hazards.	
7	The driver is approaching towards a traffic signal-controlled intersection (one travel lane in either direction) with a green light in the travel lane. A car in the opposite lane across the intersection briefly signals left before abruptly taking a left turn, driving across the driver's path.	

4.1.4 Experimental Design and Hypothesis

In this study, a between design experiment was used and participants were randomly assigned to one of three groups - Original Dashboard, Basic Dashboard, or Advanced Dashboard. They were asked to drive through seven scenarios mentioned in Table 6. They drove through scenario 1-6 while engaging the L2 system and drove scenario 7 manually, without engaging L2 system. The ordering of drives was counterbalanced across participants in each group using Balanced Latin Square method (Williams, 1949).

First, we hypothesize that when compared to the Original Dashboard, Basic and Advanced Dashboard will help participants effectively take back control from L2 system when needed. The first hypothesis was examined for scenario1-4 shown in table 6. Second, we hypothesize that while drivers' situational awareness is higher during the manual drive compared to automated drives for those using the Original Dashboard, there will be smaller difference between situational awareness of drivers in manual and automated drives for those using the Basic and Advanced Dashboard. The Second hypothesis was examined for scenario 5 and 7 shown in Table 6.

Note that participants in the Advanced dashboard group received feedback regarding the road geometry and object on the road, prior to takeback control requests. Take back control requests were presented 5 seconds earlier leading to the hazards for both Advanced and Basic dashboard groups (Scenario 1,2,3,5). Feedbacks regarding road geometry (scenario 1,2,3,4) and objects detected (scenario 5) were presented 8 seconds before hazards for the Advanced dashboard group**.**

4.1.5 Procedure

After participants gave their consent, they were randomly assigned to one of the Original, Basic or Advanced Dashboard groups. The same procedure as Phase I was employed to run participants. All participants drove through seven scenarios. Participants were asked to drive scenario 1-6 (see Table 6) while engaging the L2 system, and scenario 7 manually. In order to compare situational awareness of drivers in manual and automation mode, participants were asked to complete the SART questionnaire, once after scenario 5 and once after scenario 7.

4.1.6 Dependent and Independent Variable

One dependent variable similar to Phase I, was drivers' takeover reaction, which was binary coded (Successful transfer of control was scored '1' and unsuccessful transfer of control was scored '0'). The first dependent variable was examined for scenario 1-3. The second dependent variable was the overall SART score, which was calculated similar to Phase I. The first independent variables was dashboard design (Advanced, Basic, Original). The second independent variable was scenario (Table 6).

4.2 Results

4.2.1 Take Back Control Events

For descriptive purposes, the percentage of participants who took back control in each dashboard design group was calculated for each of the scenarios 1-4 and is shown in Figure 16. The percentage of participants who successfully took back control for each group of Advanced Dashboard, Basic Dashboard, and Original Dashboard.. In all scenarios, the percentage of successful take back control was highest in the Advanced dashboard group compared to the Basic and Original Dashboard group. Note that unlike scenarios 1-3, for scenario 4, no hazard materialized. Hence, participants in the Basic dashboard group did not receive any "take back control" message through the dashboard and the participants in the Advanced dashboard group were only presented with the road geometry on the dashboard. Therefore, as presented in Figure 16, while 35.72% of the Advanced dashboard group participants took back control from the car in scenario 4, no participants from Basic and Original dashboard group took back control in scenario 4.

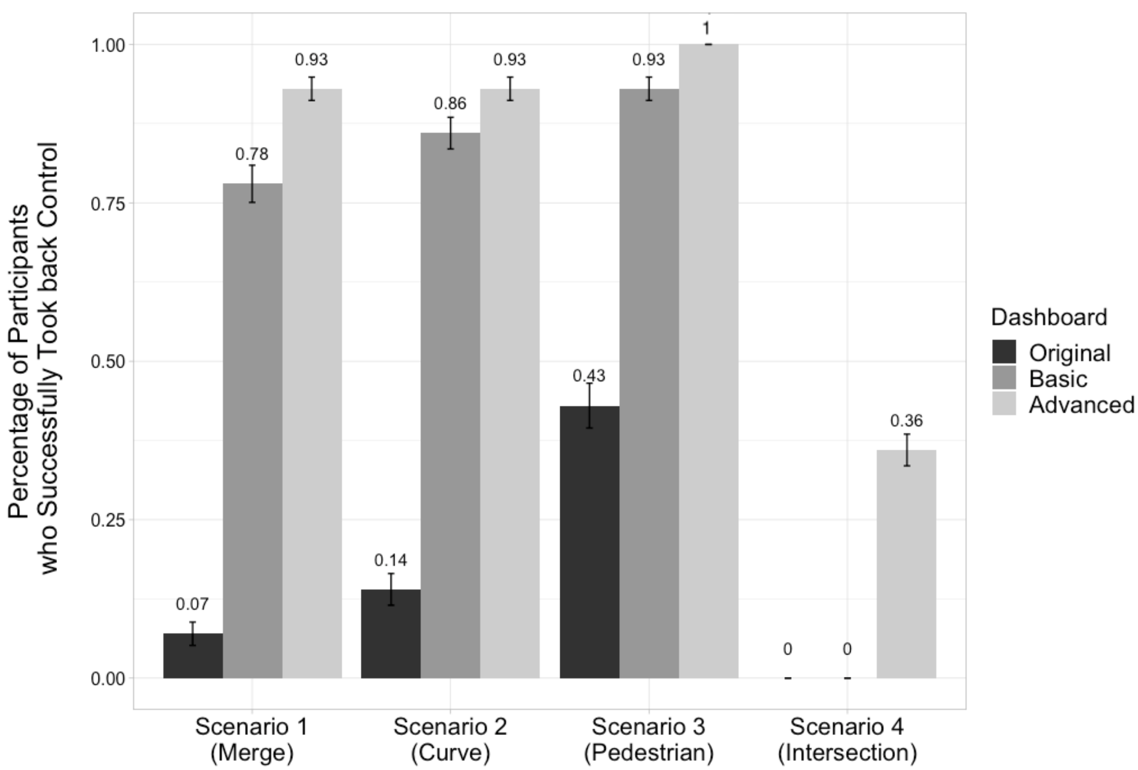


Figure 16. The percentage of participants who successfully took back control for each group of Advanced Dashboard, Basic Dashboard, and Original Dashboard.

To determine whether the effect of dashboard was significant for scenarios 1-3, a logistic regression model within the framework of GEE was used. In this model, type of dashboard (Advanced dashboard Group, Basic dashboard group, Original dashboard group) was included as treatment and scenarios were included as repeated measures. The analysis of the data showed a significant main effect of treatment (Wald Chi-Square = 45.055, p-value < 0.001).

4.2.2 Situational Awareness

The mean overall SART scores for scenarios 5 and 7 for each dashboard group were calculated. The results showed that the average overall SART score was highest in the Advanced Dashboard group (Mean = 23. 07, SD = 0.14) compared to the Basic (Mean = 20.82, SD = 1.25) and Original Dashboard (Mean = 17.61, SD = 4.25) groups. Figure 17 shows the mean overall SART scores for each scenario in each dashboard group. Note that on an average the participants' overall SART score was higher for the manual drive in scenario 7 (Mean = 22.38, SD = 0.59) compared to the L2 drive in scenario 5 (Mean = 18.62, SD = 3.96). However, due to the difference between scenario 5 and 7, i.e., having a car stop in front of the driver (scenario 5) versus having a car from the opposing lane turn in front of the driver (scenario 7), one cannot be sure whether the difference between the SART scores at the two scenarios was observed due to the usage of L2 systems in scenario 5 or the difference of the hazardous situation in the two scenarios.

Considering the difference between the two scenarios, to determine any significant difference between mean overall SART scores in each dashboard groups, a one-way ANOVA analysis was conducted twice (separately for each scenario): once for the L2 drive (scenario 5) and once for the manual drive (scenario 7). Results show that there was no significant difference between dashboards for the manual drive in scenario 7 (F (2, 39) = 0.166, p-value > 0.05). However, there was a significant difference between dashboard group for the L2 drive in scenario 5 (F (2, 39) = 6.433, p-value < 0.05). To investigate which of the dashboards were significantly different from each other for the L2 drive (scenario 5), a Bonferroni post hoc analysis was performed. The results showed that mean overall SART score for the Advanced Dashboard group was significantly higher than that of the Original Dashboard group (p-value < 0.01). However, there was no significant difference between Advanced and Basic Dashboard groups.

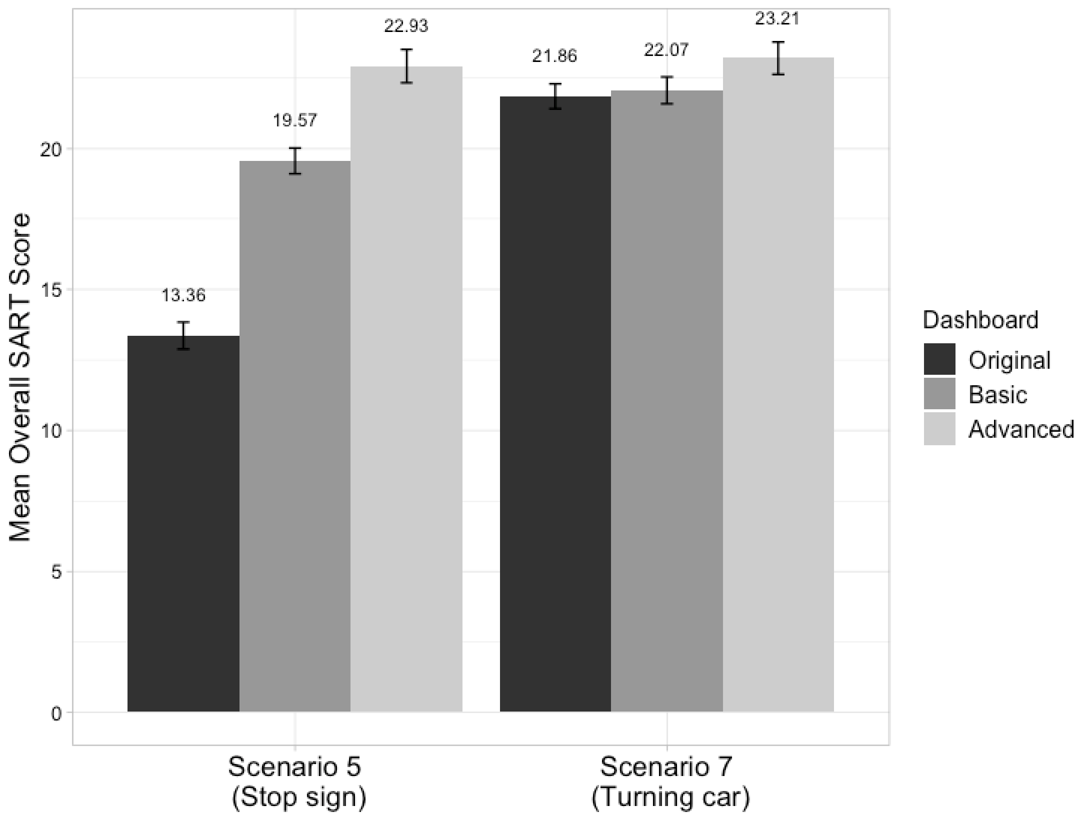


Figure 17. Average overall SART scores for Advanced Dashboard, Basic Dashboard, and Original Dashboard.

5 CONCLUSION

This study aimed to design and test a new driver-centered HMI interface which will support drivers in their understanding of L2 vehicle status and aid them in safely retrieving control when needed as suggested by Hoc et al (2009). To achieve this, three Phases were carried where the first Phase tested the drivers performance in L2 vehicles while driving in different scenarios using the Original Dashboard. In the second Phase, the original dashboard interface was modified through four design iterations, resulting in Basic and Advanced Dashboards. The third Phase of the study tested these in-vehicle interfaces (Basic Dashboard and Advanced Dashboard) in comparison to the Original Dashboard.

Results from Phase I showed that participants over relied on L2 system particularly at curve scenario. Also, their interview responses indicated that they needed a better feedback system which provides information regarding system status and road geometry. Most of them requested an appropriate interface that provides prompt and redundant (visual, audio) feedback for take back control from the system when it was needed.

In the second Phase, an initial dashboard prototype was provided based on participants' responses in Phase I. Next, individual co-design sessions were conducted with participants to assess their understanding of the suggested designs and gain their suggestions regarding shape, size, and placement of dashboard elements. They were also given a chance to add any other objects and feedback on the dashboard regarding the L2 system. The design was then improved through a heuristic evaluation and pilot testing. Three dashboard interfaces (Original Dashboard, Basic Dashboard, Advanced Dashboard) were then prepared to be tested in the final Phase. It should be noted that in the newly dashboard designs, three challenges of interface design for L2 vehicles mentioned in previous studies have been addressed. First challenge was mode confusion (Kyriakidis et al., 2017) which addressed by providing an informative presentation of system status through an LED icon (car between lanes). Second challenge was take-back control request delivery (Banks et al, 2018) which was addressed by redundant audio and visual feedback to ensure optimal take-back control actions when needed (Basic and Advanced Dashboard). Third challenge was to revert driver attention back towards hazardous areas (Blanco et al., 2015). This was achieved by providing participants with road geometry and object detected feedback (combination of LED icons and beep) which helped the drivers to be alert and revert their attention towards the hazards ahead.

In third Phase, the effect of new dashboard designs on participants' performance and satisfaction was investigated. These results shows that, despite the significant positive effect of Basic Dashboard, Advanced Dashboard was more effective in terms of helping drivers take back control in a timely manner. Note that in scenario 4 where there was no take back control message, none of the participants in the Basic and Original dashboard groups took back control, and only 41.7% of participants in the Advanced Dashboard group managed to take back control. This shows that while showing information regarding road geometry increased the number of successful take back control for participants in Advanced Dashboard group compared to Basic and Original Dashboard groups, 58.3% of participants in Advanced Dashboard group still did not take back control while approaching the intersection. Considering the dynamic nature of intersections and L2 systems' limitations, failing to take back control (e.g., continuing with the same speed while maintaining same lateral position) at intersections could result in drivers compromising their safety. For example, many ACC systems may not detect the sudden appearance of pedestrians or vehicles on the roadway (Tesla, 2019) and in many others, system may not brake for a vehicle it has never detected as moving (Cadillac, 2018).

Another aspect investigated in this study was the situational awareness of the drivers in scenario 5 (Automated drive) and scenario 7 (Manual drive). Results from the SART questionnaire showed that the participants in the Advanced Dashboard group were more situationally aware than the participants in the Basic and Original Dashboard groups on an average. Our finding regarding the Original Dashboard group SART scores, is aligned with previous studies which show that drivers' situational awareness decreases while driving automated vehicles (Endsley, 1999; Merat & Jamson, 2009). This issue was not observed for Advanced and Basic Dashboard groups, implying that the new dashboard design increased the drivers situational awareness during the automated drive to the level which was not significantly different than manual drives.

5.1 Limitation and Future work

This study has some limitations that may affect its generalizability. Experiments in Phase I and III were conducted using driving simulator. An on-road study is necessary to generalize these findings to the open road. Phase III used a between-design experiment to address its hypothesis. In these experiments, it is difficult to maintain complete homogeneity across groups despite randomization. It would be useful to consider a within-subject design with matching or block randomization techniques to eliminate confounds. Finally, there were limited scenarios considered in Phase I and III. Having a larger variety of scenarios would help to generalize the finding of the study.

5.2 Implications

This study adds to the limited literature regarding dashboard design for L2 vehicles and also provides suggestion to be implemented for practical use, both for commercial vehicles and future research. Results showed that the performance and satisfaction of drivers improved significantly when using advanced dashboard design. It could be noted that unlike Advanced Dashboard design, variants of the Basic Dashboard design are available in commercial L2 vehicles. This study showed that the drivers' performance could be improved by providing additional information (e.g., roadway information). Hence it might be useful to explore methods to improve drivers' performance in current L2 vehicles with similar dashboard as the Advanced design. Training the drivers to understand the ODD limitations of L2 vehicles particularly regarding road geometry and objects on-road can be helpful to prepare drivers for oncoming take back control situations.

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