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Master's Dissertation 2016

Human-Machine Interface Design of a Level 3 automated Vehicle for Safe Car-Driver Handover on Highway

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SUMMARY OF MASTER'S DISSERTATION

Student Identification Number	81434690	Name	Petchbordee Phumayta

Title

Human-Machine Interface Design of a Level 3 Automated Vehicle for Safe Car-Driver Handover on Highway

Abstract

A Level 3 Automated Vehicle has a special characteristic called transition of control between human and vehicle. Level 3 automation can carry on dynamic driving task for certain conditions. There are 2 ways of handling control: from vehicle to human and human to driver. For example, at the highway junction, the driver needs to carry out dynamic driving tasks before entering the highway and then handover the dynamic driving task to the vehicle once on the highway. Later, the vehicle will request the driver to intervene its dynamic driving task before exiting the highway. Each of them have different needs and requirements.

This research focuses on developing the Human-Machine Interface for Level 3 Automated Vehicle for safe car-driver handover on highway. To have a safe handling control handover, the designed HMI becomes a vehicle warning system. The system is designed in a situation where the driver is distracted and is doing non-driving related tasks on the highway. The highway exit is approaching, and the car requests the driver to intervene its dynamic driving task.

The developed HMI system has 3 main methods of warning: Visual (graphic warning), Audio (sound warning) and Tactile (vibration warning). The system consists of 3 components: digital cluster for graphic warning, speaker for sound warning and wireless device for tactile warning. The system warns the driver at 5, 2 and 1 minutes before exiting the highway.

The designed system was then put into test to measure system effectiveness verified by an experiment that measures the transition success percentage, comfortability rating and annoyance rating, rated using a 5-point scale base. The transition success percentage verifies the system ability to catch the driver's attention. The comfortability and annoyance ratings verify that the system sends the intervention requests in an acceptable way for the driver.

Key Word(5 words)

Level 3 automated vehicle, Human-machine interface, Warning system, Handover, Highway

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Chapter 1 Introduction

For vehicle warning systems, there are many factors that contribute to the arising of accidents such as, when the driver is concentrated or focused on the driving task but is not focused on critical parts of driving or on checking the speedometer. This situation will not change in Level 3 Automated Vehicle since the driver is still required to focus on driving related tasks when the driver is in control of the vehicle. On addition of the transition of vehicle control to the car, the driver must be prepared before taking vehicle control.

In recent years, car manufacturers introduced car safety technologies. Mercedes Benz introduced their Sonar technology, lane keeping assist and rear-end collision prevention assist. Volvo also introduced safety technology for pedestrians. These technologies implicate the needs of safety from vehicle to driver and pedestrians, which in turn implicates that the car will be Level 3 Automated Vehicles in the near future. Even though there are numbers of safety technologies introduced in the automobile industry, the way of displaying vehicle information to the driver has not changed as much.

While the Human-Machine Interface of the vehicle stays the same, some of the luxurious car manufacturers have begun to use digital graphic displays in their vehicle to display information. But most of the information is displayed through the dashboard via a speedometer, tachometer and oil temperature meter, which is generally displayed in analog. The functions of the vehicle warning system can be categorized as: Visual, Audio and Tactile according to human sense. Some system or device can provide more than one function.

1.1. Background

The design of HMI was done focused on handing over control from car to driver. Therefore, developing the Human-Machine Interface needed to concern the driver's driving behavior to make the designed HMI an effective system. Thus, knowledge of driver behavior is essential to define the problem and system specifications.

In Level 3 Automated Vehicle, the driver does not need to constantly monitor the road. Thus, there is a high chance that the drivers are distracted during the request to intervene dynamic driving task [5].

1.1.1. Level 3 automated vehicle

There are 6 levels of automation from 0 to 5 according to the new SAE international standard J3016 [1]. Level 0 is no automation, and level 5 is full automation. The system with a higher level requires lower need of human control. Hence in level 0 automation, the driver needs to perform all dynamic driving task (operational task of steering, braking, accelerating, monitoring the vehicle or road and tactical of responding to events when changing lanes, turn, use signal, etc. according to SAE international standard J3016), whereas in level 5 automation, the driver does not need to perform any dynamic driving tasks. Referred systems used to rate level of automation include driver assistance systems, combined driver assistance system and automated driving systems, excluding warning and momentary intervention system.

According to SAE international standard J3016, Level 3 automation is called Conditional Automation. "The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene", which is a request to intervene as a notification sent by automation system to the driver to prepare or resume dynamic driving tasks.

The main key to distinguish level 3 from level 2 automation is that in level 3, the system performs all dynamic driving task whereas in level 2, the driver still needs to perform some part of the dynamic driving task. In addition, the main key to distinguish level 3 from level 4 automated vehicle is that in level 3 automation, the human will need to respond according to request from the vehicle and perform dynamic driving task. The system in level 3 automation can perform dynamic driving tasks at certain condition and will request driver to intervene and take control at some point, whereas in level 4 automation, the system can carry out dynamic driving tasks even if the driver does not respond to requests to intervene from the system.

Table 1.1: Level of automation defined by SAE international J3016

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving modes)
Human driver monitors the driving environment						
0	No automation	the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some driving modes
Automated driving system monitors the driving environment						
3	Conditional Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver	Some driving modes
4	High Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some driving modes
5	Full Automation	the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

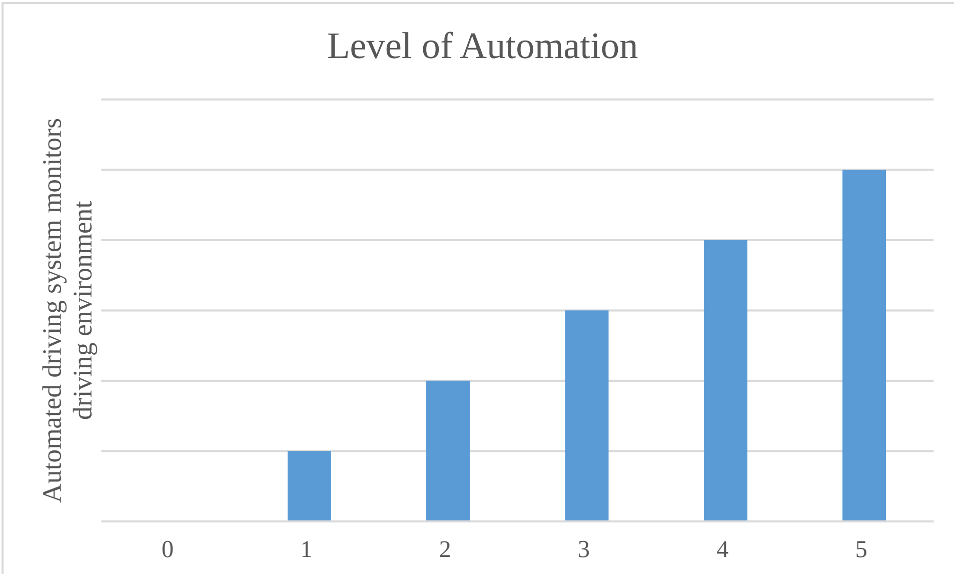

Figure1.1: level of automation distinguished by automated driving system monitoring of the driving environment

1.1.2. Human-machine interface (HMI)

1.1.2.1. Human-machine Interface Definition

Human-Machine Interface (HMI) is also referred to as User Interface (UI). It is usually displayed in graphical format as an operator panel or terminal for monitoring, controlling and managing the process of the operating machine. E.g. The operator panel includes actions to control and display the state of the machine for an operator to send commands and receive information for monitoring the process which the operator can send information to the machine by button or touchscreen to control the machine. Type of display use differs depending on the application from entry level for simple user interface needed application to high end level where complex and high load of information is needed (see figure1.3a for more information). HMI can be a display on the machine, portable with built in battery or centralized in control rooms. Usability of HMI system is determined by processing speed, ability to render complex graphics, response rate and flexibility to serve various operator interactions [2].

In addition, HMI not only includes graphic display but everything that can act as an indicator that the operator can observe from the machine. For instance, a laptop, track pad, keyboard, mouse and display is considered as HMI. Keyboard and mouse is used as a channel to send information from operator to machine, and the operator can monitor the process using the laptop's display screen.

1.1.2.2. Human-machine Interface in industrial design field of human-machine interaction

According to Griffin Ben's "Interfaces" Presentation, “The user interface (UI), in the industrial design field of human–machine interaction, is the space where interactions between humans and machines occur. The goal of this interaction is to allow effective operation and control of the machine from the human end, whilst the machine simultaneously feeds back information that aids the operators' decision-making process. Examples of this broad concept of user interfaces include the interactive aspects of computer operating systems, hand tools, heavy machinery operator controls, and process controls.”[3]. Hence, HMI can be any device or component that can send or receive information from human or machine.

Table 1.2: HMI Form Factor Level & Requirements according to requirements [3]

HMI Form Factor	Requirements
High end	• Up to WUXGA display • 2D/3D graphics • User interface application • Video playback • HTML5
Mid end	• Up to XGA Display • 2D Graphics • User interface application
Base	• UP to XGA Display • Light-weight user interface
Entry	• Up to QVGA display • Simple user interface

1.1.2.3. Human-machine Interface in automotive application

Driving focus user interface

In automotive application, the Human-Machine Interface is used for communication between the driver and the car. E.g. For the driver to be able to do basic steering, acceleration pedal, brake pedal, steering wheel, gear knob and cluster is need. The driver gains speed by pressing on the acceleration pedal and stops the car by pressing on the brake pedal, controls direction of the vehicle by rotating the steering wheel, the driver pushes and pulls the gear knob to send commands to move car forward/reverse and monitor speed and car status by cluster. All mentioned component is Human-Machine Interface since they make operator (driver) be able to operate the machine (car) and monitor the process. The cluster is the main interface that the driver uses to monitor the car status such as speed, temperature and fuel. Therefore, the driver obtains a lot of data from the cluster alone. See figure 1.2 picture a) for an example of cluster user interface design.

Infotainment user interface

Human-Machine Interface design does not focus only on driving purposes, but also design for entertainment purposes as well. As can be seen from various interfaces for infotainment introduced by different automakers such as iDrive by BMW in figure 1.2 picture c) and Mercedes-Benz center console layout, designs are designed to support features such as radio control, phone call and climate control.

Figure 1.2: Examples of HMI design for automotive application [4]

1.1.3. Characterization of driver inattention

Historically, driver distraction has typically been associated with secondary tasks such as dialing a cell phone, conversing with a passenger, and adjusting the radio. Driver distraction has been said to lead to driver inattention. Drowsiness has been described as another cause of driver inattention. With the video data available in this study, new categories of "driver inattention" were discovered. The two new categories were "driving-related inattention to the forward roadway" and "nonspecific eye glance." "Driving-related inattention to the forward roadway" involves the driver checking the speedometer, rear-view mirrors, or blind spots [5]. This new category was added after viewing numerous events for which the driver was clearly paying attention to the driving task, but was not paying attention to the *critical aspect* of the driving task (i.e., the forward roadway) at an inopportune moment.

Inattention, which was operationally defined as including: (1) secondary task distraction, (2) driving-related inattention to the forward roadway (e.g., blind spot checks), (3) moderate to extreme drowsiness, and (4) other non-driving-related eye glances, was a contributing factor for 93 percent of the conflict with lead vehicle crashes and minor collisions. In 86 percent of the lead vehicle crashes/collisions, the headway at the onset of the event was greater than 2.0 seconds.

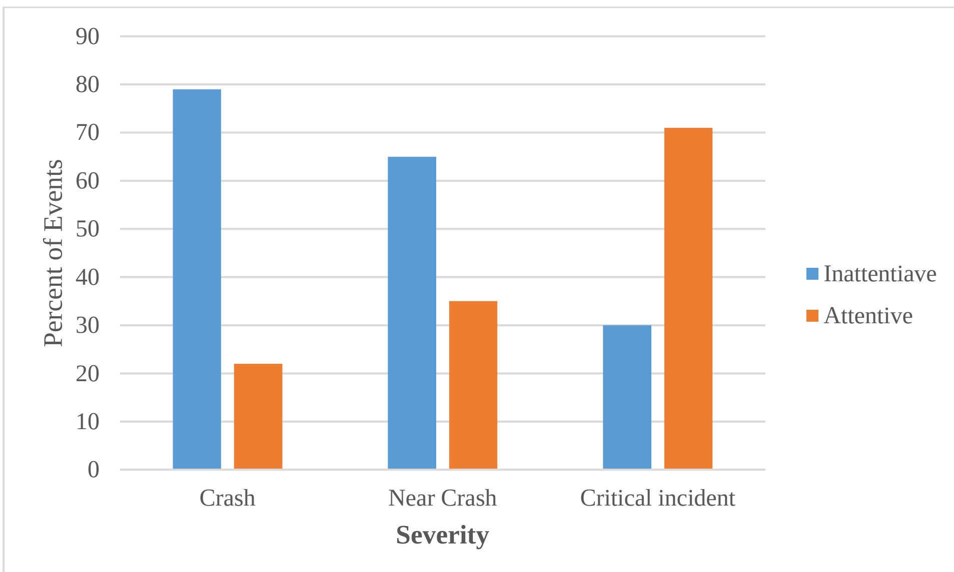

Figure 1.3: Percentage of events for attention by severity level.

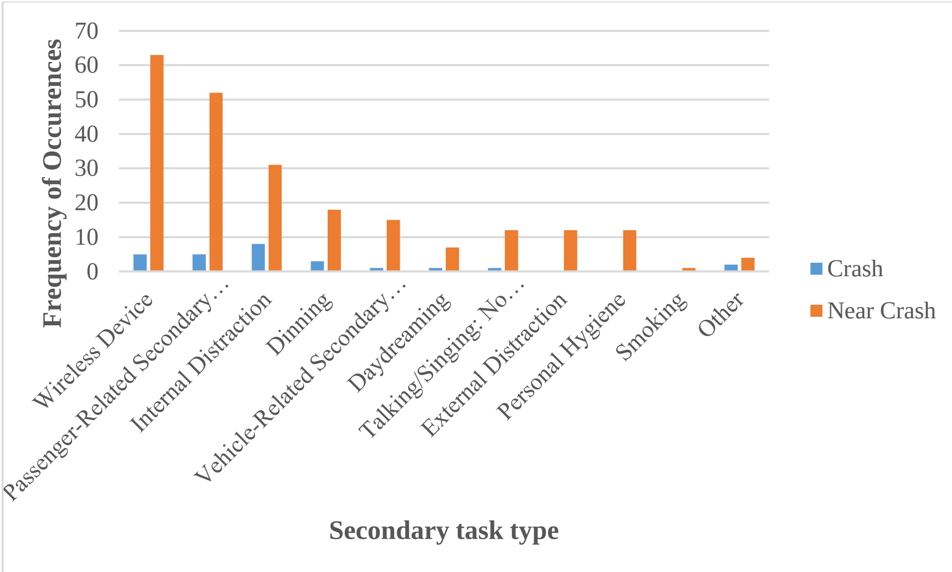

Figure 1.4: Comparison of crashes and near-crashes against the frequency of occurrences of the presence of a distracting agent as a contributing factor.

1.1.4. Collision Warning Timing, Driver Distraction, and Driver Response to Imminent Rear-End Collisions in a High-Fidelity Driving Simulator

Rear-end collisions account for almost 30% of automotive crashes. Rear-end collision avoidance systems (RECASs) may offer a promising approach to help drivers avoid these crashes. Two experiments performed using a high-fidelity motion-based driving simulator examined driver responses to evaluate the efficacy of a RECAS. The first experiment showed that early warnings helped distracted drivers react more quickly – and thereby avoid more collisions – than did late warnings or no warnings. Compared with the no-warning condition, an early RECAS warning reduced the number of collisions by 80.7%. Assuming collision severity is proportional to kinetic energy, the early warning reduced collision severity by 96.5%. In contrast, the late warning reduced collisions by 50.0 % and the corresponding severity by 87.5% [6].

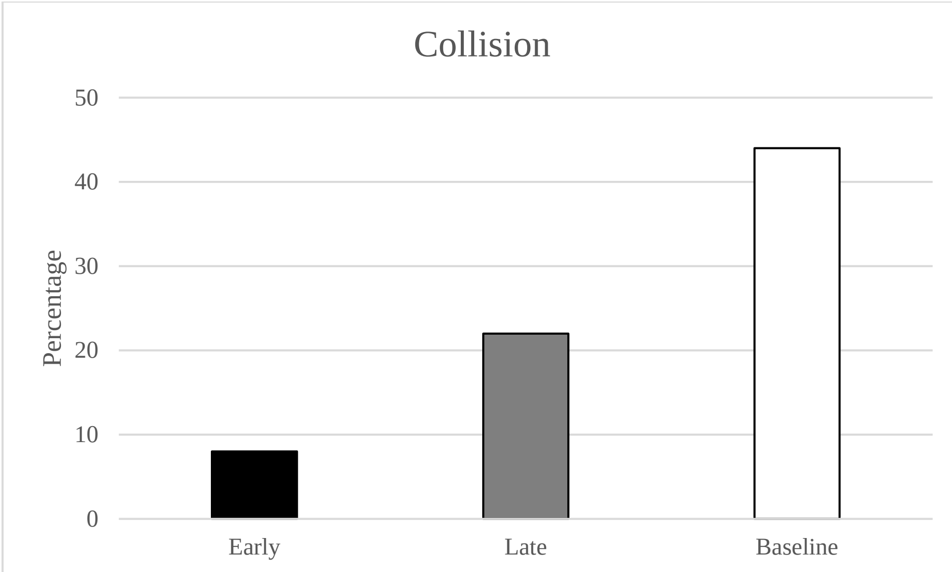

Figure 1.5: Collision percentage comparing early warning, late warning and baseline (no warning)

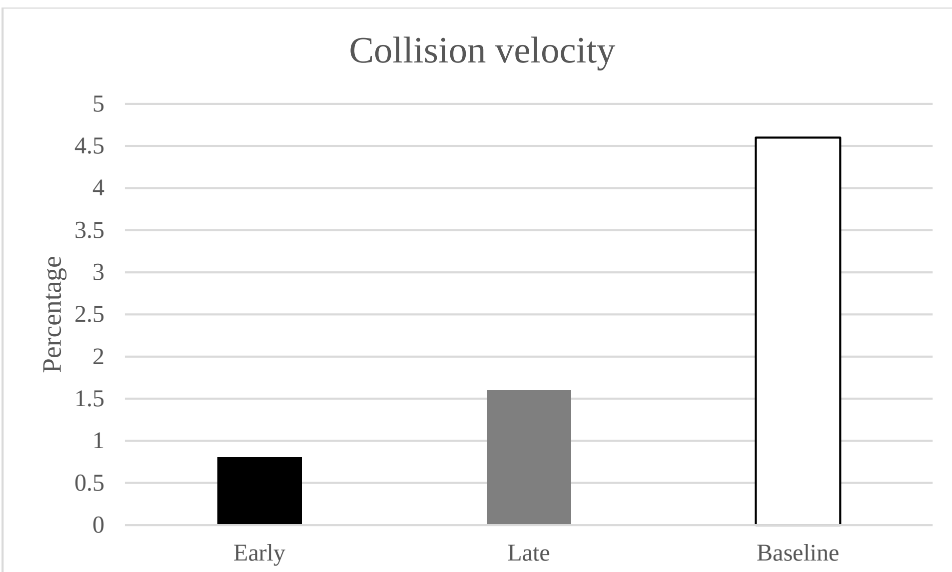

Figure 1.6: Collision velocity (m/s) comparing early warning, late warning and baseline (no warning)

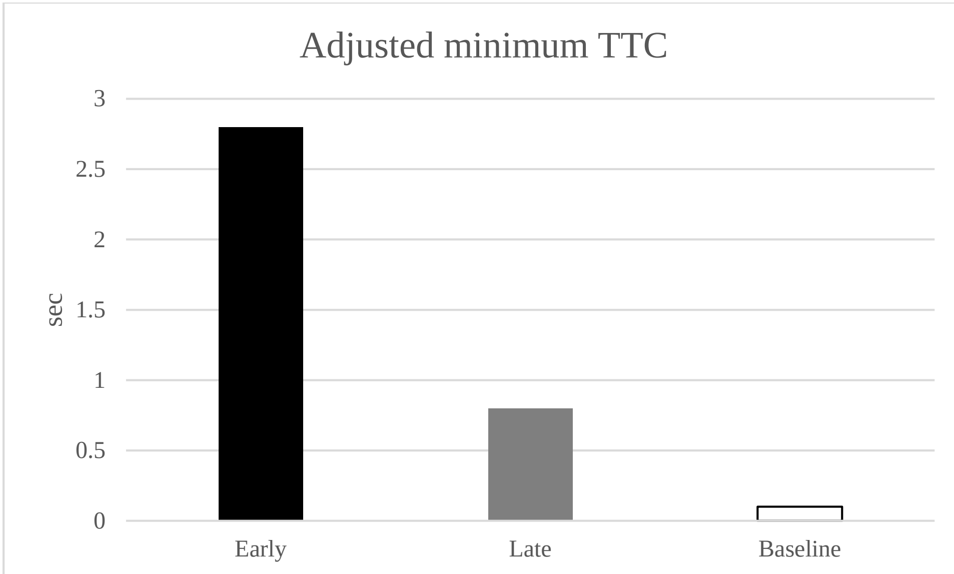

Figure 1.7: Adjusted minimum TTC comparing early warning, late warning and baseline (no warning)

TTC represents how much sooner the driver would have needed to begin braking to avoid collision with the lead vehicle. The adjusted TTC complements the collision and collision velocity measures by indicating the safety benefit.

1.1.5. Previous study

There are many researches studying improvements to HMI by many approaches and solutions, with several of technologies including Wind shield display to LED light. For instance, “Language-Based Multimodal Display for the Handover of Control in Autonomous Cars” [7] research focuses on handing over of control from car to driver for Level 3 Automated Vehicles. The researcher tries to communicate how urgent the situation is to the driver by using modality of the sound while trying to distract the driver by have them play games on a tablet to simulate unattended driving situations where road environment is shown on the computer monitor. There are 3 different scenarios with different urgency of “Danger! Collision imminent. You have to control.” where collision is about to happen, “Warning! GPS signal weak, want to take over?” and “Notices! Toll ahead 5 pounds, want to take over?”. One of the tests conducted with using modality of sound of urgency of high, medium and low respectively. The other one uses uni-modality sound for all scenarios.

The sound alert modality depends on how urgent the situation is, for example in a situation that may cause collision or accident, the modality of the alerting sound is more dramatic and fast while normal activity such as receive new email is less dramatic. Result of the experiment shows drivers can perceive urgency of situation better when using different modality sounds as shown in figure1.8. In addition, researchers found that many drivers got irritated from using uni-modal sound for every scenario.

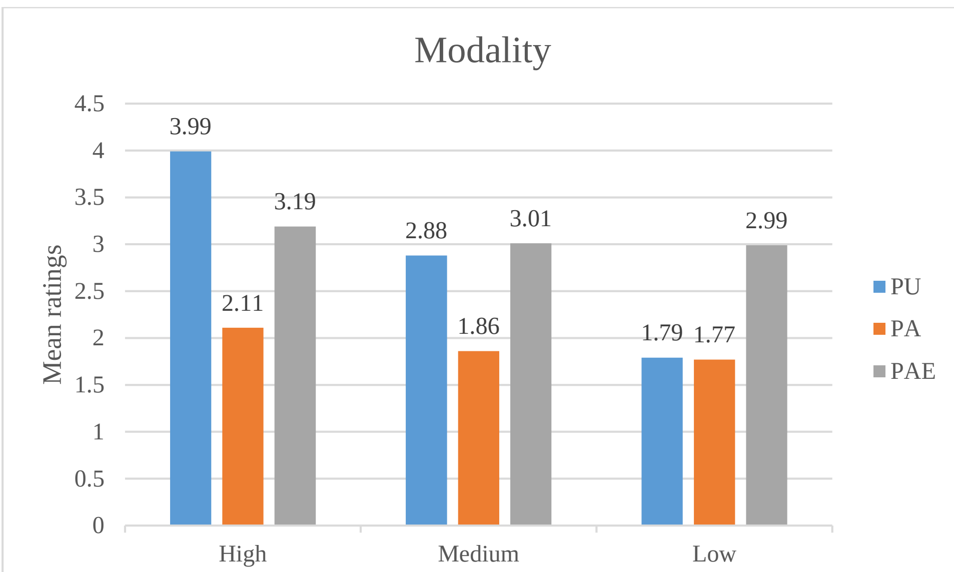

Figure 1.8: Result of “Language-Based Multimodal Display for the Handover of Control in Autonomous Cars” experiment showing “PU” perceive of urgency, “PA” perceive of annoyance and “PAE” perceive of alerting effectiveness.

Some of the research improves HMI by adding functions to component within the vehicle such as "Haptic Seat for Automated Driving: Preparing the Driver to Take Control Effectively - Ariel Telpaz" [8] which uses haptic seats for informing the position of other cars around the driver by using high and low position of the seat which have vibrators implanted underneath the seat's outer skin. As a result, using haptic seats does improve driving performance. The drivers take less time on changing lanes, checking rear and side mirrors more often compared to without using haptic seat. Therefore, this haptic seat will surely help Level 3 Automated Vehicle in the situation of handing over control from car to driver as haptic seats help to prepare the driver before taking control.

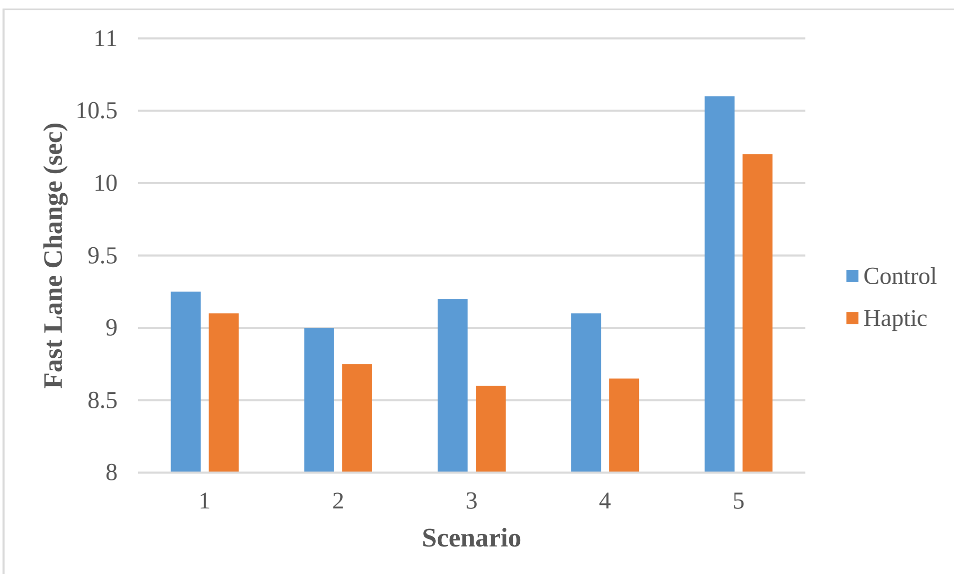

Figure 1.9: Result of "Haptic Seat for Automated Driving: Preparing the Driver to Take Control Effectively"

1.2. Objectives

This research focused on developing the Human-Machine Interface for Level 3 Automated Vehicles for a safe car-driver handover on the highway. The system aimed to catch the driver's attention in an acceptable way of warning for the driver. The developed HMI will help to prepare the driver before taking control of the car. Since this HMI is focused on handover of control from car to driver, the designed HMI is a sub-system of the vehicle, as all of the functions will be focused on handover of control from car to driver. Transition time from handover control between car and driver is a unique characteristic of Level 3 Automated Vehicle, which at the current time has no suitable conceptual HMI.

1.2.1. Originality

The developed HMI aims to deliver an efficient warning system for the handover of control from vehicle to human in the situation of handover control from car to driver on highways. The HMI focused on preparing the driver to be ready to safely intervene the dynamic driving task.

The designed system consists of 3 components: digital cluster, speaker and wireless device. These components work together to deliver the thesis's objective. The digital cluster is responsible for graphical warning, the speaker is for sound warning, and the wireless device is for graphic, sound and tactile warnings. The user-interface used in the experiment was created by the researcher.

The designed system was then put into test in an experiment. The experiment verifies if the designed warning system works or not. However, only 2 of the 3 components were tested in the experiment. The wireless device was excluded. The result of the experiment is obtained in both quantitative and qualitative form. 3 main aspects are transition success rate, comfortable rating and annoyance rating. Comfortable rating and annoyance rating were obtained from a questionnaire.

In addition, the questionnaire contained 2 questions of potential of improving system effectiveness by including a wireless device in the system.

There are two options to choose from. To be used as a "display" which are Wind Shield Display (WSD) and Digital Cluster. The reason for choosing the Digital Cluster is that the technology already existed, used in some sport and luxurious vehicles. WSD can potentially be introduced for common use in the near future, and has not been used in any vehicle productions yet. The designed layout of the digital cluster can also be integrated to WSD use. Mobile devices can be selected to be used as this element has function of all visual, audio and tactile. Thus, mobile device has the potential to improve system effectiveness

Comparing to similar papers

1. Transition to manual: Driver behavior when resuming control from a highly automated vehicle [9]

The paper focused on the same situation as researcher's paper in term of handover control from car to driver in level 3 automated vehicle on highway.

However, there are differences in the condition. The paper study condition when manual control is needed in order for vehicle to change lane which is different from researcher's paper of preparing driving to take control of dynamic driving task before exiting highway.

Furthermore, the paper does not concern about designing warning interface or strategy but concern about time it took for drivers to successfully resume dynamic driving task by looking from pattern of eye movement.

2. Language-Based Multimodal Displays for the Handover of Control in Autonomous Cars [7]

The paper focused on the same situation of handover control from car to driver in level 3 automated vehicle and warning strategy as same as researcher's paper. In term of warning strategy, warning system consists auditory warning and graphic warning as same as researcher's system of experiment which does not include tactile warning.

There are difference in detail of warning strategy, the paper focused on effect of using difference modality of warning sound to driver sense of urgency which is different from researcher's strategy of interval warning in graphic, auditory and tactile warning. In addition, focused condition is different, the paper focused where the car in front decelerate and manual control is needed from distracted driver where researcher's paper focused on exiting highway and manual control is need from distracted driver.

3. Collision Warning Design to Mitigate Driver Distraction [10]

The same areas of focus between the paper and researcher's paper are focusing on warning strategy of when and how to present warning information and concern about user acceptance included in the experiment as well.

However, the warning strategy and situation of focus is different. The paper focus on preventing collision with the car in front when the driver is trying to complete auditory email task and lead vehicle brake. Hence the paper do not focus on handover control when exiting highway. The warning system consist of audio and haptic warning which are speaker and haptic seat where auditory warning format is MIDI. Hence the components in the warning system is different where researcher system include digital cluster, speaker and wireless device for graphic, audio and tactile warning. Warning strategy used in the experiment was graded-stage warning which presents a warning signal proportional to the degree of threat such as louder auditory warning.

1.2.2. Thesis motivation

Initially, the researcher intended only to work on the dashboard, designing the dashboard layout by using prioritizing method to locate gauge and indicator position. The originally aim was to make the dashboard more convenient and comfortable to use, and potentially increase driving performance.

In the researcher’s point of view, showing speed digitally is more comfortable to read than using a traditional analog display. The researcher has been using a number of cars and noticed that when driving, a car that has a digital speed display is more comfortable to control the speed without spending eye glance time to read speed compared to an analog one. Also, changing from driving a car with a digital speed display to one without makes the researcher feel annoyance, while changing from one that does not have a digital display to one that does, does not cause any annoyance. With that being said, in the researcher’s opinion, the driver can adapt to use a digital speed display without any effort, but changing back to an analog display can make the driver feel annoyance because it is harder to read the car speed.

Displaying speed digitally is better than analog even if the font size is small, which can be seen in cars such as Mercedes-Benz E class W212 and Mercedes-Benz SLK R172. Those cars display speed digitally in a size that is a lot smaller than its own analog speedometer.

However, as the study progressed, the researcher studied display devices to find the most suitable one. The researcher noticed that the Head Up Display (HUD) has the potential to be a better way of displaying information since HUD can project information on to the windshield, and is a digital kind of display. But even if projecting information onto the windshield is more convenient for the driver to see information, the result is that the HUD can cause annoyance to the driver, and limit the angle of sight. Hence, the HUD is not suitable for application for a driver sitting in a driving position. In addition, the HUD had been used for many years in the automotive market e.g. Nissan S13 and Toyota Prius, but the HUD was not successful for car application, as drivers have said the HUD is annoying, and many tend to turn the HUD off. However, the HUD is more successful in motorcycle application, with the projector locked to the driver's head orientation and does not cause any annoyance to the driver.

Technology of the screen display evolves drastically every year, but very few of these technologies make it to implementation in vehicle production. Nowadays, the screen can display information in such high detail and quality that the viewer can even see information on the screen from almost any angle, which has the potential to help the driver to receive more detailed, precise information and even in a more convenient way for both drivers and the automaker company.

Recently, Tesla launched the Tesla autopilot mode on to their car. The Tesla autopilot mode is a new function added to their Tesla model S mass production vehicle as an update, a function that the vehicles never had when they first left the factory. The autopilot mode makes every Tesla model S be able to partially drive on its own. It uses lane assist steering with adaptive cruise control, various sensors to detect the position of nearby vehicles, and a computer to make decision in steering the vehicle.

Still, the Tesla model S does have an LCD screen display on the dashboard. Many Tesla autopilot users complain that sometimes they are confused with the autopilot function, and do now know if the function is activated or not. The design of the user interface fails to show when the car has control, and when the driver has to control, which becomes an important and key point in designing the UI.

In the autopilot mode, the system is not yet able to fully drive on its own. While the autopilot mode is on, the driver still needs to constantly monitor the road while driving. This means it is not yet a Level 3 Automated Vehicle, since in level 3, the driver can let the vehicle fully control the car in certain conditions without the need to monitor the road.

With the level 3 automation, the driver needs to receive more information than a level 2 automation vehicle in which, the same way of displaying information will not be substantial any more. Therefore, there is high potential that a new kind of display will be needed for these vehicles.

Chapter 2 Summary

The study focused on developing the Human-Machine Interface for a Level 3 Automated Vehicle, with the design starting from key characteristics of the vehicle in transition of control between driver and car. The study chose to focus on the handover of control from car to driver on the highway. According to Background Section 1.1, the driver would likely be inattentive once the car drives by itself for a certain amount of time. Hence the HMI must be able to catch the driver's attention, with the designed HMI needing to have a warning system.

The study uses the Model-Based Systems Engineering method of using the SysML language to develop and express the system. The key function of the designed system is in interval warnings. There are 3 timed warnings: the 5 minute mark, the 2 minute mark, and at the 1 minute mark. Components selected for warning are the digital cluster, speaker and wireless device.

The User-Interface of the cluster was developed using the SCADE display, showing the advantages of using a digital cluster, consisting of layers of display. Each warning mark has different warning contents of graphic, text and sound warnings as shown in table 4.2.

The study conducted an experiment to verify the system effectiveness. There were 12 participants in the experiment, with a balance between male and female, ages ranging between 24-30 years, and participants having and not having a driving license. The transition successful rate is measured, and other areas that the experiment verifies are warning performance, comfortable and annoyance ratings, all based on 5-scale rating. Within the experiment, participants were asked to intervene the dynamic driving task before the car passed the highway exit. If the participant failed to intervene in time, the transition is considered as a fail. The participants were later asked questions about their thought one the system in terms of performance, comfortableness and annoyance. Furthermore, the potential of wireless device to improve system effectiveness is studied in the experiment as an extra question to the participant, since the wireless device was not tested in the experiment. Workflow of the experiment is explained below in figure 2.1.

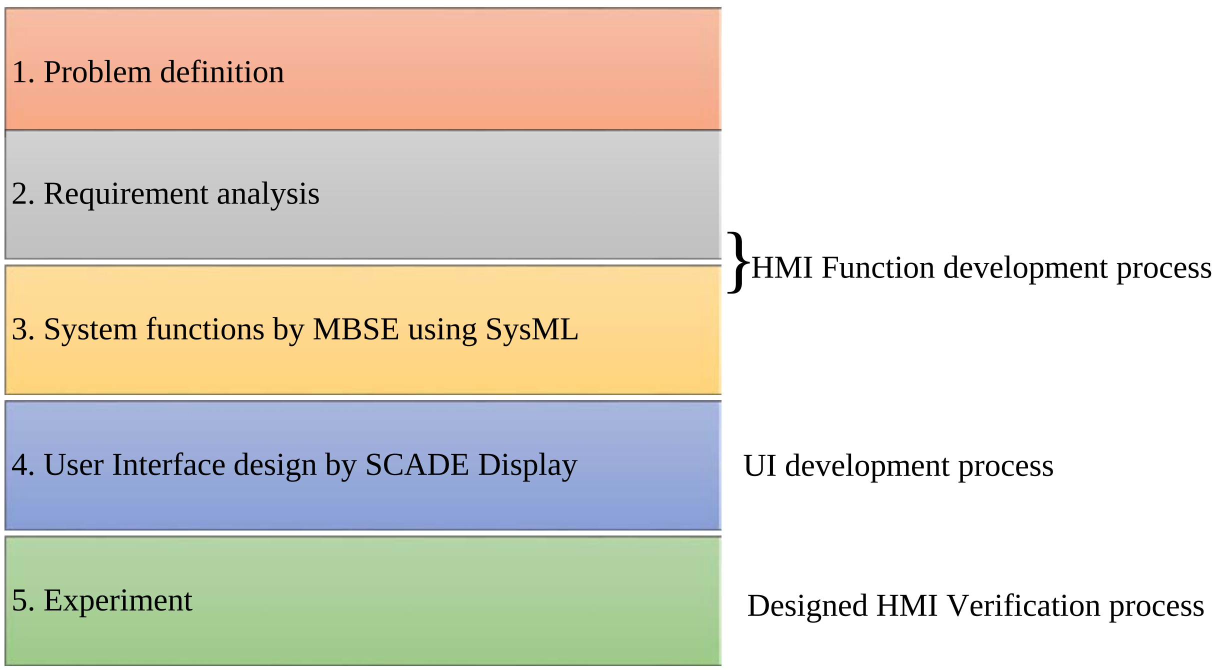

Figure 2.1: Work flow of the study

Chapter 3 Concept design

3.1. Model based system engineering (MBSE) Design Process

Model-Based Systems Engineering is used as a first stage for concept development. The MBSE process is the root of all functions developed in the final Human-Machine Interface which will be shown at a later stage. The MBSE process is when the problem is defined. The defined problem of safe handover of vehicle from car to driver when exiting the highway is used to develop the HMI specification which is processed to become the HMI requirements. The developed requirements will then define the functions of the HMI.

3.1.1. Requirements analysis

From the defined problem and specifications, the developed requirement has to look in various perspectives. Safety is the highest priority of concern when developing the system which puts the driver and passenger's lives on the line. If the developed system cannot grab the driver's attention, the result will be fatal. However, the developed system of HMI should be able to grab the driver attention without causing uncomfortable feelings for the driver and at the same time being safe. This is the second priority when developing the HMI for this particular objective. Keeping this in mind means that the driver needs to be warned before exiting the highway (transition period) which brings warning performance criteria, and, as mentioned, the system should not cause an uncomfortable ride for the driver as well, hence driving comfort is another criterion.

For the warning performance criteria, to grab the driver's attention, the system has to utilize the human perception of information effectively. There are 5 ways of how a human percepts information, called senses. Sense is a physiological capacity of organisms that provide data for perception [11]. The human's 5 senses are: sight (visual), hearing (audio), taste, smell and touch (tactile), of which 3 out of 5 can be used for this type of application as taste and smell could cause the ride to be uncomfortable and there is no existing way of how to make the driver percept these senses in automotive technology yet. The warning should be instant without any second of delay; a second of delay at a critical time may cause a fatal accident. The information output from interface to driver needs to be accurate, precise and clear. For example, the warning sound should be short, precise, clear and unambiguous as sending a very long item of information by sound may cause the driver to lose focus half way through the warning, and may lead to misunderstanding with received information if the information content is ambiguous. The key characteristic of warning used is designed from the key characteristics of a Level 3 Automated Vehicle, which is transition. When exiting the highway, the transition from car to driver takes place. Hence, there is a need for the driver to prepare themselves before taking control of the car. This leads to the key characteristic of warning, which is an intervals warning. This interval warning will be discussed later in the function diagram section.

The driving comfort criteria is prioritized as second place. Driving comfort consist of 4 things which are: usability of wireless device, annoyance rating, easy to read graphic and clear and easy to understand warning sound. Usability of wireless device exists here since the most non-driving related task that the driver does is using a wireless device while driving, such as cellphone and tablet. This implies that the same activity will be applied to a Level 3 Automated Car as well with a much higher rate since even though in Level 1 or 2 Automation the driver is needed to constantly monitor the road while driving, many drivers do not, and use a wireless device instead. Annoyance rating needs to be done to verify that the developed HMI is in a tolerable range. Easy to read graphic with clear and easy to understand warning sound needs to be made to reduce annoyance rating.

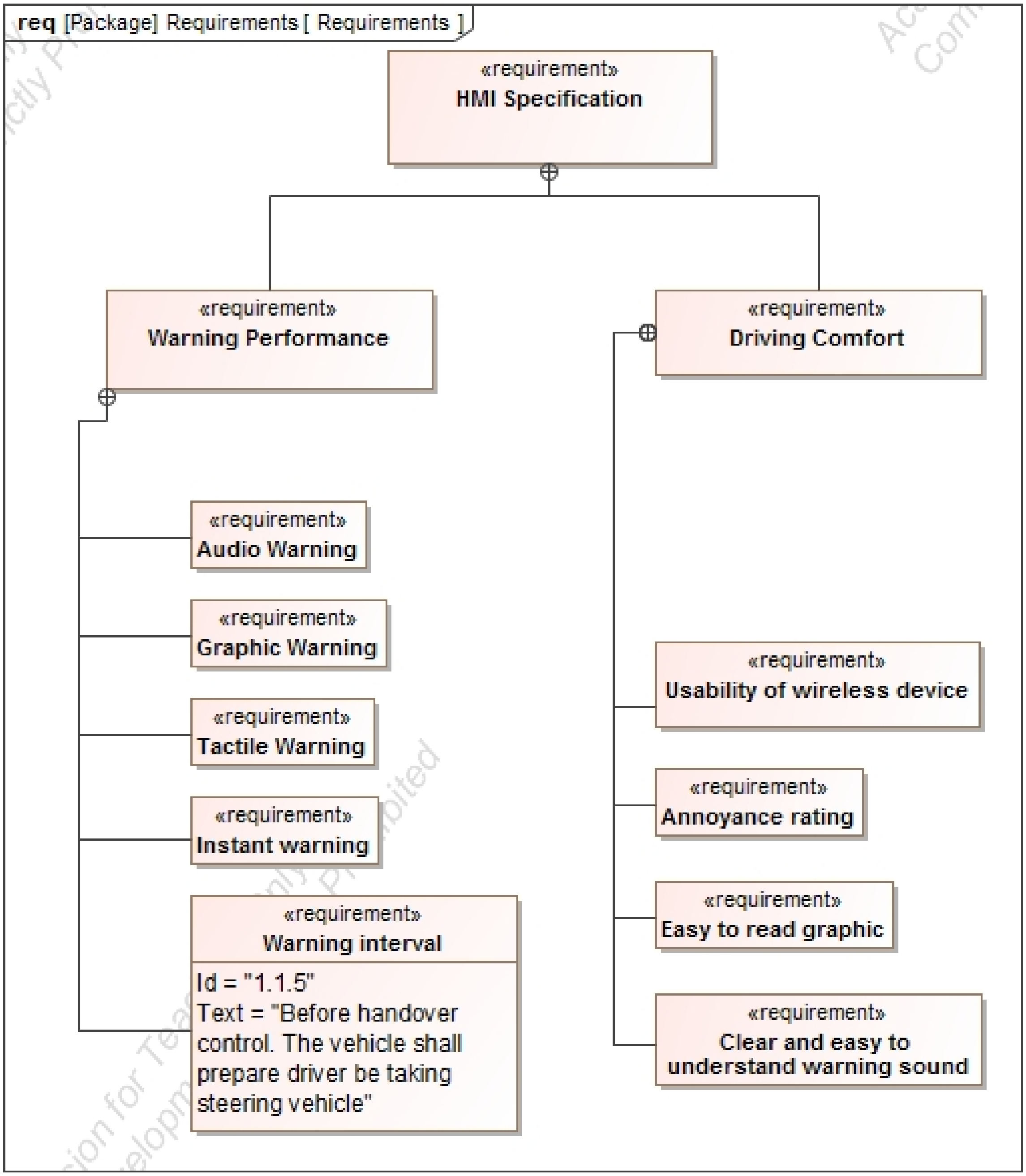

Figure 3.1: Developed Requirements diagram from analyzed specification

3.1.2. System function development process

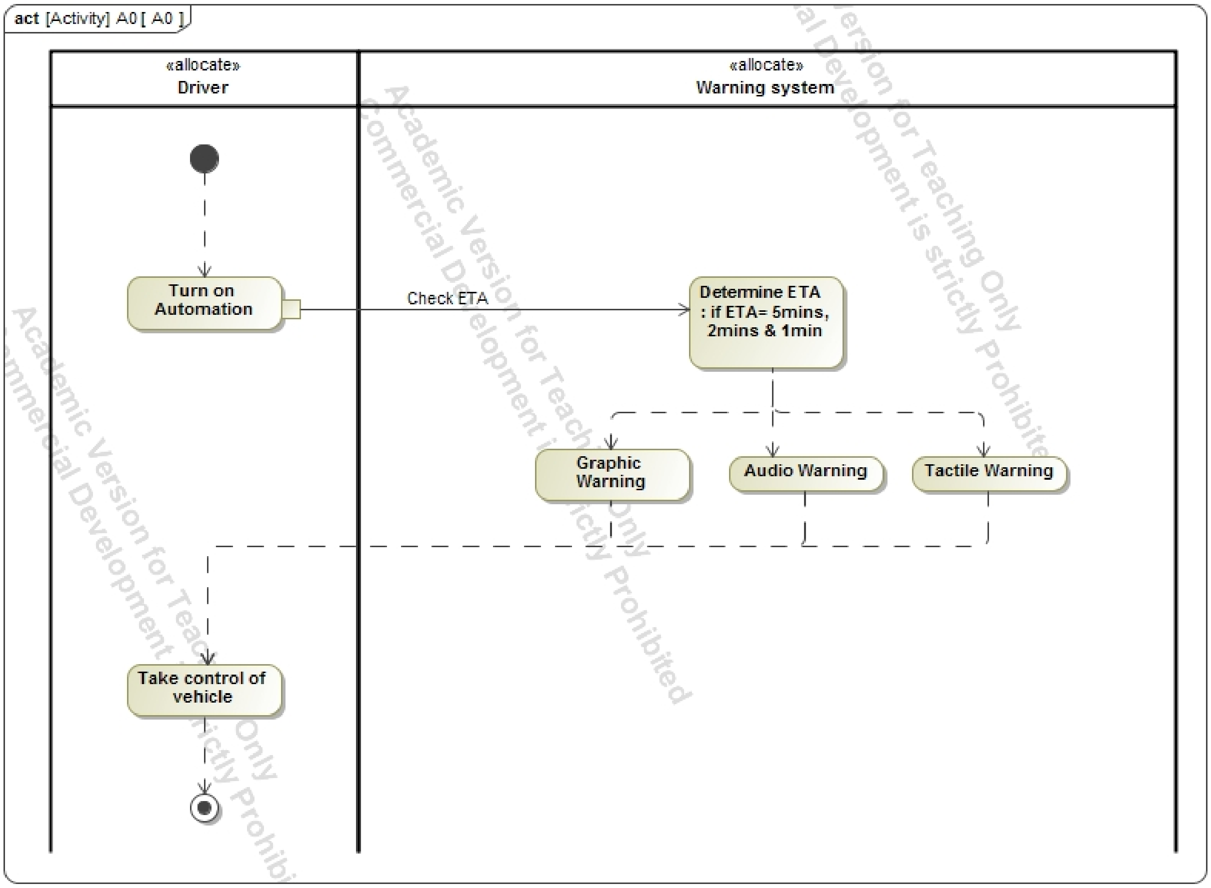

Figure 3.2: Activity diagram A0 show functions of warning system

Functions of the warning system are then developed after requirement analysis is finished (some function is added from later phase of MBSE process revisit between stages to improve the system continuously). Every function exists to satisfy one or more requirements, see figure 3.1. As mentioned, this system is designed to focus on handover of control from car to driver. Hence the developed functions start after the automation is already on (computer control the car) and the driver is not monitoring the road.

The system needs to know the estimated time of arrival to exiting the highway. This data will later be used for graphic, audio and tactile warning. Hence the function of determining ETA comes as the first process before the warning starts. In addition, data of ETA is passed on to graphic, audio and tactile warnings to produce different and suitable warnings for different moments in the transition phase, see figure *3.2*.

The warning function starts in the transition period as selected of 5 minutes, 2 minutes and 1 minutes. This is to prepare the driver before taking control of the car. Since the driver needs time to prepare themselves before they can actually resume driving. The system gave a 5-minute gap for the driver to finish their non-related driving task. This can provide both safeness and driving comfort as the driver does not need to rush finishing the activity they are up to, and the driver can resume driving in time before the automation system cannot handle driving the car.

After Activity diagram A0 is introduced, the researcher searched for suitable components to be used for the HMI system. The component can be any device in the vehicle. Including device from the driver such as mobile device and wearable device which can be seen in present days. The component list is shown in figure 3.3.

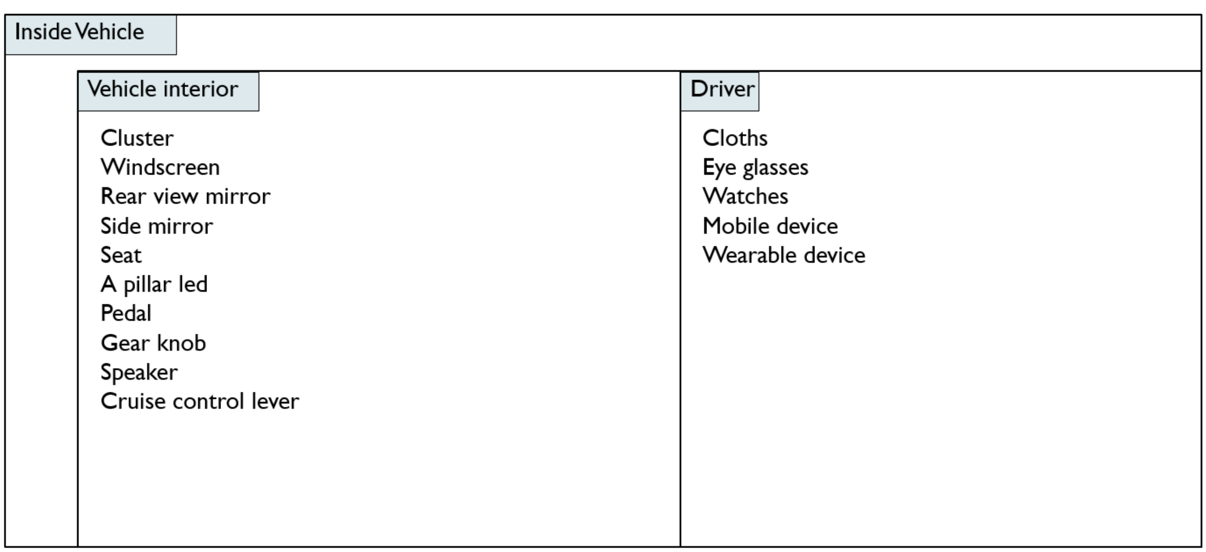

Figure 3.3: Components/device inside the vehicle lists

The research starts to analyze and link how humans perceive information from those components. Again, the 5 human senses are introduced in figure 3.4 to link components with how the driver perceives information e.g. How the driver perceives pedal and seat is by touch (tactile). The 3 components selected to be used are cluster, speaker and mobile device.

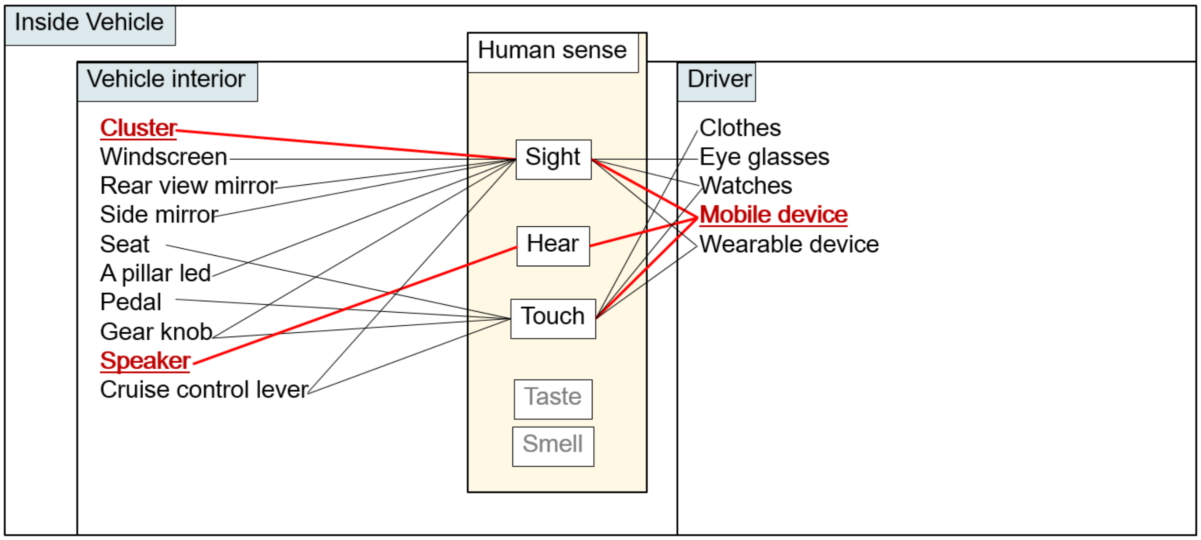

Figure 3.4: Diagram shows the relationship between component and how the driver perceives information from each components

The cluster is responsible to send information to the driver by visual methods. The warning graphic function will apply to the component. The cluster is one of the chosen component because in current technology, cluster is the most effective component used to display information to the driver, and creates driving behavior of checking the cluster for information or state of the car (e.g. speed, fuel and check engine light). There are two competitors when selecting the component responsible for visual warning. There are cluster and wind screen (Windshield display). The wind shield display has advantages both in terms of angle of vision and comfortableness. The WSD can utilize most areas of the windshield is display text or graphics. However, the WSD is a very new technology that has not yet been introduced in any mass production vehicle. The technology is still under its development process and therefore has the uncertainty of not making it to production. There is a new kind of cluster which is digital and uses TFT or LCD or an alternative kind of screen to display information digitally. This means that the digital cluster can have many layers in one screen and changing layout of display on the go is now possible. In addition, clusters were used for a long time, usually analog, and it is the current way of how drivers perceive information.

The speaker is responsible for the warning sound. The speaker is a simple device for sending information in the form of sound. Most modern cars even come with voice control. The car can communicate with the driver for the driver to give basic commands such as phone call via speaker and microphone (e.g. Ford fiesta 2015). The speaker is not only used as a component for entertainment features but for safety features as well (e.g. safety belt and improperly closed door alert). Hence, the speaker is the most effective component to be used for sending the warning sound.

For the mobile device, the device has a graphic display (visual), built in speaker (audio) and vibration (tactile). The mobile device is the main device responsible for tactile feedback since the behavior of human to keep mobile phone close to themselves makes this device very effective for this application. The device can also be designed to give various levels of vibration that can make the driver perceive urgency. Mobile devices can provide visual and audio feedback, but the device was not selected to do this as the device cannot provide the same effectiveness in this area since the area of display and speaker is not as powerful as the other 2 selected components.

In the researcher's opinion, the mobile device has the potential to improve the warning system's effectiveness if utilized properly, as the device can allow the human driver to perceive information via 3 of the 5 senses. In addition, the device will be the ideal device in the scenario of driver using a mobile device during the transition period. The mobile phone can give the driver a warning by text notification, graphic and sound.

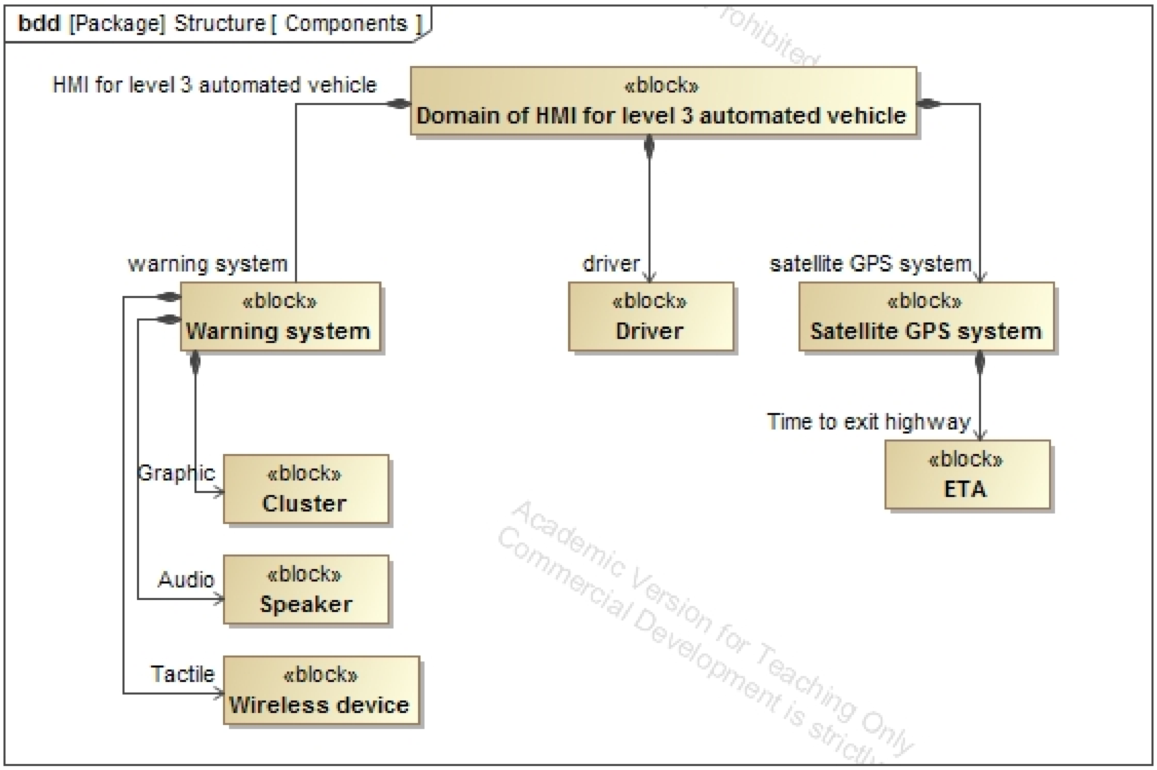

Figure 3.5: Block diagram showing components within the system

The selected components to be used for the warning system is shown in figure 3.5. The driver is an included element in the system as the HMI system is made for the driver. The relationship between the warnings system and driver is that the warning system will alert the driver when the situation needs the driver to prepare for transition before exiting the highway. The warning system needs to deliver alerts to the driver for safety when exiting the highway, after which the driver will then carry out the task of driving the car. As mentioned the component responsible for graphic, audio and tactile warnings are cluster, speaker and wireless device respectively.

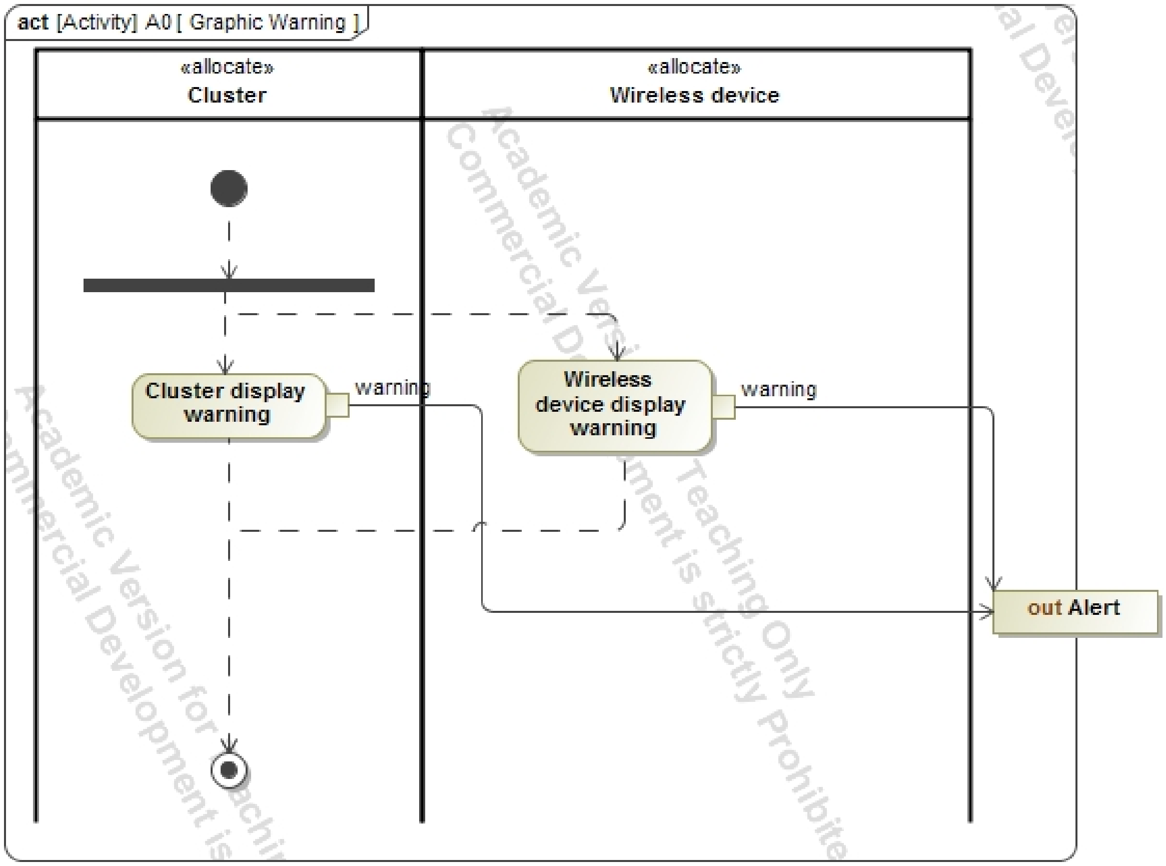

Figure 3.6: Activity diagram of Graphic warning function

For the graphic warning function, there are two selected components that are responsible. The cluster is the main responsible component and the wireless device (mobile device) is a secondary component. Both of them need to be in sync and display the same information. As mentioned before, the content of display needs to be unambiguous. The output of this function would be an alerted driver who saw the graphic warning. This similarly applies to the audio warning where the audio warning function consists of speaker and wireless devices delivering an alerted driver who heard the warning sound as can be seen in figure 3.7. For tactile warning, there is only one device responsible for the tactile warning function, which is wireless device as can be seen in figure 3.8. The output of the tactile warning function is an alerted driver by vibration of the wireless device. In addition, the situation awareness (sense of urgency) can be an output as well if there are different levels of vibration intensity. For example, for an urgent condition a high level of vibration will activate. For a normal condition, a low level of vibration activates.

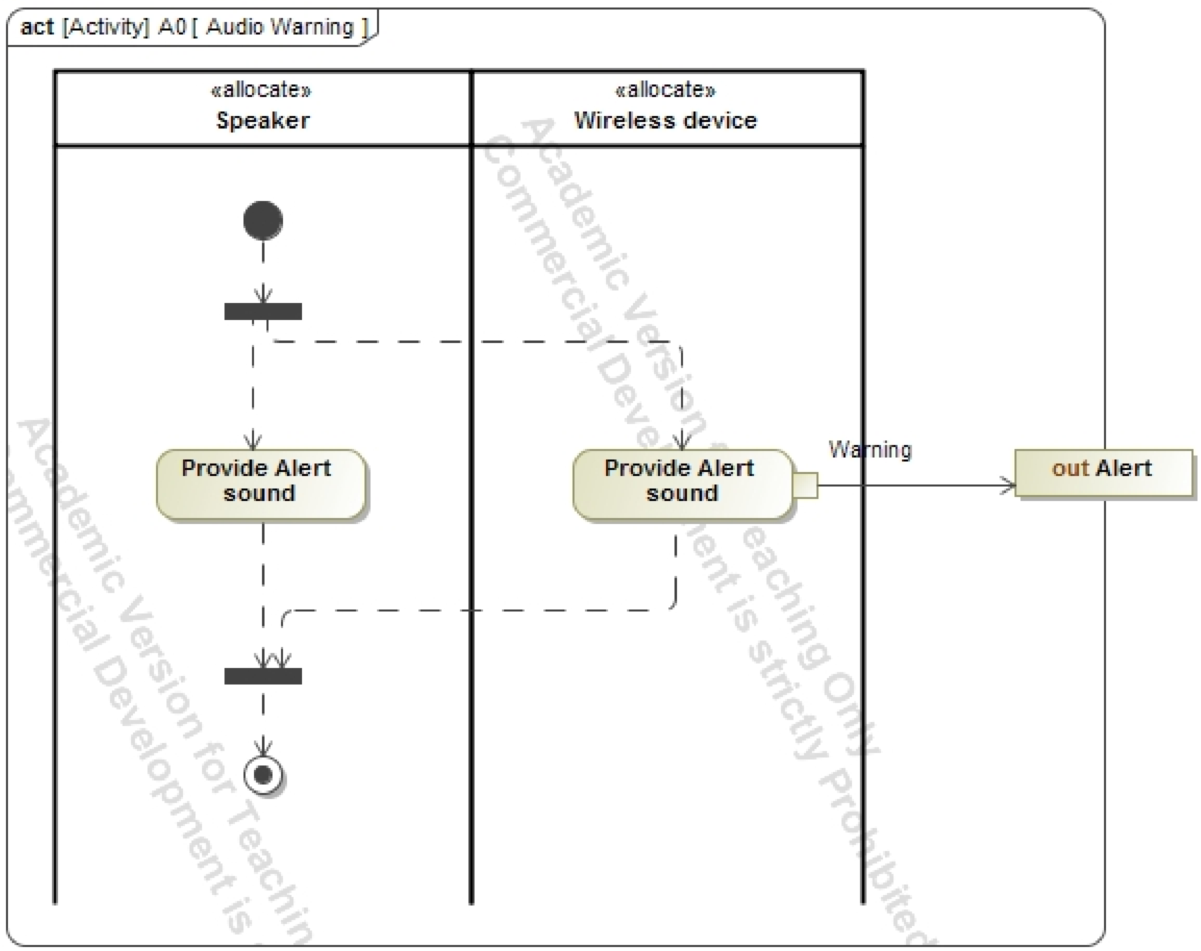

Figure 3.7: Activity diagram of Audio warning function

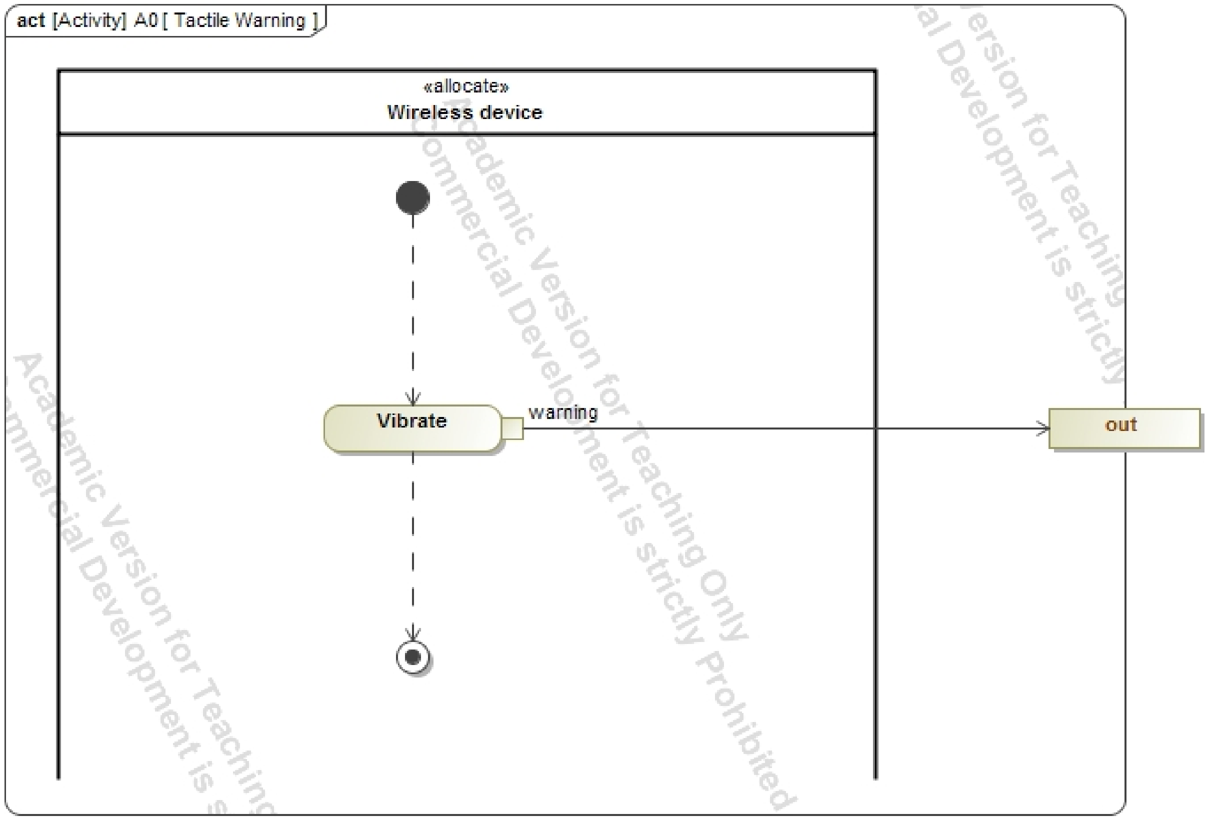

Figure 3.8: Activity diagram of Tactile warning function

3.1.3. Warning system sequence explanation

At the start of the sequence is the driver driving the car onto the highway where the condition is all met for the automation system to take control of the car. The driver will then let the automation system take control of the car by releasing the pedal and steering. The car travels along the highway until the route reaches the exit of the highway and the automation system cannot comprehend how to control the vehicle anymore. The warning system comes to work here to make sure that the driver will get in control of the vehicle in time. The warning system will alert the driver to take control. The driver will then take control and exit the highway safely. The system's action is executed and done. The timeline of the events can be seen in figure 3.9.

The designed HMI is a sub-system of the overall HMI for a Level 3 Automated Vehicle. The designed system covers how the warning system should act after the vehicle is already in automation mode on the highway. The situation that the system is designed for is in all processes of entering the highway when automation is activated and the driver has already ceased control of the car.

According to the Level 3 Automated Vehicle definition, the driver does not need to constantly monitor the road once automation is activated. Hence the driver is laid back from the driving state. At this stage the driver needs an alert to remind them when there is need of control from the driver. Exiting the highway is where the transition takes place. Before the vehicle exits the highway, the driver shall already be in control of the car. First, the warning process took place to catch the attention of and to remind the driver to take control of the car. Then the driver prepared themselves to resume driving the car.

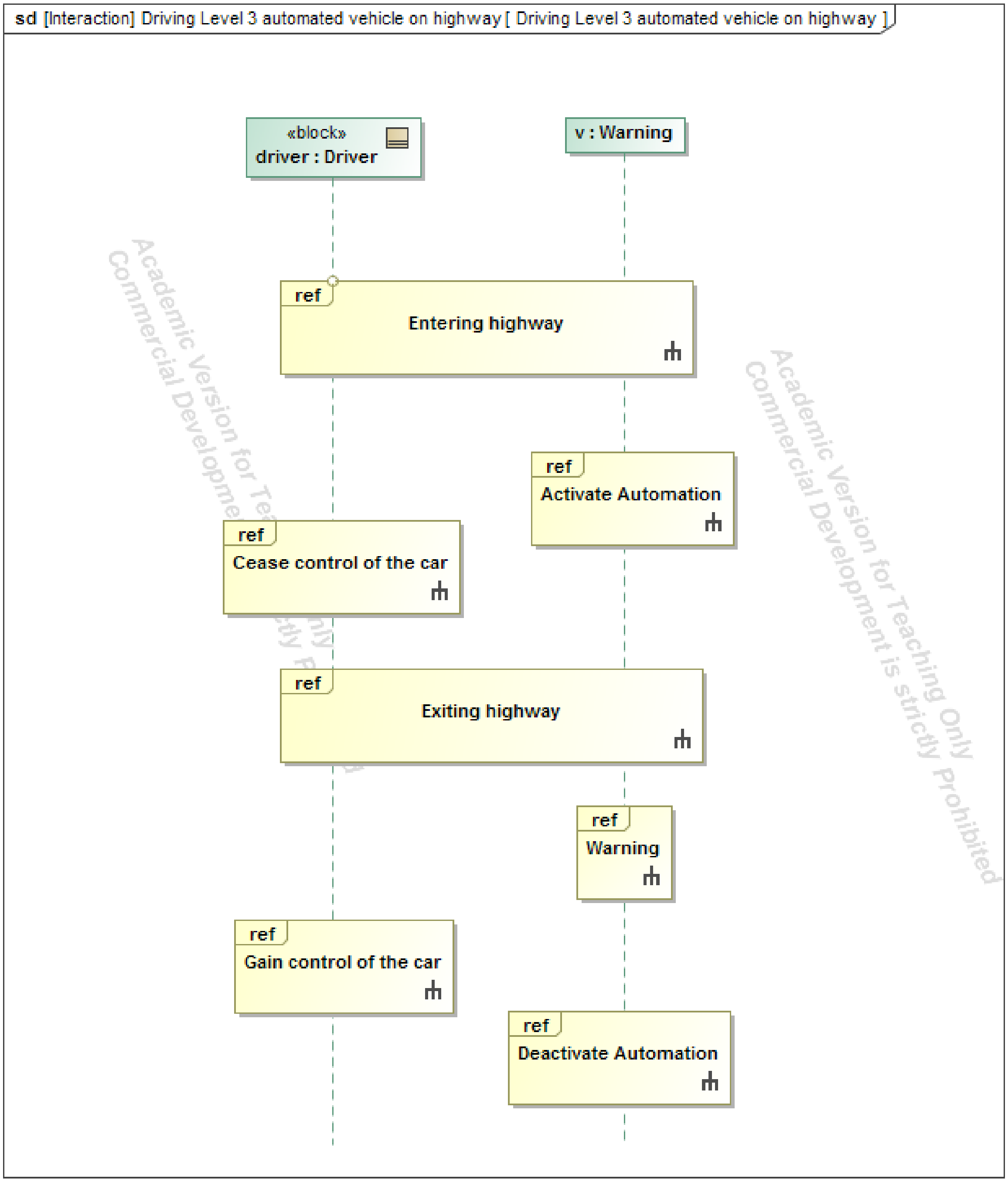

Figure 3.9: Sequence diagram of the system

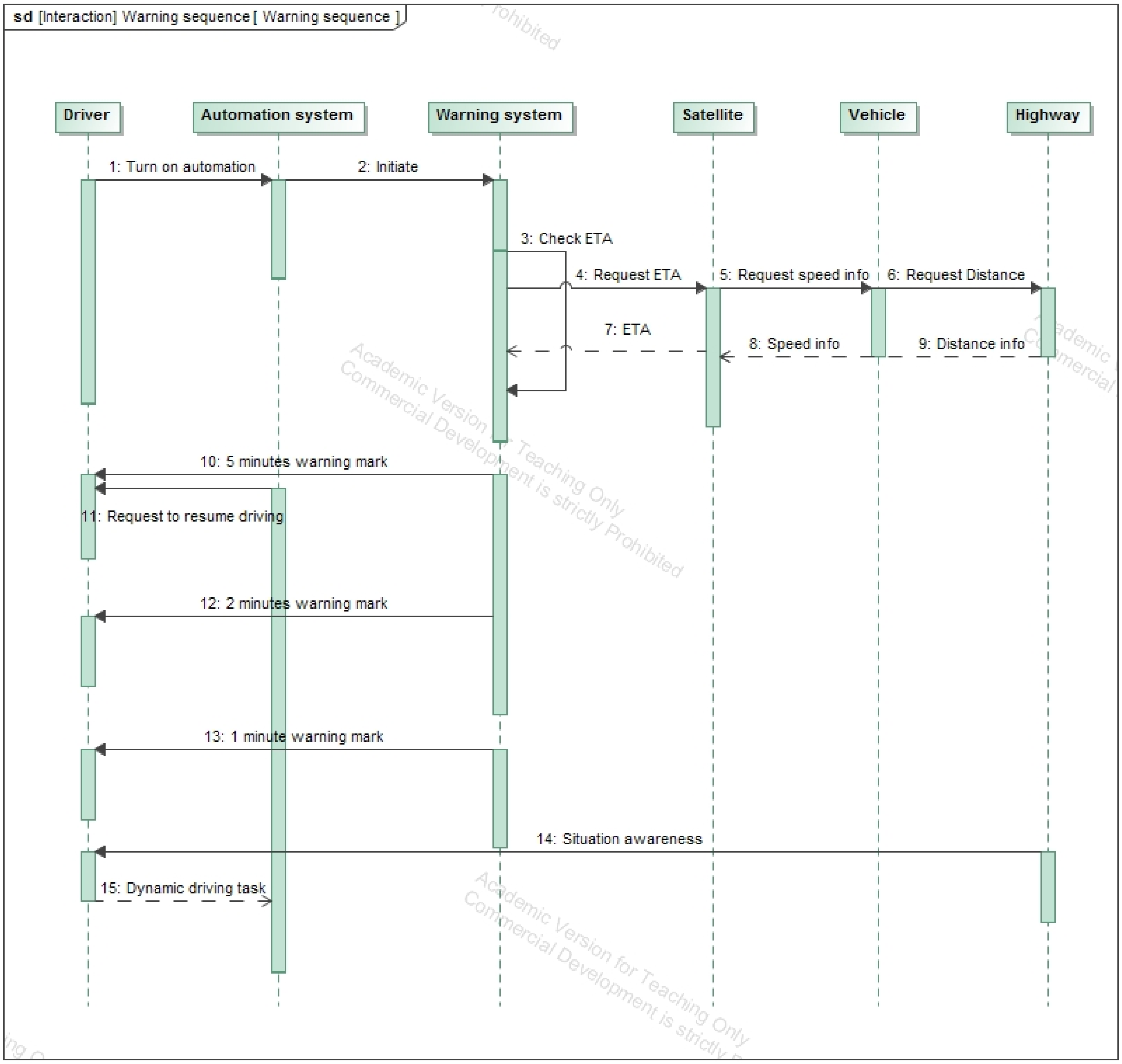

Figure 3.10: Warning sequence diagram

3.1.4. System overview explanation by Use case diagram

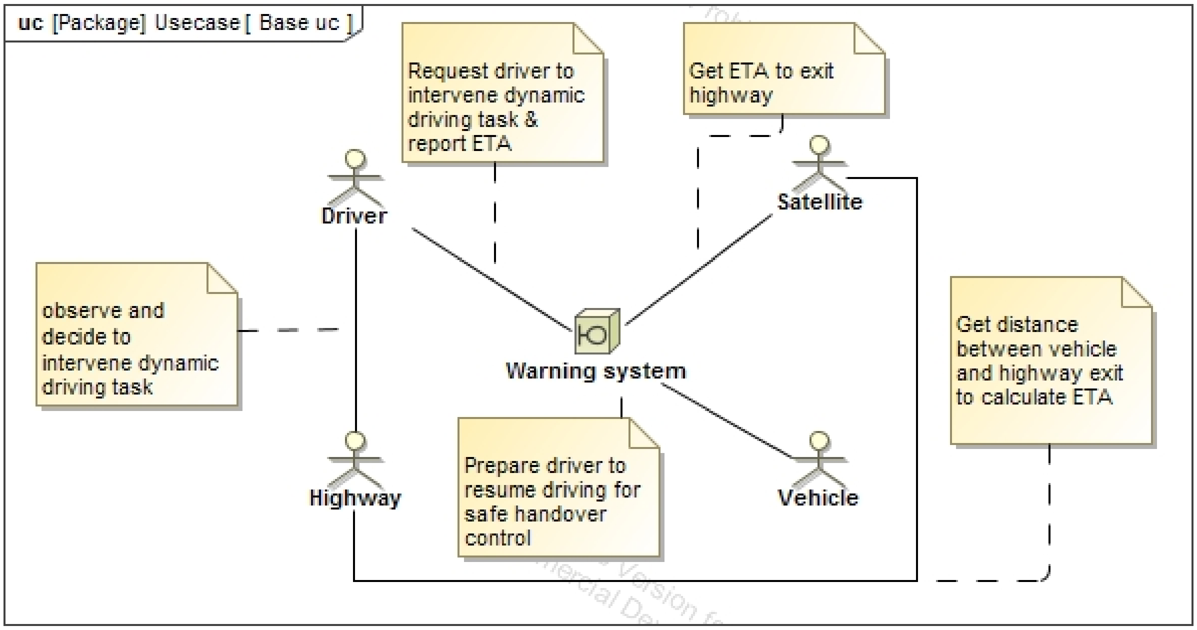

Figure 3.11: Use case diagram of System overview with main stakeholders

For the system to be able to know where the driver going to exit the highway, the system need to obtain destination and ETA to highway exit from car navigation system which link to satellite system. As long as the system know these information, precise and appropriate request to intervene which is warning intervals of 5, 2 and 1-minute mark can be given to the driver. These will deliver safe handover control from car to driver.

3.2. User interface design using SCADE display

3.2.1. Introduction to SCADE display

According to the SCADE Display 17.0 Technical data sheet, the "SCADE display is one of Ansys Embedded software family of products and solutions that empowers users with a versatile graphics design and development environment for embedded Human-Machine Interfaces (HMI)" and is used as a tool for HMI development in many leading companies in different areas such as automotive, aerospace and rail transportation. The SCADE Display provides a modelling tool to create an interface in graphical format with high quality editing such as transparency management at graphical primitive level management with real-time visualization, texture management, haloing, anti-aliasing and mask. For more information, see SCADE Display 17.0 Technical data sheet [12].

3.2.2. Cluster user interface design

The SCADE display was used for graphical prototyping and design, in this case to create a cluster user interface and warning interface and simulation to be used in the experiment. The aim was to create a cluster for experimental use which has functions developed from the MBSE function development process, of which the main function is interval warning. Furthermore, the basic function of the ordinary cluster is needed for the experiment as well, therefore speedometer, indicator, trip meter and gauges was needed. The developed cluster user interface is as follows:

Figure 3.12 Cluster user interface created using SCADE Display

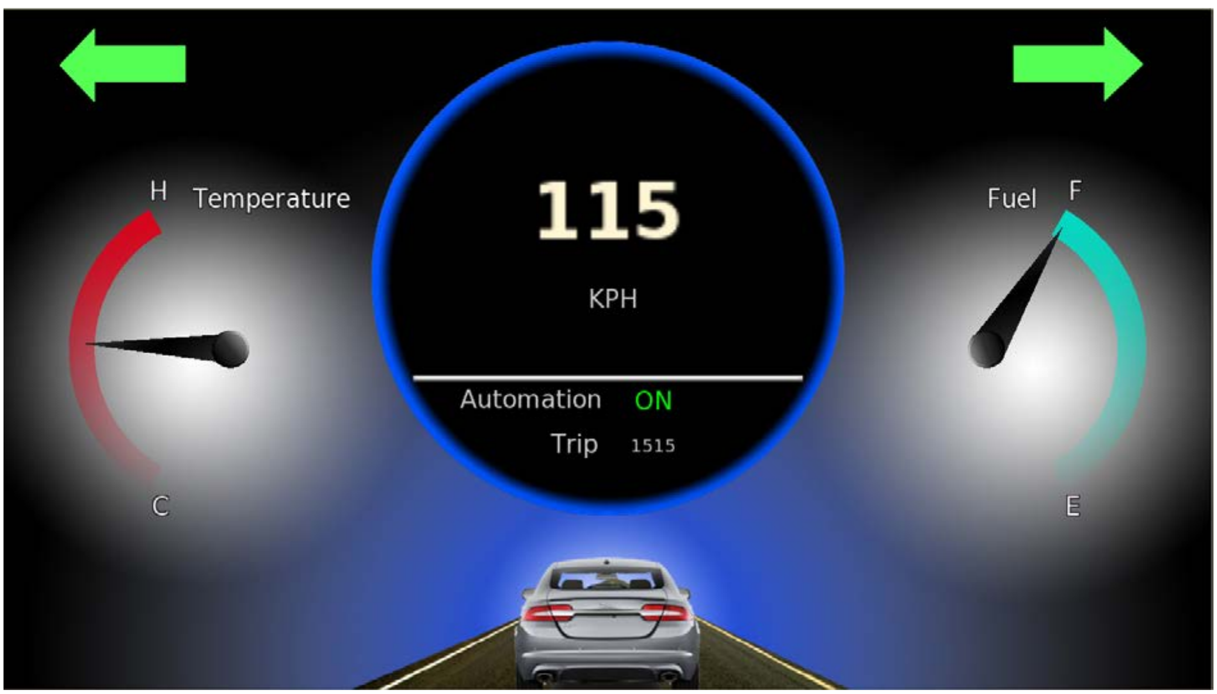

Figure 3.13 Cluster user interface created using SCADE Display with indicators on

As mentioned, the cluster created contains basic functions of the ordinary cluster of speedometer, temperature and fuel gauges and trip meter which is shown in figure 3.12. The cluster is designed to carry out the functions developed from the MBSE process. The interval warning at the 5-minute, 2-minute and 1-minute mark with indicator of automation are shown in figure 3.14, 3.15 and 3.16. Color of warning sign changes in each internal warning from blue at the 5-minute mark to yellow at the 2-minute mark and red at the 1-minute mark. The warning sign is able to appear and disappear without an additional panel with the use of the digital cluster that is able to contain layers of display, which allows the cluster to display only the needed information at that time. The warning sign is designed to appear in an area where the sign does not obscure other information of the display in the center of the cluster for the driver to easily see the signs. The cluster is then used for experimentation to study how effective the warning system is. Sound warnings were added later on since the SCADE Display does not support sound integration.

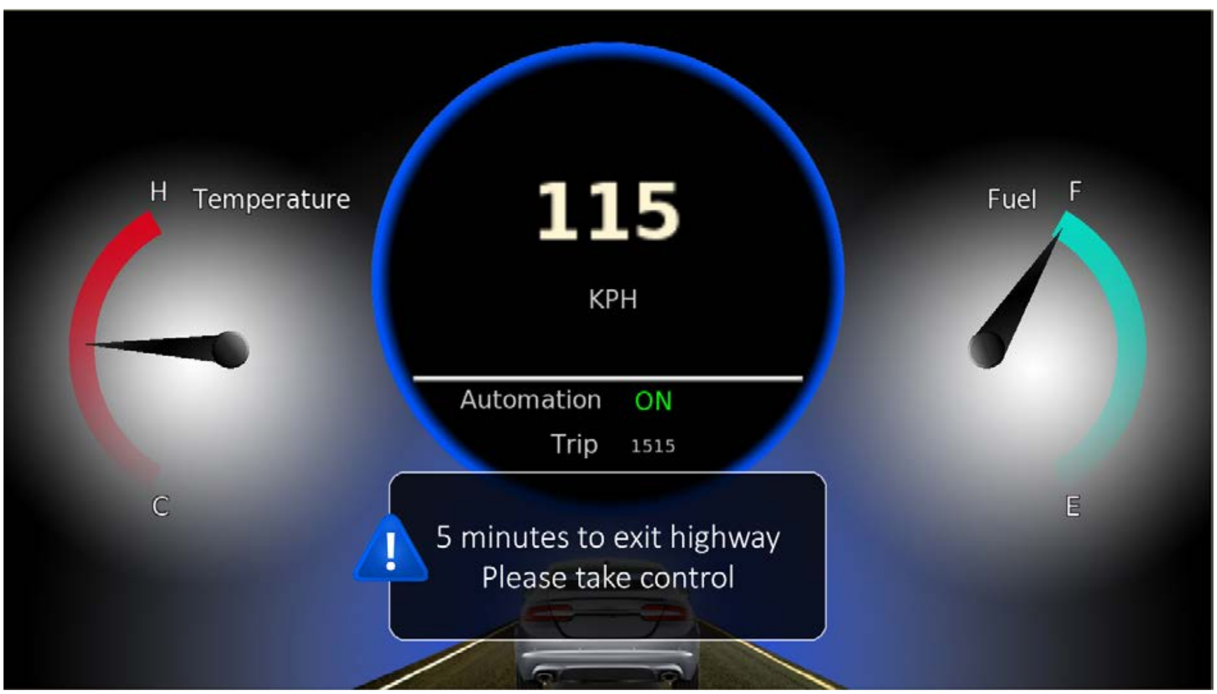

Figure 3.14: 5-minutes mark warning

Figure 3.15: 2-minutes mark warning

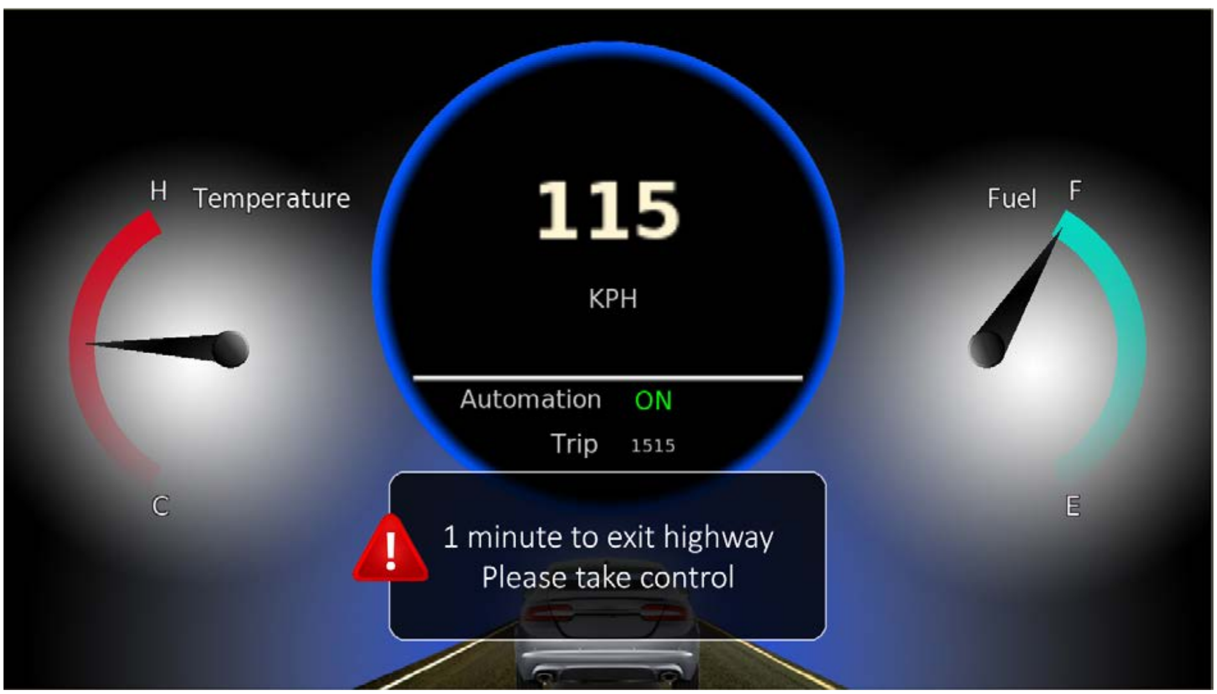

Figure 3.16: 1-minute mark warning

The cluster consist of speedometer, trip meter, automation, indicators, temperature gauge and fuel gauge where all of these components is fully functional and created from scratch. First, researcher start from drawing a draft in picture via Photoshop and insert the picture into background of sketch area and start modelling component start from speedometer, temperature gauge, fuel gauge, automation, trip meter and indicators respectively. When all of the components modelled successfully, the background that contain picture of components for draft is removed and change to background without components as shown in figure 3.17. Warning layer was put on top to display warning overlay others components contain warnings in picture format made separately via Photoshop. Properties and Plugs setting of each component is shown in section below.

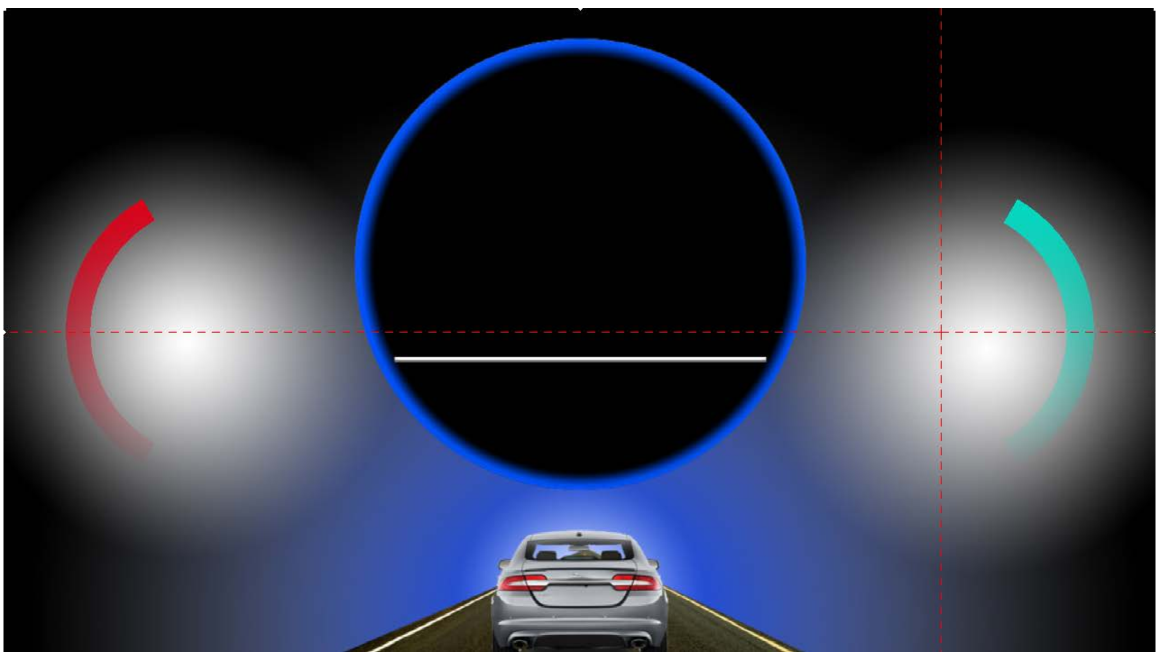

Figure 3.17: Background of the cluster

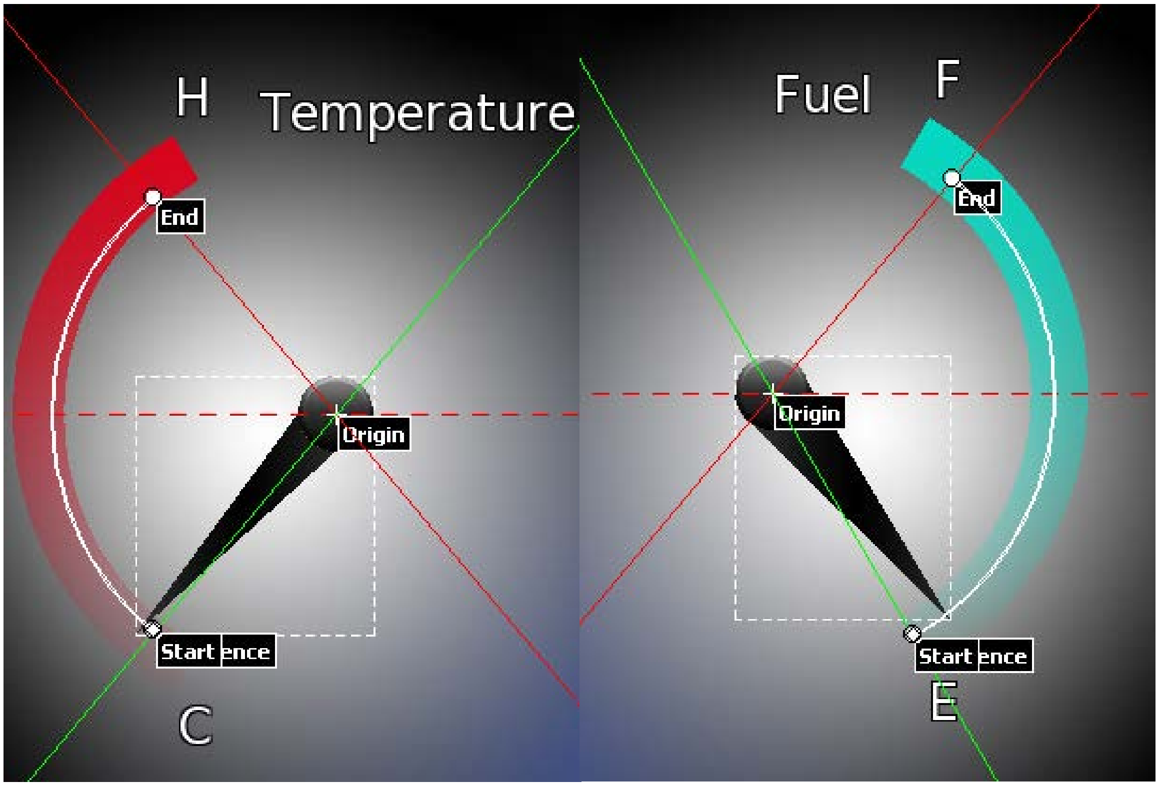

Figure 3.18: Temperature (left) and Fuel gauges (right)

Temperature and fuel gauges pointer is able to rotate to indicate high/low of engine temperature/fuel level by using rotation feature together with reading input variable named “temp” for temperature gauge and “Fuel” for fuel gauge. Dimensions and properties of temperature and fuel gauges are shown in figure 3.20 and 3.21. Pointer is created from grouping triangle and circle together (as shown in figure 3.19) and rotate the group by shown parameter which make the pointer point the bottom of the gauge scale (at “Start” in figure 3.18) when the input is 0 and point top of gauge scale when input is 100 (at “End” in figure 3.18) where center of rotation is at the center of pointer’s circle. Automation indicator and trip meter is display in text format below speedometer. Setting of Automation indicator and trip meter is shown in figure 3.23 which make automation indicates “ON” when input from variable “Automation” is “true” and goes off when input is “false” and trip meter display distance travelled from input “trip”. Above background layer there is text layer that used to label temperature gauge, fuel gauge, speedometer, automation indicator and trip meter as shown in figure 3.24. Indicator that indicates if the car is turning left or right if shown in figure 3.25 and locate on top of the cluster as shown in figure 3.26. The left or right indicator will appear when variable “left” or “right” reading is “true” and disappear when reading is “false”.

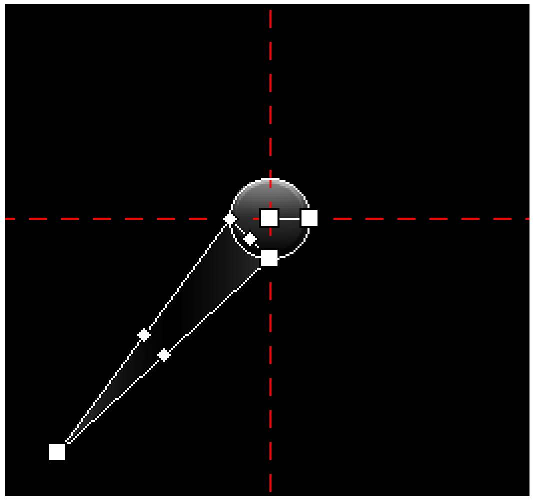

Figure 3.19: Pointer of Temperature and Fuel gauges

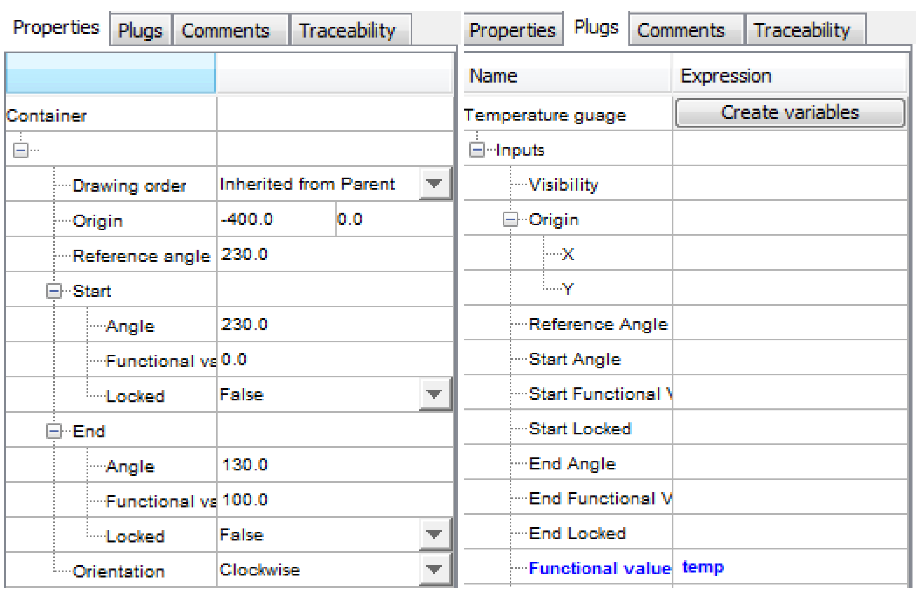

Figure 3.20: Properties and Plugs configuration of Temperature gauge

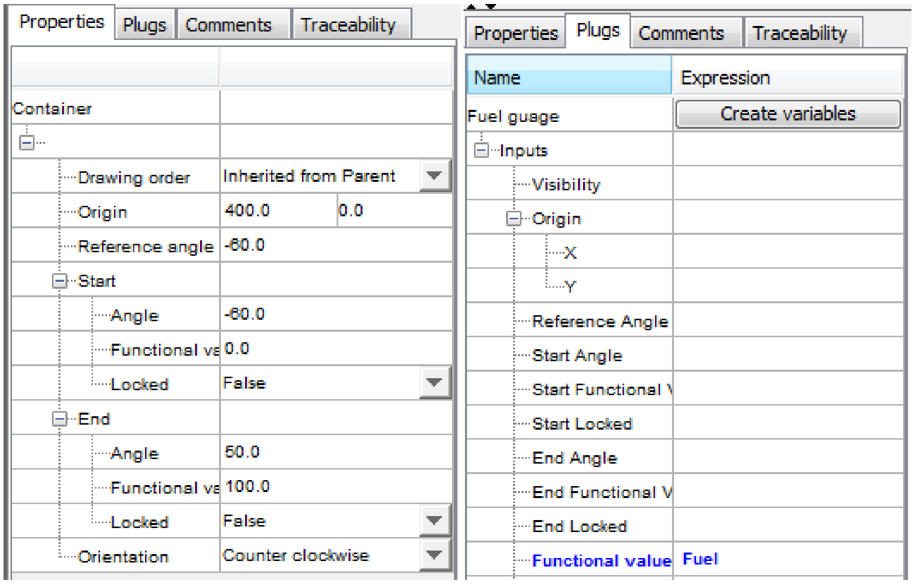

Figure 3.21: Properties and Plugs configuration of Fuel gauge

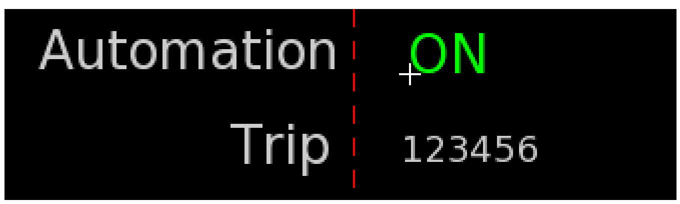

Figure 3.22: Automation indicator and trip meter

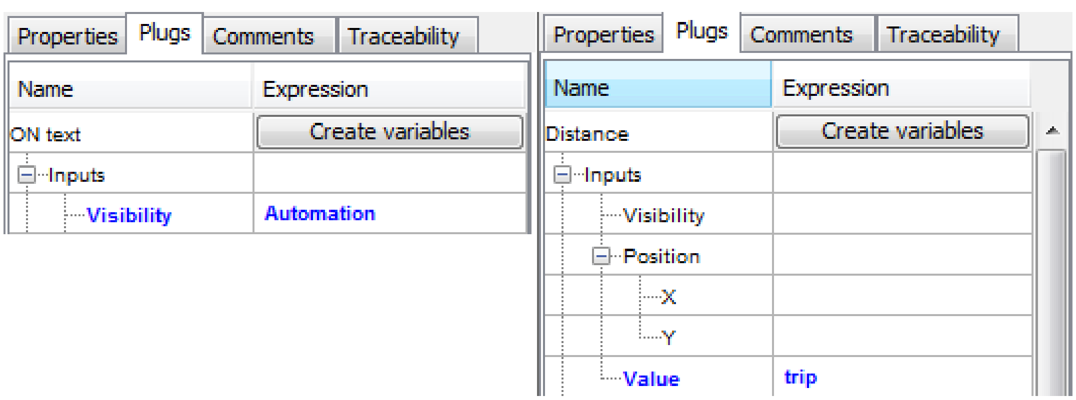

Figure 3.23: Properties and Plugs configuration of Automation indicator and trip meter

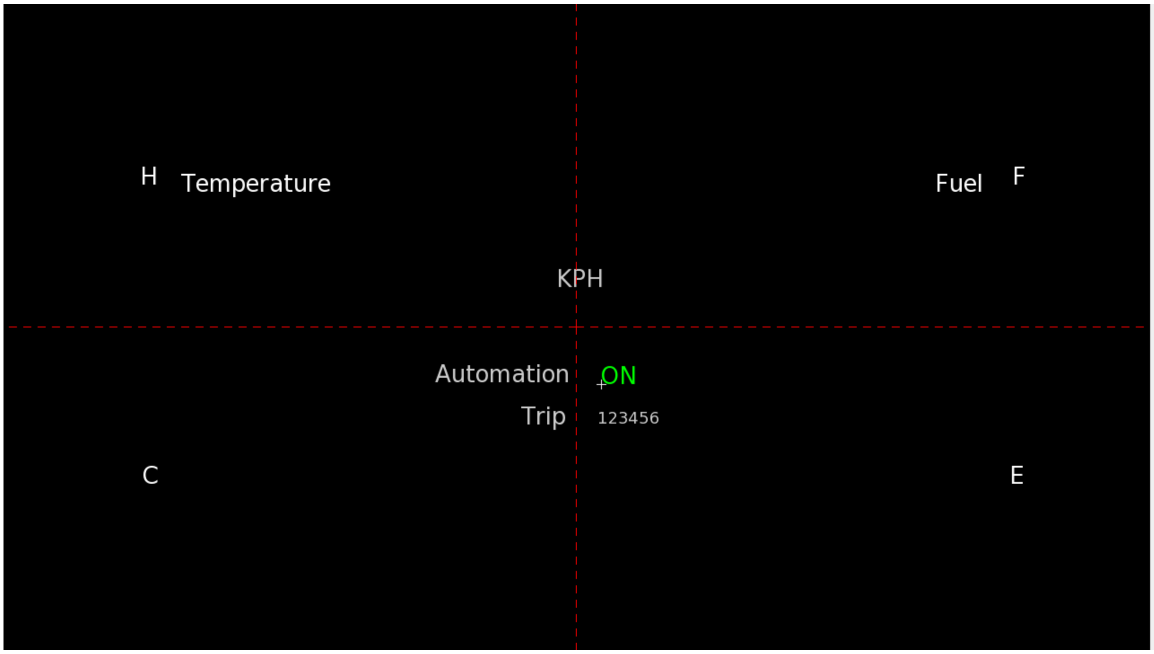

Figure 3.24: Text layer used in the cluster

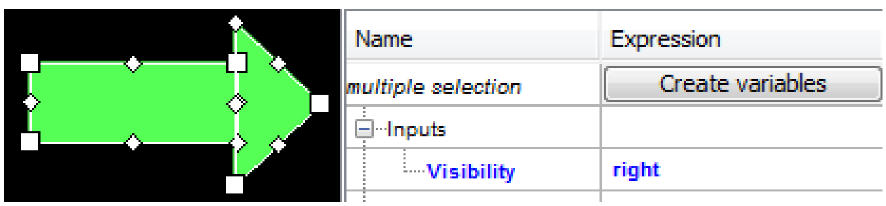

Figure 3.25: Properties of indicator

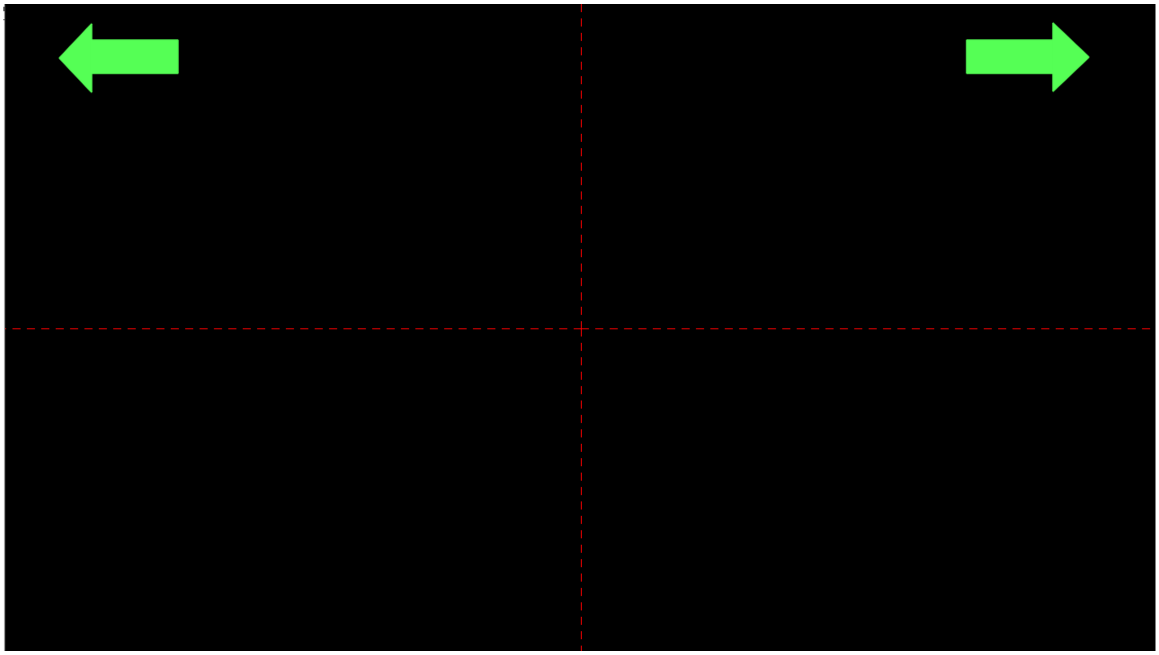

Figure 3.25: Indicator location on the cluster

Chapter 4 Experimental Design & Setup

4.1. Experiment Design

The designed HMI system was used in an experiment to verify the effectiveness of the system. The experiment content simulates a situation from where the car is on the highway with automated driving on, and the driver is distracted until the end of interval warning. In the experiment, the car begins on the highway and is already in autonomous mode, and a transition is waiting to occur where the designed HMI will request the driver to intervene to the dynamic driving task. Intervention is complete once the driver is ready to resume driving.

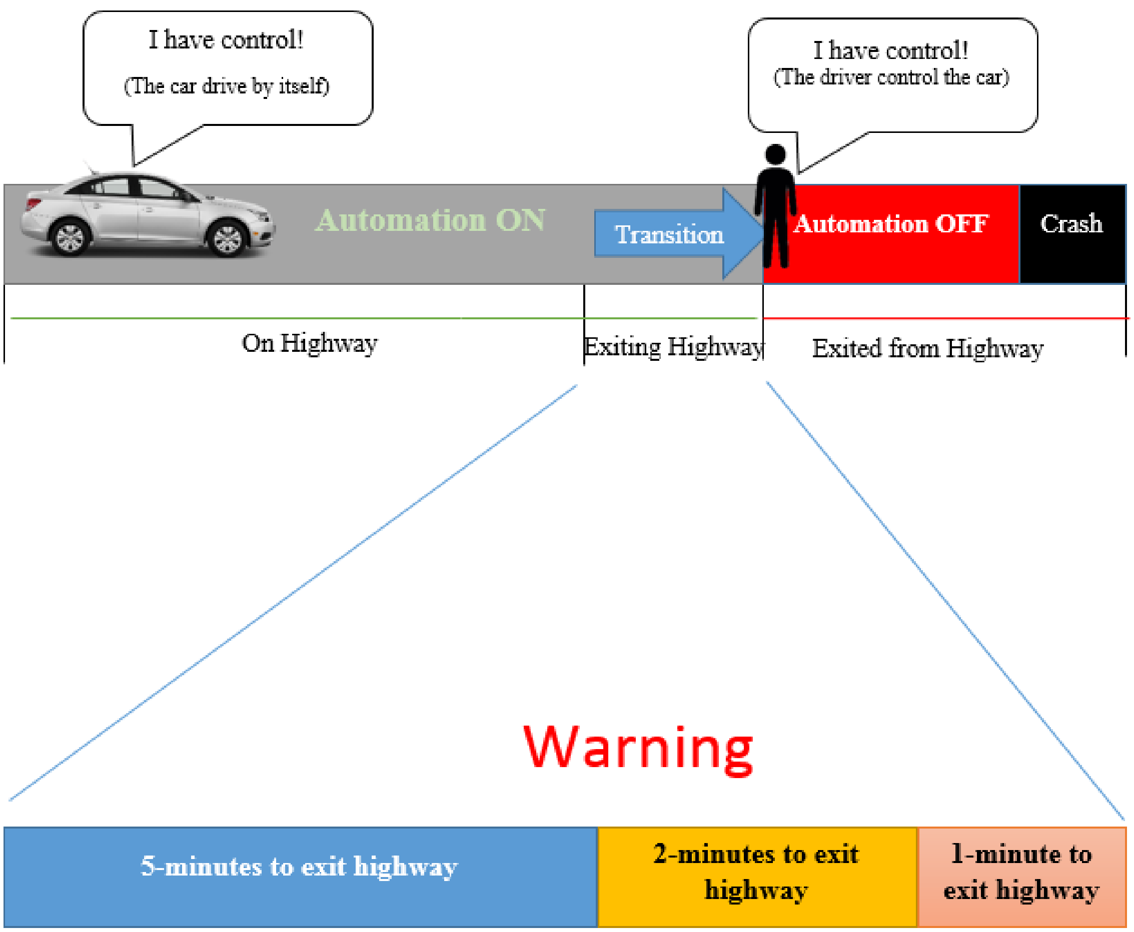

Figure4.1: Timeline explain scenario with interval warnings used for experiment

The experiment simulates the situation by using 2 monitor display. Each of them have a different role. The first monitor works as a windshield like the driver's view, and the second monitor works as a designed cluster with warning functions. PreScan is used to simulate scenarios of adaptive cruise control where the car is driving on the highway for the first monitor, and the animated cluster is generated by SCADE Display. By having two monitors working together in sync, the experiment can simulate the desired situation. The distracted driver is an element in the desired situation, therefore, the experiment is designed to take a long time, enough that the participant would relax and focus on their non-driving related task. To achieve that, once the experiment starts, there is a 5 minutes gap to get the participant bored from monitoring the road and distracted before the 5-minutes mark warning takes place.

The gear knob is selected as a trigger to intervene dynamic driving task. Pulling the gear knob is a sign to indicate that the participant is ready to resume the dynamic driving task. Once the gear knob is pulled, the movie stops and the test is finished. In the researcher's opinion, pulling the gear knob is selected as a signal since pulling gear knob as shown in figure 4.9 can give sense of a mechanism change to driver.

System effectiveness is verified by the transition success rate, and is measured from results of the questionnaire. Results from the questionnaire are measured on a 5-point scale rating to get quantitative results, and qualitative result from comments and opinions.

4.2. Experimental Setup

The experiment used 2 monitor display where the first monitor displays the driver point of view and the second monitor displays cluster interface and warnings. Each monitor plays different movie files which were rendered to work together to test the designed HMI which was built for safe handover of control from car to driver on the highway. As mentioned, the experiment was designed to simulate a situation where the car is on the highway and automated driving is on, and the desire situation where the driver is distracted from their driving related task.

Figure 4.2: Driver point of view while driving on highway used for the experiment rendered by PreScan

PreScan is used to generate the movie file where the camera position is placed in front of the car to get the driver point of view as shown in figure 4.2. The movie recorded the car driving on the highway with the surrounding of other cars to its side and in front at different speeds. The SCADE Display is used to generate the movie file for the second display as shown in figure 4.4 where the speed varies from 115-118 kph while the trip meter increases and the fuel gauge depletes, and engine temperature changes over time. It also includes interval warnings. These are to promote realism in the experiment. The movie is 10 minutes long with 1st, 2nd and 3rd warning takes place at 5:00, 8:00 and 9:00 minutes respectively. Each interval has different warning sounds. The 1st, 2nd and 3rd warning dialogs are “5 minutes to exit highway, please take control if possible”, “2 minutes to exit highway please take control”, “1 minute to exit highway please take control immediately” respectively.

To have the driver distracted from driving related task, the researcher encouraged the participant to use their mobile phone (wireless device) as instructed in the document provided (see Hand Document provided to Participants before conducting the experiment in appendix). After the HMI requested the driver to intervene, to successfully intervene the dynamic driving task, the participant needed to trigger the intervention by pulling the gear knob toward themselves.

In terms of the warning function test, 2 out of 3 types of warning was carried in the experiment: visual (graphic warning) and audio (sound warning). Because of technical issues, tactile warning and wireless device warning were not tested in this experiment as shown in the table below.

Table 4.1: Types of warnings tested in the experiment

Warning Function	Visual	Audio	Tactile
Experiment	✓	✓	-

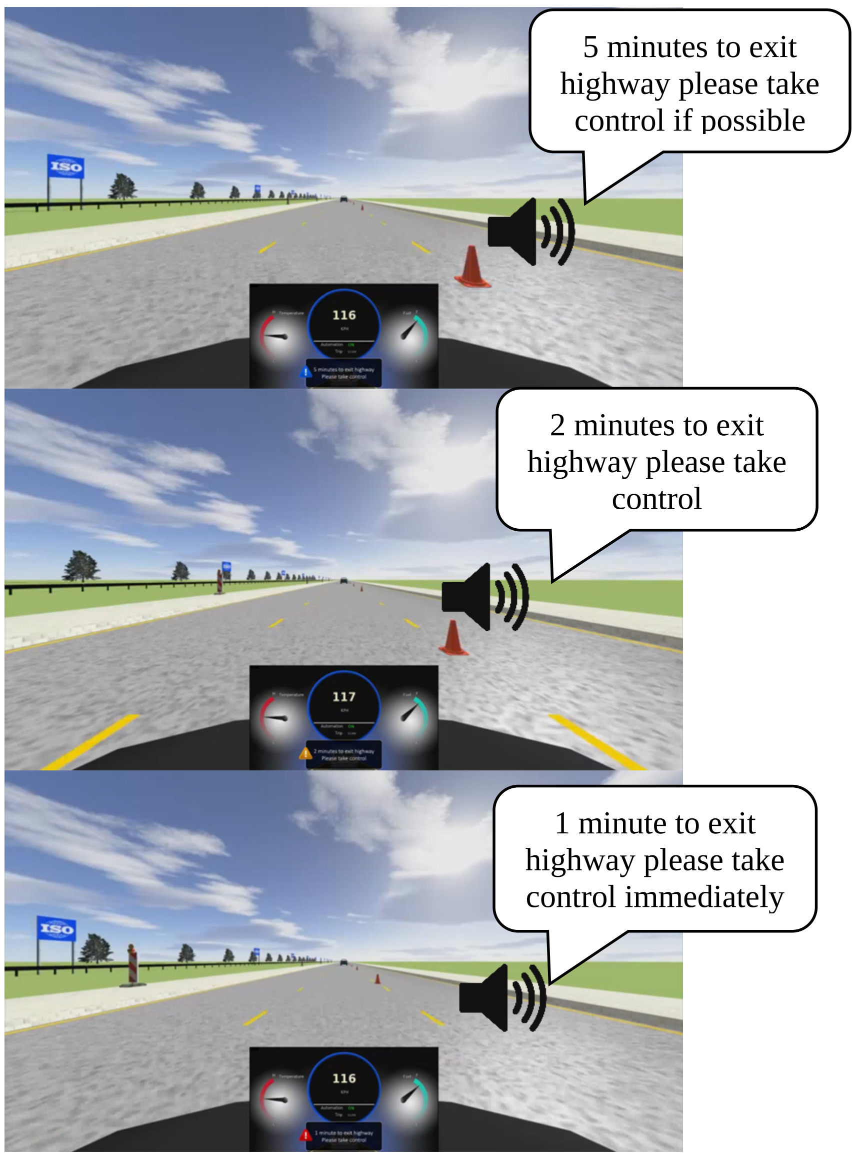

Figure 4.3: Cluster interface used for the experiment rendered by SCADE Display with driver point of view in different warning intervals along with sound warning dialogs.

Movie file content

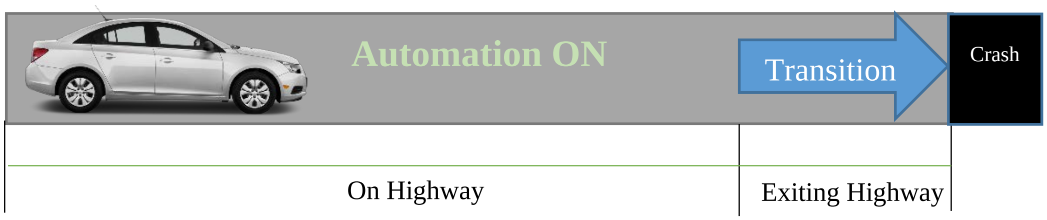

Figure 4.4: Movie files content Overview

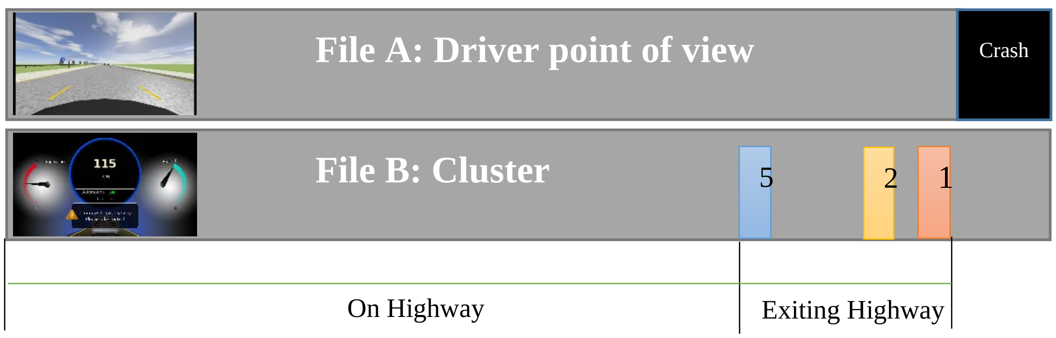

Figure 4.5: Movie files content in depth

Table 4.2: Sound & Graphic warning dialogs

Sign	Definition	Sound warning dialog	Graphic warning dialog
5	5-minutes mark warning	"5 minutes to exit highway, please take control if possible."	5 minutes to exit highway Please take control
2	2-minutes mark warning	"2 minutes to exit highway, please take control."	2 minutes to exit highway Please take control
1	1-minute mark warning	"1 minute to exit highway, please take control immediately."	1 minute to exit highway Please take control
Crash	Accident	-	-

Note that the warning sound used in the experiment was created using uni-modality sound.

4.2.1. Configuration

Figure4.6: Experiment configuration [13]

As shown in figure 4.6 above, the experiment used a computer monitor to display the driver's point of view and an iPad as the cluster. A Logitech Momo racing wheel's gear knob was used as a trigger to intervene the dynamic driving task. Pulling the gear knob is a sign to indicate that the participant is ready to resume the dynamic driving task (as demonstrated in figure 4.7). Once the gear knob is pulled, the movie stops and the test is finished. In the researcher's opinion, pulling the gear knob is selected as a signal because pulling gear knob gives the sense of a mechanism change to the driver. With that said, the participants will get a more engaged feel before taking control. Pushing the brake pedal is not recommended as it is a risky action if executed in the real world as pushing brake pedal hard could cause the car to sudden decrease its speed and may cause accident. The experiment was recorded and conducted in a laboratory.

Figure 4.7: Demonstration of pulling gear knob as a trigger to intervene dynamic driving task

4.2.2. Components list

3 main components of the experiment are computer monitor, iPad and steering wheel. All component connect to a computer except for an iPad which operate separately. Computer monitor used to display driver point of view is FlexScan EV2336W shows Simulation in 1080p resolution. An iPad shows cluster interface in 720p resolution. Steering wheel is Logitech momo racing wheel used for trigger intervene dynamic driving when participant is ready to resume driving. To reduce unwanted noise during the experiment, in-ear headphone was used to eliminate surrounding noise. The in-ear headphone used is Audio technical in-ear headphone CKB50.

Table 4.3: Experiment component table lists

Component	***Role***	***Parametric***
FlexScan EV2336W	Driver point of view	Resolution 1920x1080
iPad2	Cluster	1024-by-768-pixel resolution at 132 pixels per inch (ppi)
Logitech momo racing wheel	Trigger intervene dynamic driving task from driver	-240° rotation Rubber steering wheel -Sequential stick shifter
Audio technica In-ear headphone CKB50	Speaker	-Balanced Armature Driver -Frequency response 20 - 15,000Hz

4.3. Measured parameter

The transition success rate and time taken until the participant pulls the gear knob to stop the test was recorded once the test is completed, and a questionnaire was handed to the participant to measure warning performance, comfortability and annoyance of the system. In addition, the participant's details of age, gender and possession of driving license is recorded.

Table 4.4: Data Measured from the experiment

	Parameter	***Objective***	***Unit***
Safeness	Transition success rate	Verify system objective of safe handover from car-driver	%
	Time to stop		mm:ss
Warning performance rating	Graphic warning catch your attention	Verify/Determine warning system effectiveness	5 point scale base rating
	Sound warning catch your attention		
	The warning system can catch your attention		
	Interval of warning (5, 2 minutes and 1 minute) is a suitable intervals		
	The warning system is effective for distracted driver		
	Cluster and speaker is effective for warning		
Comfortability rating	Speed meter is easy to read	Verify if the system comfort enough to be use	5 point scale base rating
	Temperature, fuel and other gauges are easy to read and understand		
	It is Easy to notice if Automation mode is "on" or "off"		
	Digital cluster is comfortable to use		
	Graphic warning is easy to read		
	Sound warning sound is clear and easy to understand		
Annoyance rating	Graphic warning is annoying	Verify that the system warn driver in an acceptable way (user acceptance)	5 point scale base rating
	Sound warning is annoying		
	The warning system is annoying		

4.4. Experiment procedure

To make sure all participants understood the experiment and knew what to do, a handout document with explanations were provided to all participants. Brief information of Level 3 Automated Vehicles and the warning interface were included in the document (see Hand Document provided to Participants before conducting the experiment in appendix). In addition, the researcher instructed the participant to use their mobile phone and to pull the gear knob trigger whenever they want within 5 minutes since the first warning starts. Every participant used headphone for sound warning during the experiment to cancel other sound and control experiment environment to stay the same for every participant.

The experiment was started by running the movie file on the screen from a computer monitor and an iPad with the participant sitting on a chair in front of the screens. Once the participant pulled the gear knob, the experiment is finished. The movies stopped, and the time recorded. Then a questionnaire was handed to the participant to fill in. Comments and opinions were recorded on site by the researcher. A picture from the footage of the experiment is shown in figure 4.8.

- Participant read handout document with additional explanations
- Start the test and video record once the participant is ready
- When the participant resume driving record the time
- Handout questionnaire to participant immediately to get fresh idea/data from participant
- Record all data, comments, opinions and insights

*Note that each participant’s result were recorded individually for post analyzing.

Figure 4.8: Footage of the experiment showing participant distracted and using mobile phone

Chapter 5 Results

5.1. Result Overview

The main objective of conducting the experiment was to verify system effectiveness in 4 main aspects of safeness, warning performance, comfortability and annoyance. The result of the experiment is shown below in figure 5.1. Transition success rate was 100%, Warning performance rating was 3.74, Comfortability rating was 3.63 and Annoyance rating was 1.50.

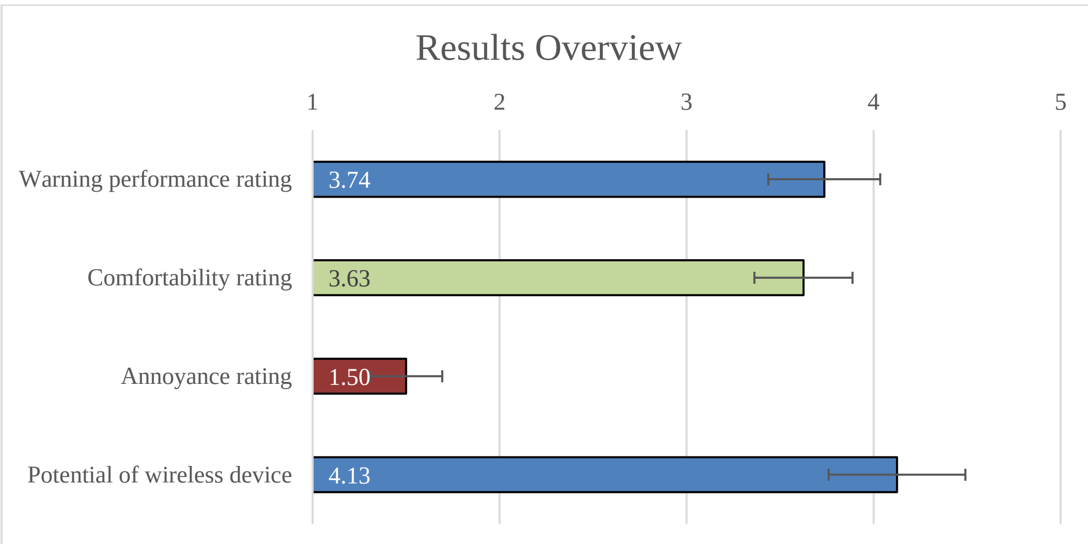

Figure 5.1: Result overview of the experiment

In the experiment, none of the participants failed to intervene their dynamic driving task. However, having 100% response to the request to intervene does not imply that the system is decent. If the system warns the driver in an inappropriate way, then the system is not practical. A warning performance rating of 3.74 is pretty good in the researcher's point of view, as the rating has the graphic warning performance included, which was expected be low. Comfortability rating and Annoyance rating of 3.63 and 1.50 respectively imply that the system is comfortable to use and warns the driver in an acceptable way since Annoyance rating is very low at a rating of 1.5.

5.2. Participants detail

The experiment had 12 participants mixed in both male and female, between the ages of 24-30, and 7 of the participants possessed a driving license. Details of the participants who participated in the experiment are shown in figure 5.2, 5.3 and 5.4.

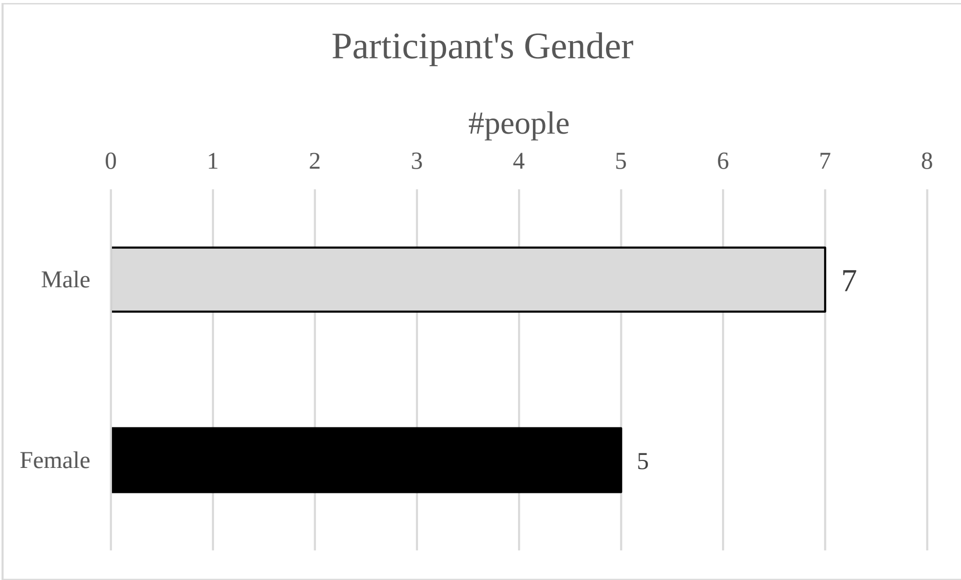

Figure 5.2: Participants grouped by gender

Figure 5.3: Participants grouped by age 24-26 and 27-30

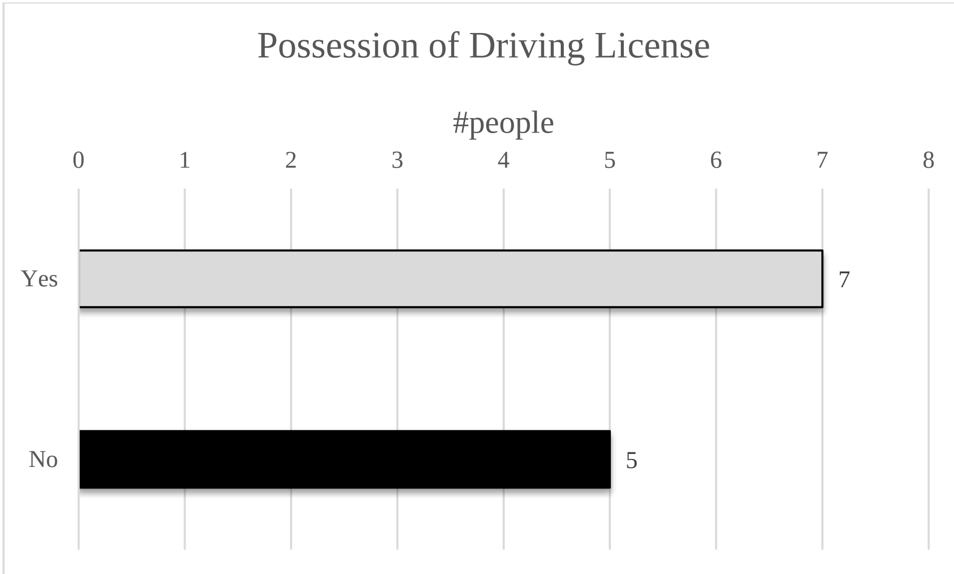

Figure 5.4: Participants grouped by possession of driving license

5.3. Transition success rate

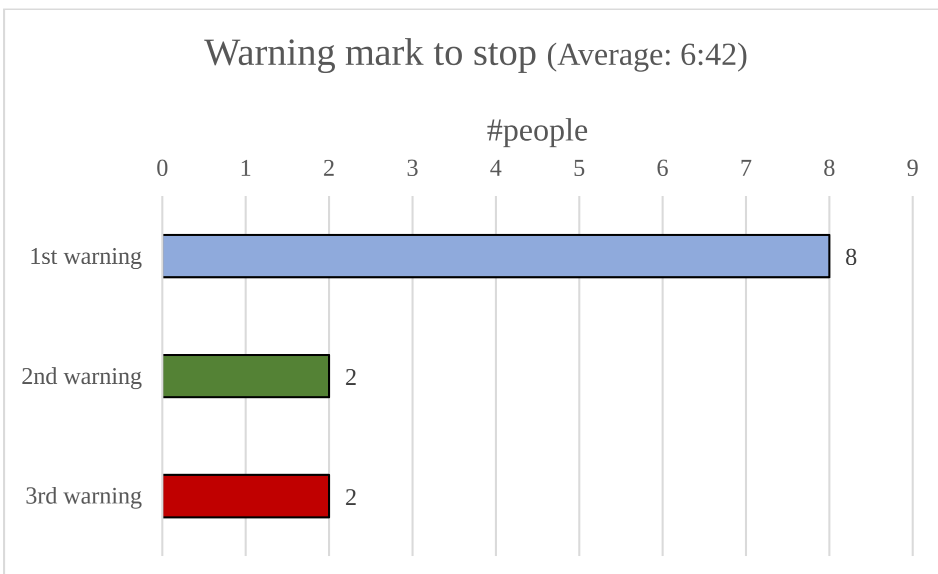

Figure 5.5: Result showing where participant stopped by 5, 2, and 1-minute mark warning

The transition success rate of the experiment is 100%. According to figure 5.3.a, most participants intervened the driving task at the first warning (8 out of 12 participants stopped at the 1st warning). 2 participants stopped at the 2nd warning, and 2 participants stopped at the 3rd and final warning.

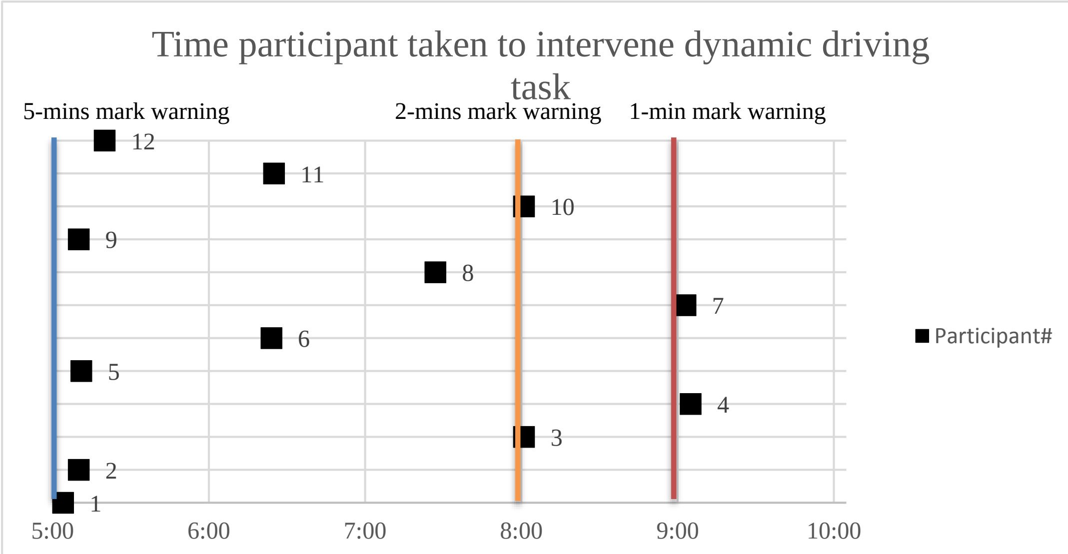

Figure 5.6: Result of time taken for participant to intervene dynamic driving task where 5, 2 and 1-minute mark warning take place at 5:00:00, 8:00:00 and 9:00:00 respectively

Furthermore, many participants intervened right after the warning began. 5 stopped at the 5-minutes mark warning, 2 stopped at the 2-minutes mark warning and 2 stopped at the 1-minute mark warning. 3 participant stopped in between the 5 and 2-minutes mark warning. Those 3 participants mentioned in the same way that they did not feel compelled to stop using their mobile phone yet as there was still plenty of time left at the 5-minute mark warning.

5.4. Warning performance rating in depth

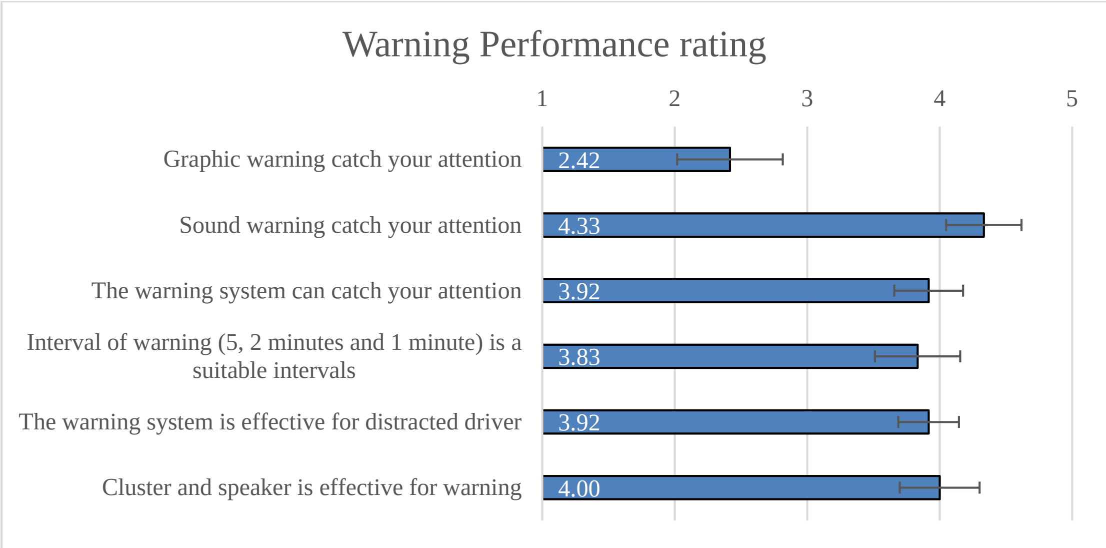

Figure 5.7: Result of Warning Performance rating from questionnaire

According to figure 5.1, the overall rating of warning performance is 3.74. The warning performance rating had 6 factors, and as expected, the graphic warning did not catch participant's attention. Excluding this factor, the rating increases to 4, which is a very high rating. The sound warning was able to catch every participant's attention, and as 1 of the participants mentioned, the sound warning should have different modalities to motivate the participant to stop their non-driving related task. There was also a concern that the warning sound might interfere with music being played in the car, which can be prevented by adding the feature of muting music when a warning takes place. Overall, the warning system can catch everyone's attention and is effective for a distracted driver, in the participants' eyes. For the interval of warning used, which was at the 5, 2 and 1-minute mark, it was found to be a suitable interval for most participants. Even though some participants mentioned that they think the 1-minute warning mark gives them little time to act, they were against the idea when asked if the 1-minute warning should be removed. These participants said having one more interval warning (e.g. at the 5, 3, 2 and 1-minute marks) the warning would be better. This recommended interval should be considered for future experiment/work. There is the user-interface issue about the position of the graphic warning that appears in the bottom-center of the cluster where many participant complain that they could not see the warning at all since their vision of the warning area was blocked by steering wheel. Thus, the user interface could be improved by changing position of the warning area to appear on the top-center of the cluster.

5.5. Comfortability rating in depth

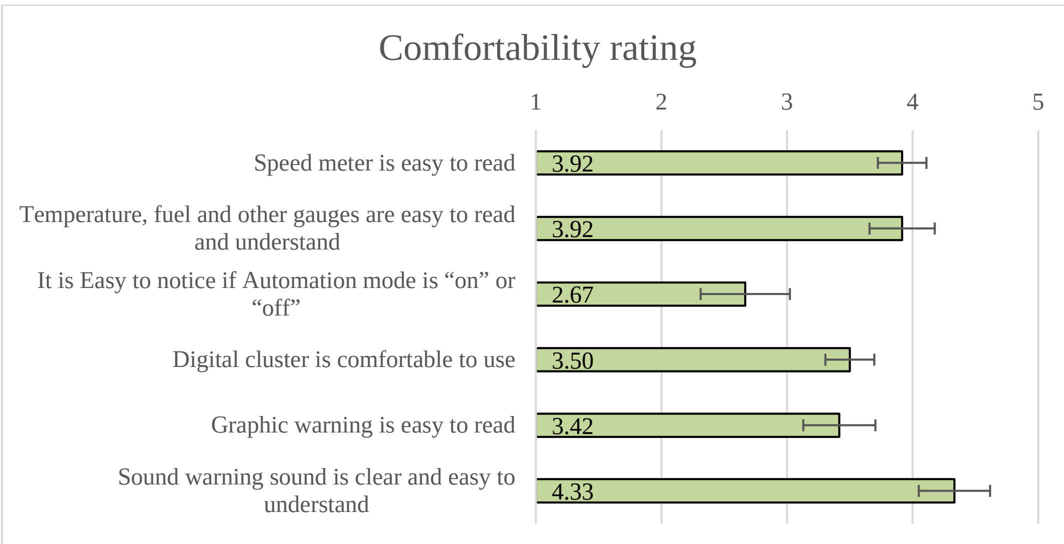

Figure 5.8: Result of Comfortability rating from questionnaire

According to figure 5.8, the result of statements “Speed meter is easy to read”, “Temperature, fuel and other gauges are easy to read and understand” and “Digital cluster is comfortable to use” are in a pretty good range, rated more than 3.50 in every statement, implying that the integrated digital cluster in the car will not cause the driver frustration from using the digital cluster. In terms of user interface, the graphic warning that appears in the cluster is easy to read (does not concern about position of display that blocked by steering wheel). Many participants mentioned that changing the warning sign color is really helpful, and some recommended a change to the first warning sign from blue>yellow>red to yellow>orange>red to give more sense of urgency. The sound warning used in the experiment was clear, and the directions were unambiguous. None of the participants complained about the warning sound, other than the uni-modality of the sound used as mentioned in, 5.4. Warning performance rating in depth.

5.6. Annoyance rating in depth

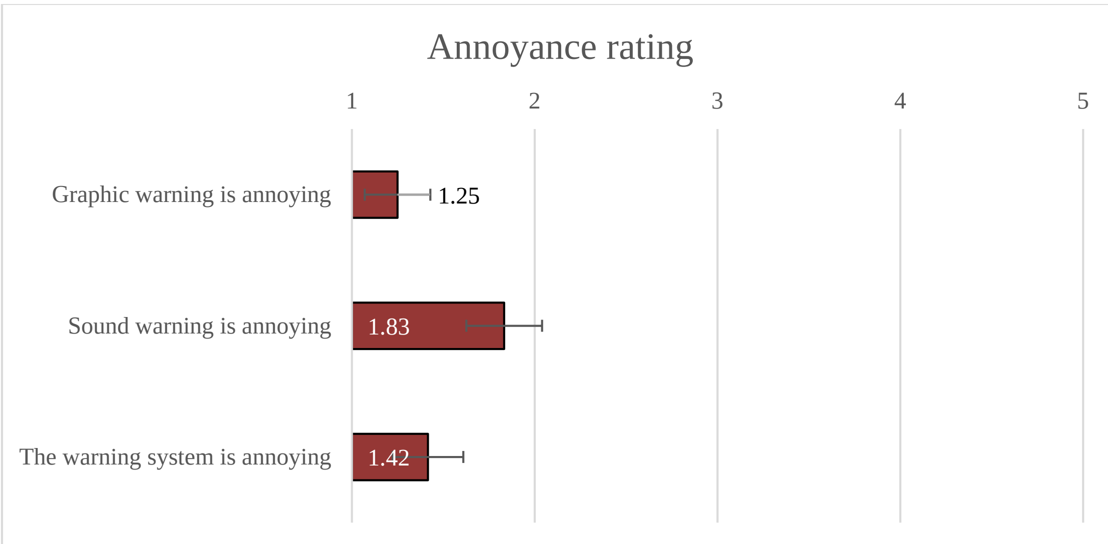

Figure 5.9: Result of Annoyance rating from questionnaire

The overall rating of Annoyance is very low, rated at 1.50. The Graphic warning had the lowest annoyance rating at 1.25 since very few people noticed the warning on the cluster. As expected, the sound warning annoyance rating is higher than the graphic warning at 1.83. However, the rating of 1.83 is very low, and implied that the sound did not annoy participants and was able to warn in an acceptable manner. Thus, the warning system was able to warn the driver in an appropriate way.

5.7. Potential to improving system effectiveness by including wireless device to the system

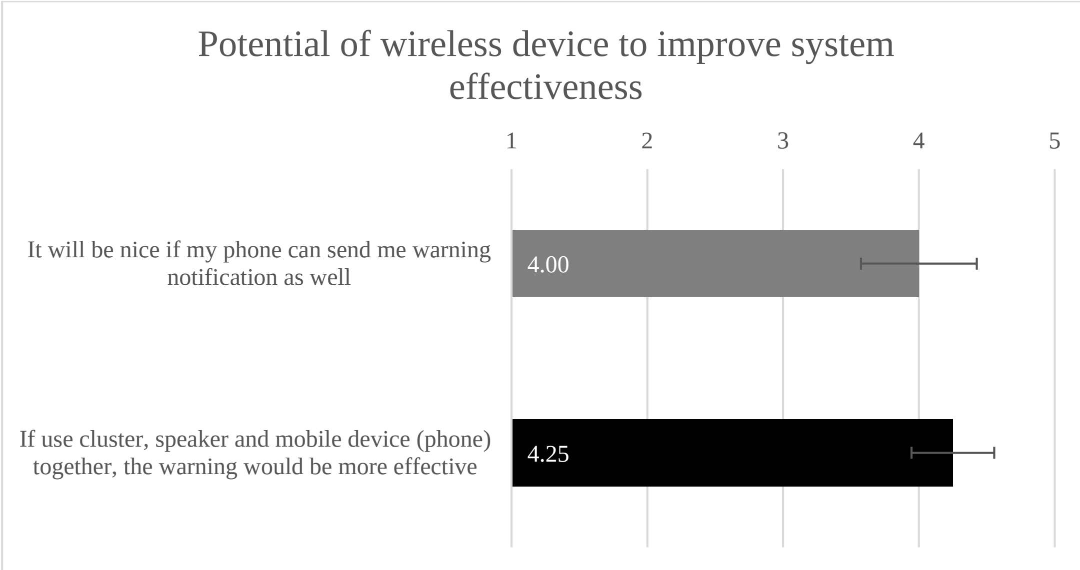

Figure 5.10: Questionnaire results concerning of Potential to improve system effectiveness by including wireless device to the system

None of the participants recommended to add/change selected components used in the system. However, they all agreed when the researcher suggested to add mobile phone notifications into the warning system. This proves that a wireless device would have the potential to improve the system effectiveness.

5.8. Result Discussion

The overall rating of the system is pretty decent. This does not mean that the system is good enough to put in use. However, the result implies that the designed system does have the potential to be put in use with further development. There is plenty of room to improve user interface, especially for the cluster.

Many participants complained about the position of the graphic warning. The graphic warning appeared in an area that was obscured by the steering wheel for many participant, as they laid back making their eye sight position lower than usual. This would not be the case if the participant needed to drive the car. For the sound warning, some participants suggested to have a different modality of sound in each warning interval which would provide a sense of urgency to the driver. Since participants participated in the experiment mixed in both possession of driving license and not, the researcher anticipated to see differences in these 2 groups. However, there was no significant difference, as none of them failed to intervene and stopped mostly at a time when a warning took place. Hence, this system effectiveness is the same for those who can and cannot drive a car.

The transition success rate of the experiment is 100%, but the sample is too few to verify that the system is safe enough to integrate into a real Level 3 Automated Vehicle. In the researcher's point of view, there might be more than hundreds of sample needed to make sure that the system is safe since the driver's and passenger's life are on the line. The result of the experiment only tells that the system does have potential. During the experiment, many participants still monitored the road for a certain time and kept their glance at the monitor. Results of the test might be different if each participant had experienced the experiment many times, as they will get used to the system and become more relaxed and comfortable during the experiment. The researcher expects that they will not monitor the road anymore. The same situation will occur in the real application since they will use the car every day and experience the warnings numerous times.

In term of annoyance, the system would be nothing even if the system can get 100% transition successful rate, but warns the driver in an intolerable manner with a high annoyance rating. From the result, the overall annoyance rate of the system is 1.50, which in the researcher's opinion is a low number and means that the system warns the driver in an acceptable manner.

To include a wireless device to the experiment would be intriguing as almost every participant agreed that the system would be even better, and they expect themselves to be using a mobile phone in real circumstances. Hence, if the system could send the mobile phone a notification as well, the system can almost certainly get the driver attention.

Chapter 6 Conclusion

6.1. Conclusion

The study used the Model-Based Systems Engineering method of using the SysML language to develop and express the system. The key functions of the designed system is the interval warnings. There are 3 times of warning: at the 5-minute mark, 2-minute mark and 1-minute mark. Components selected for warning were the digital cluster, speaker and wireless device.

The system was verified and tested by conducting experimentation and a questionnaire. There were 12 participants who participated in the experiment, mixed in gender with both male and female, age ranging between 24-30 years, and with/without a driving license. The transition success rate was measured. Other areas that the experiment verified were warning performance, comfortable and annoyance, for which the results were based on a 5-scale rating. In addition, the wireless device function was not included in the experiment but the potential of a wireless device to improve system effectiveness was measured in the experiment as an extra question to the participant in the questionnaire.

According to the result, the transition success rate of the experiment is 100%. Overall rating of Warning performance, Comfortability and Annoyance are 3.74, 3.63 and 1.50 respectively. None of the participants failed in the transition test. Hence the system had potential as a warning system that sent alertness to the driver as an output from the system.

The overall performance of the Warning performance of 3.74 also consisted of graphic warning as a factor in evaluation, where graphic warning rating is low at 2.42 compared to the sound warning at 4.33. Graphic warning was expected to have a lower rating than sound since the researcher anticipated that the participants would not be looking at the cluster, and introduced sound warning as a countermeasure. As expected, the Comfortability rating was the reverse variation to

Annoyance rating. In the researcher's opinion, a Comfortability rating of 3.74 is a good number. Providing too much of a comfortable ride to the driver would result in the driver being too relaxed and sleepy, which leads to an accident. The Annoyance rating of 1.50 means that participants were not irritated or frustrated from using the system at all. In depth, the sound warning has the highest annoyance rated at 1.83.

6.2. Future work

Potential of the system is proven. The system must be further developed before being implemented in a real vehicle. The user interface of the cluster could be more user-friendly, and the location of the pop-up warning area should re-locate to the top center instead of the bottom center since many participants complained that the warnings were blocked by the steering wheel arch. Automation mode of "on" and "off" is not obvious enough and should be changed. For instance, when automation mode is turned on, the vehicle figure in the cluster could change color to green, and change back to normal when automation is turned off. The color of the warning sign that pops-up on the cluster should be changed as well according to a participant who suggested that the color should start with yellow then orange and red, rather than blue, yellow and red to give more sense of danger which could result in a faster time of intervention.

The experimentation scale can be larger, where number of participants are increased to provide more accurate results. In terms of measured parameters, behavior of participant could be studied further by having a participant participate in the test 3 or more times, and measure their result of where the participant intervenes in driving, and how they change as they participate in more and more tests. This is to measure what participants would do after using the system many times and get used to it to the point where they become relaxed and comfortable, which is the point that they are most likely to fail to intervene driving the most. This applies to how the system will be in a real operation as well. The driver will experience the system every time they get on the highway so they will get used to the system in no time. If participants fail to intervene the driving, then the system needs to be redesigned, or new functions need to be introduced.

According to the result, most participants said that they were warned by the sound and not by the graphic warning, therefore the sound warning is very effective when the driver is distracted or inattentive, and should be selected as a component in a warning system of this type in this kind of situation.

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Chapter1

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Chapter3

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To my Father and Mother**, Luekrit Petchbordee** and **Nutcha Petchbordee** who encouraged me to enroll in to Keio University and provide me financial support for such a long time. Both of you taught and guided my way of living. Thank you very much for always being by my side through good and hard times in my life. Without you both I would not be my today self.

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Appendix

Hand Document provided to Participants before conducting the experiment

Questionnaire

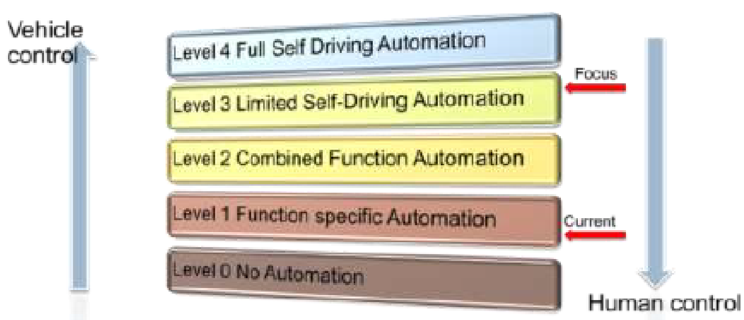
Explanation

In year of 2025-2030, it is estimated that fully self-driving car will made on to production(level 4 automation) [1]. But before then, there is level 3 automated vehicle which is capable driving by itself in certain condition. E.g. on highway driver can let the car drive by itself but the driver need to drive the car when exit the highway.

Fully self-driving car (level 4 automated vehicle) pictured:

Ref: https://www.mercedes-benz.com/en/mercedes-benz/next/automation/the-age-old-dream-of-the-driverless-car/

Level of Automation



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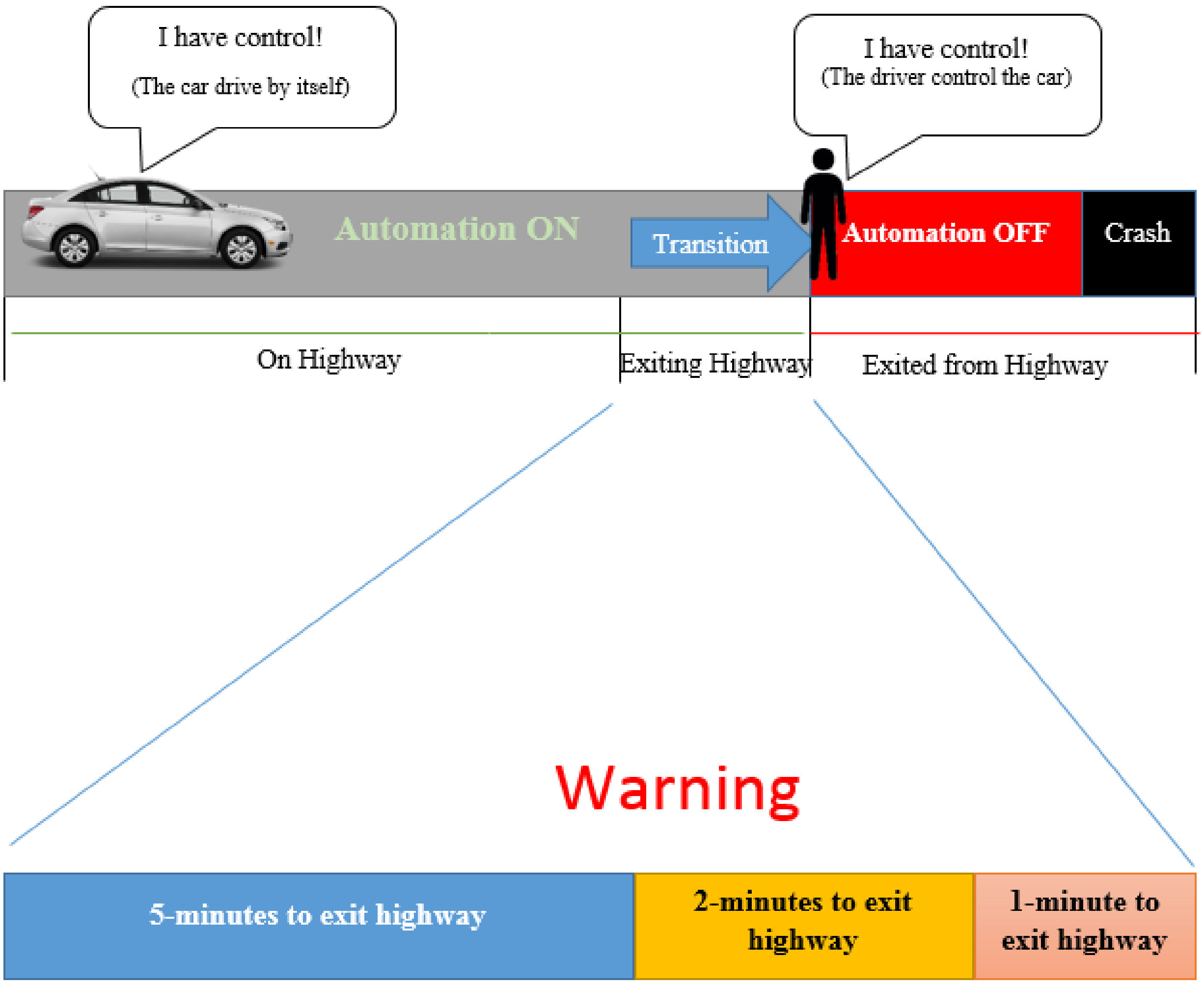
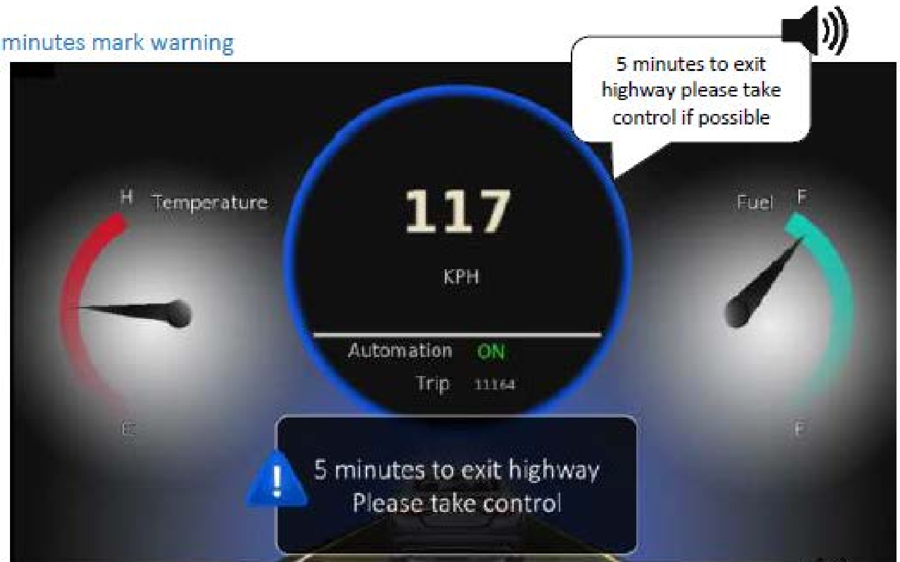
Situation

This experiment want to simulation the situation that driver need to get back in control. Changing control between car-driver is called transition. To get driver ready to drive the car before the automation not capable to drive is the goal of the test.

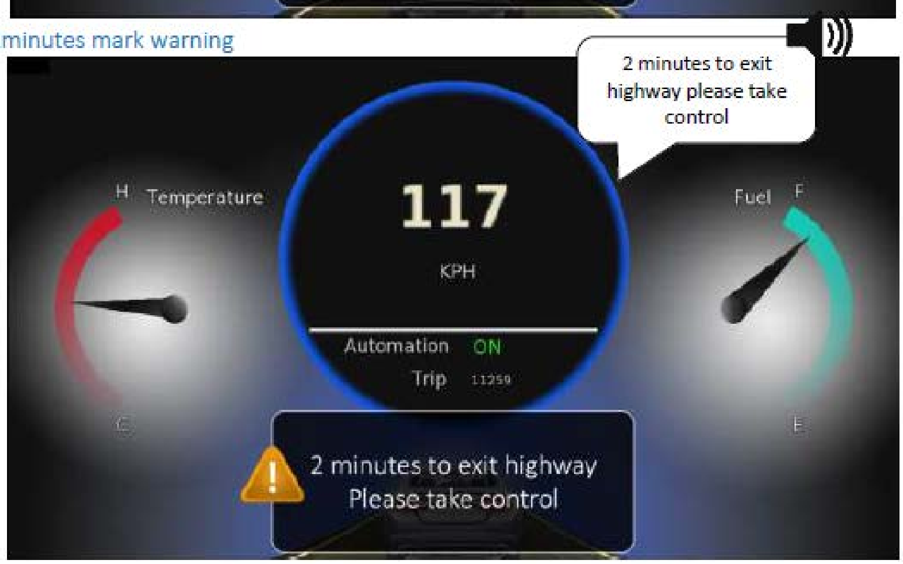


Warning interface

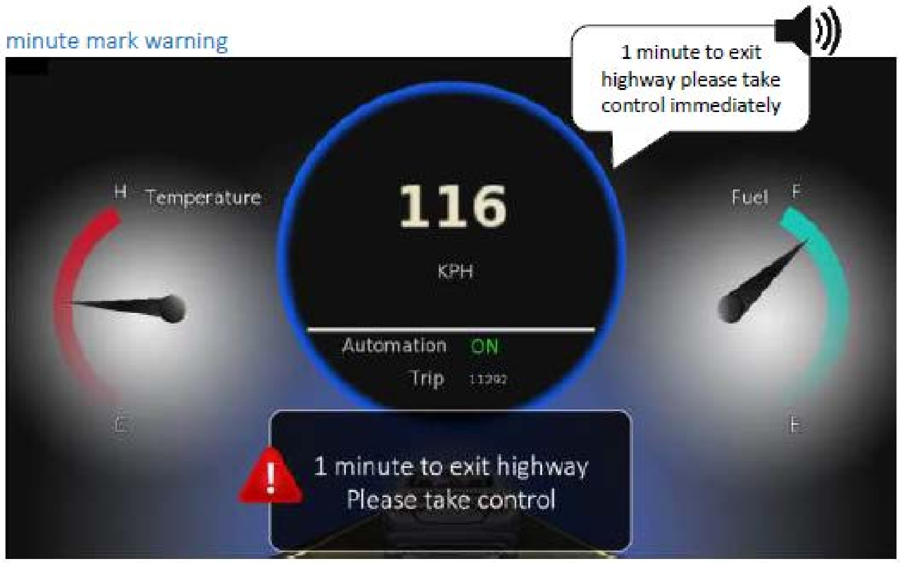
5minutes mark warning



2minutes mark warning



1 minute mark warning



Instruction

- Get distracted, once the movie start, please use your mobile device to browse anything on the internet e.g. Facebook and Instagram.
- 5, 2 and 1 minute mark warning will be given.
- Please stop the movie before the car crashes by pulling gear knob.
- Participant can stop whenever they like within transition time.

Enjoy!

Questionnaire document handed to participant after the experiment

Participant's detail

Possession of driver's license: Y / N

Age: ________ Gender: Male / Female

Please tick the following boxes with ✓ to rate the following statements from 1-5 base on your opinion. (1=strongly disagree, 2= disagree, 3=I think so, 4=agree & 5=strongly agree)

Statement	*1*	*2*	*3*	*4*	*5*
1. Speed meter is easy to read					
2. Temperature, fuel and other gauges are easy to read and understand					
3. It is Easy to notice if Automation mode is "on" or "off"					
4. Digital cluster is comfortable to use					
5. Graphic warning is easy to read					
6. Graphic warning catch your attention					
7. Sound warning sound is clear and easy to understand					
8. Sound warning catch your attention					
9. The warning system can catch your attention					
10. Interval of warning (5, 2 minutes and 1 minute) is a suitable intervals					
11. The warning system is effective for distracted driver					
12. Graphic warning is annoying					

13. Sound warning is annoying					
14. The warning system is annoying					
15. Cluster and speaker is effective for warning					
16. It will be nice if my phone can send me warning notification as well					
17. If use cluster, speaker and mobile device (phone) together, the warning would be more effective					

Comments/Opinions:

____

____

____

Experiment Result

Table a: Detail of each participant in the experiment

Participant	Driving license	Age	Gender
1	Y	27	Male
2	Y	24	Male
3	Y	27	Female
4	Y	25	Male
5	N	28	Male
6	Y	25	Female
7	Y	30	Female
8	N	29	Male
9	N	24	Male
10	N	24	Male
11	Y	25	Female
12	N	27	Female

Table b: Questionnaire result of each question from each participant with time of intervene driving task

Participant	Time to stop	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17
1	5:04	4	4	2	4	3	3	5	5	4	4	4	1	2	1	5	5	5
2	5:10	4	4	3	3	4	3	4	4	4	4	3	1	1	1	3	5	5
3	8:01	4	4	1	4	5	4	5	5	4	5	5	1	2	1	5	4	3
4	9:05	4	4	2	3	3	1	5	5	5	4	5	1	2	1	5	5	5
5	5:11	5	2	5	4	4	5	5	5	5	5	5	1	1	1	5	5	5
6	6:24	4	5	4	4	4	2	4	5	5	3	4	1	2	1	3	2	3
7	9:03	4	5	3	4	4	1	5	4	4	3	4	1	3	2	4	5	5
8	7:27	5	4	4	4	4	1	4	4	4	4	4	1	1	1	5	5	5
9	5:10	3	5	1	2	2	2	5	5	3	5	3	2	2	2	4	5	5
10	8:01	4	4	3	4	4	4	5	5	4	5	4	1	2	2	4	1	4
11	6:25	3	3	2	3	2	1	2	2	2	2	3	1	1	1	2	4	4
12	5:20	3	3	2	3	2	2	3	3	3	2	3	3	3	3	3	2	2
Average	6:42	4	4	3	4	3	2	4	4	4	3.8	3.9	1.3	1.8	1.4	4	4	4.3

Table c: Average score of each statement in the questionnaire

Statement	Description	Score
1	Speed meter is easy to read	3.92
2	Temperature, fuel and other gauges are easy to read and understand	3.92
3	It is Easy to notice if Automation mode is “on” or “off”	2.67
4	Digital cluster is comfortable to use	3.50
5	Graphic warning is easy to read	3.42
6	Graphic warning catch your attention	2.42
7	Sound warning sound is clear and easy to understand	4.33
8	Sound warning catch your attention	4.33
9	The warning system can catch your attention	3.92
10	Interval of warning (5, 2 minutes and 1 minute) is a suitable intervals	3.83
11	The warning system is effective for distracted driver	3.92
12	Graphic warning is annoying	1.25
13	Sound warning is annoying	1.83
14	The warning system is annoying	1.42
15	Cluster and speaker is effective for warning	4.00
16	It will be nice if my phone can send me warning notification as well	4.00
17	If use cluster, speaker and mobile device (phone) together, the warning would be more effective	4.25

Table d: Overall rating in term of Warning performance, Comfortability, annoyance, potential of wireless device to improve system effectiveness

Overall Rating	Score
Warning performance rating	3.74
Comfortability rating	3.63
Annoyance rating	1.50
Potential of wireless device	4.13

Table e: Standard deviation of Warning Performance, Comfortability and Annoyance rating

Warning Performance Rating						
#Statement	6	8	9	10	11	15
STDEV	0.39807	0.284268	0.259905	0.321769	0.228908	0.301511
Comfortability Rating						
#Statement	1	2	3	4	5	7
STDEV	0.192996	0.259905	0.355335	0.194625	0.28758	0.284268
Annoyance Rating						
#Statement	12	13	14	-	-	-
STDEV	0.179435	0.207194	0.192996	-	-	-
Potential of wireless device Rating						
#Statement	16	17	-	-	-	-
STDEV	0.426401	0.304636	-	-	-	-