Automated Lane Keep assist System

A study on the formation and evolution of the mental model of the user of ALKS

Shantanu Shivankar

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by

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Abstract

The mental model is a very rarely studied topic when it comes to human-machine interaction. Nearly all the studies that are done in this field are on measuring the actual performance of the human while performing collaborative task with the automation system rather than understanding the complete picture of how the human is understanding and interpreting the automation, is his actions due to just chance or does he/she have logical reasoning for his/her actions.

This research consists of recognising the factors that affect the mental model, designing the experiment that measures the mental model as well as the factors that affect it. This work focuses on ALKS (Automated lane keep assist system) which is a subset of the SAE level 3 automation system for which the rules are laid down by UNECE(United Nation Economic Commission for Europe) [25].

The approach of this research consists of an experimental setup in which the participants are given training and then are allowed to experience the level 3 automation in the driving simulator. The training and the simulation is designed to give a different depth in the functionalities and limitations of the system. The weak training just briefly describes the limitations of the system and how to interpret the user interface based on research done by Strand [35] with the consumer of level 2 automation system, on the other hand, the stronger training explains in detail the functionality and the limitations of the system along with the video explanations of how the automation will react in the different scenarios. Both the training are available in English and Dutch depending language preference of the participant. The participants are divided into 2 groups both of them are given different training but both of them experience similar driving conditions on the driving simulator. Later the performance of the mental model, as well as the performance of the factors affecting the mental model are measured. Each participant receives the training once and is subjected to 3 trials of the driving simulation to understand the learning effect of the mental model and its related factors.

The results of the mental model performance show that there is a significant gap of 5.5% between the weak and the strong mental model group just after the training, this trend then continues until the last trial where a significant gap of 6.5% in the mental model score. A positive learning curve is also observed starting from the training to the last trial, the learning curve has a positive trend but the data is statistically insignificant to show the difference in the learning rate of the two different groups.

There is a significant gap observed between the automation acceptance level of the two groups, although there is no significant rise in the level of acceptance of automation from just after the training to the last trials their difference in the acceptance level is present after the training and all the trials. For the trust level, the difference between the two groups is statistically insignificant, the difference is too small and the number of participants for the experiment is too less. Analysing the pragmatic significance of the trust data, a positive trend can be seen for the strong group whereas the weak group shows a negative trend, even though at the start of the experiment the weak group had a higher trust level. For situational awareness, the weak model group shows the lower situation awareness throughout the lap as compared to the strong mental model group.

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Nomenclature

Abbreviations

$ALKS$ Automated Lane keeping system

$EgoVehicle$ The vehicle on in which the automation system is working

$Leadvehicle$ The vehicle which is directly ahead of the ego vehicle

RDW The Road traffic department, Dutch: Dienst Wegverkeer

SAE Society of Automotive engineers

$StrongGroup$ The group that receives elaborate training

UI User interface system

$UNECE$ United Nation Economic Commission for Europe

$WeakGroup$ The group that receives brief training

1 Introduction

The level of automation used in vehicles is increasing. Technologies like ACC (Automatic cruise control) and LKS (Lane keep assist) systems increase efficiency and reduce the fuel consumption of the traffic on the road. These technologies should also reduce the number of accidents caused on the road by reducing human error, which currently accounts for 90% of road accidents[1]. However, automation in itself poses some risks due to the lack of maturity of the technology. Thus for the automation to maintain the positive balance of safety, the automation has to remove the involvement of the human from the driving loop and also to ensure that it does not introduce error due to the lack of maturity of the automation system itself.

Unfortunately, the human contribution to the driving task cannot be completely removed until SAE level 5 automation is implemented, and this goal will take a few decades to be reached. Meantime in the market vehicle manufacturers are introducing automated systems that need to interact occasionally with humans. Therefore, human-machine interaction poses another source of risks requiring specific attention to ensure a safe vehicle automation system.

Human factor research has shown that the vehicle automation system tends to reduce the safety risk posed by the use of this automation system as compared to the human-only operating system, but the automation system has some serious drawbacks of its own. It faces some great pitfalls like the lack of situation awareness, loss of skills, mental over/under-load, behavioural adaptation or misuse/disuse of automation. So the automation system should be developed taking into account the human capabilities and limitations for the safe interaction between humans and machines to eliminate all the possible human errors while the human becomes the part of the driving loop. This can be only done by designing the automation with the human-centric approach and analyzing the role of the human in automated driving systems.

Currently, the existing automation system still requires the driver to be in the driving loop to share and monitor the driving task. However, more advanced automated driving features that allow the driver to be out of the driving loop for an extended period are expected to be introduced in the market soon.

These **"more"** automated driving systems (SAE Level 3) need to be properly scrutinized to allow for safe public road operations. These systems, in which the driver is kept out of the loop for an extended period, pose several risks due to technological limitations, human-machine interaction aspects, ethics and liability issues which need to be investigated before such a system can be approved for use in the real traffic with real people on the road.

In this perspective, it is important to understand how the human acquires the knowledge on the capabilities and the limitations of an automated system and how the accuracy of this knowledge will affect the safe interaction between human and machine. One of the methods to understand this problem is to know about the mental model of the driver.

1.1. A brief introduction on the concept of mental model

1.1.1. Definition of mental model

A mental model is an operator's knowledge of system purpose and form, it's functioning, and associated state structure ([6]). It represents working knowledge of system dynamics and structure of physical appearance and layout, and causal relationships between and among components and processes.([24]).

The mental model can also be defined more precisely as a long-term memory knowledge structure, that is "a representation of the typical causal interconnections involving actions and environmental events that influence the functioning of the system"[13].

The mental model represents the knowledge of the components of a system, their interconnection, and the processes that change the components. It is the knowledge that forms the basis for users to construct reasonable actions and explanations about why a set of actions is appropriate[11].

The second definition [13] (para 2 section 1.1.1) describes the formation of the mental model in a dynamic situation and is different from the theory of the abstract syllogism, which defines the mental model based on-premises and conclusions. Mental models allow people to account for and predict the physical system's behaviour[15].

According to Johnson-Laird, P.N. ([16]), the mental model of the user of the automation system enables him/her to draw inferences and make predictions, to decide on their actions, and to control system operation. In allowing an operator to predict and explain system behaviour, and to recognise and remember relationships between system components and events, mental models provide a source to guide the human operator's expectations[19]. So the initial mental model starts from the point of obtaining the first knowledge about the system from any source. The correctness and the level of the mental model depend on the source of the knowledge about the system.

1.1.2. Type of mental model

The cognitive theory[33][32] divides the formation of the mental model into 2 types depending on the method of acquiring the knowledge. The use of theoretical knowledge/book learning results in the building up of declarative knowledge, leading to the formation of the general mental model. On the other hand, the use of practice and experience leads to the gain of procedural knowledge, which results in the formation of the applied mental model. Both mental models are important in the correct and complete formation of the mental model for the automation system. Figure 1.1 represents the cycle of evolution of the mental model.

Another method of understanding and describing the mental models is the use of the predictive processing framework [12]. This uses the concept of a hierarchical generative model which is embedded in the brain, after learning how the state or the event in the world or one human operator's body generates the sensory input. Predictive processing suggests that frequent exposure to reliable statistical regularities in the driving environment will improve generative model predictions and increasingly automatised performance. Further, failures may be understood in terms of limited exposure to functional limitations, and therefore, as an inappropriately tuned generative model in such situations[32].

In this thesis, the cognitive theory of studying the mental model is used. In the case of automated vehicles, not much neuromuscular movement can be observed, which will not lead to the proper mental model created by the predictive processing framework. Also, this method largely depends on the use of the right hardware, maybe use a real level 3 vehicle and edge-case scenarios to create the mental model in real traffic conditions.

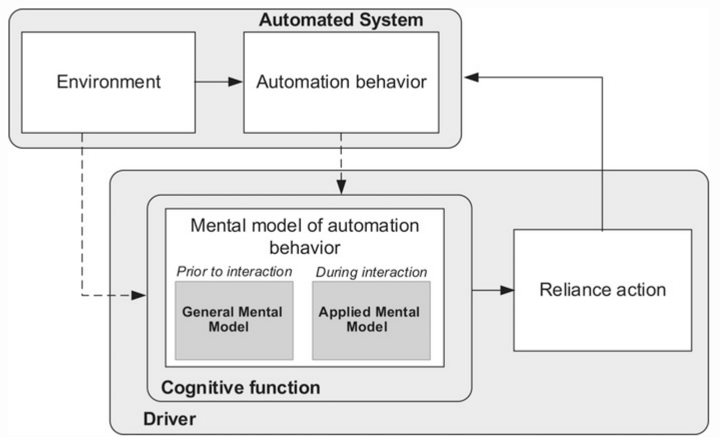


Figure 1.1: Simple description of Mental model on automation reliance[32]

Apart from this the DDT maneuvers supported by the system is limited to the full lateral and longitudinal control, emergency and minimum risk maneuvers and giving the request for the transfer of control. The automation system is responsible for all OEDR activity on the road but if the capability of the system

1.1.3. Desired ideal mental model

According to Seppelt and Trent [32] the mental model of the human for any automation should be based on the 3P of the automation (purpose, process and performance). Beggiato M [8] experimented on the mental model of the users of the SAE level 1 automation system keeping the benchmark of the ideal mental model as a parameter for comparison. This ideal mental model was based on the principle of the 3P system and was designed for the level 1 automation system. The same principle could be applied to the study of the mental model for the level 3 system where the ideal mental model will be based on the 3P of the level 3 system. This can be also fine-tuned to a custom level 3 automation system which includes some but not all the features of the complete level 3 automation system. In this thesis, we will work with the ideal mental model of the level 3 system that confirms the UNECE R.157 regulations. The regulations are later discussed in the section 2.1

Considering the 3P of the level 3 system that confirms to UNECE R.157 regulations, the ideal mental model of the system can be created in the following way:

1. **Purpose:** The purpose domain of the ideal mental model should have the clarity of the purpose of use of automation that is the automation is intended to be used

to reduce the driver load of driving when the vehicle is operating in the domain of its ODD, but the automation is not usable if the automation reaches the end of the ODD or the system failure occurs. Also when in use for the level 3 system unlike the level 1 or 2 the driver can completely disengage from the driving activity until the car reaches the limit of its ODD or request for the take over of the control is given by the automation system. For the ALKS system, the purpose should be clear to the user that the system is intended to be used on the highway that complies with the DDT conditions of the system and the speed of the traffic is not more than 60 $\mathrm{km\,h^{-1}}$ and the weather conditions would allow for the safe operation of the system given that the system is still functioning as designed.

2. **Process:** The users of the level 3 automation system should be aware of the process in which the automation system does the OEDR and the DDT of the driving task within its ODD that is the user should know how the system perceives the environment and how does it execute the driving manoeuvres. This will result in the user being able to predict based on the driving conditions(traffic, weather, infrastructure etc) about the possible take over request or the reduced performance of the automation system. Level 3 system compared to levels 1 and 2 can do the OEDR and DDT for an extended period when the car is in the ODD but the car may ask the driver to take over the control, either due to automation failure or the end of ODD. The user should also be aware of the process in which the take over request has to be answered.

3. **Performance:** The users of the level 3 automation system should be aware of the performance capabilities of the automation within its ODD like the speed limit, lane changing ability, overtaking ability, minimum risk manoeuvre and emergency manoeuvres etc. The user should be aware of how the automation will make the vehicle behave under each of the manoeuvres. This will allow the users to anticipate the possible steps of the manoeuvre that the automation will/can perform when it is operating in its ODD depending on the changing driving conditions. Level 3 systems unlike the level 1 and 2 systems will handle all the DDT activity in the ODD, it will have the ability to control all the DDT manoeuvres as well as the emergency and critical manoeuvres of the car.

2

Research Question and Hypothesis

2.1. Research question

SAE level 3[30] automation system fitted in the vehicles requires both automation system and humans to work perfectly in sync to ensure safety on the highway. ALKS (Automated lane-keeping system) system is a level 3 driving automation system that offers to drive the car under its level 3 automation conditions defined by the UNECE R.157 rules. The ODD, OEDR and the DDT of the general level 3 automation system are defined by SAE J3016 [30] and the ALKS level 3 system-specific ODD, OEDR and the DDT conditions are defined by the UNECE R.157 rules. [25] Combining the SAE level 3 concept with the ALKS R.157 rules we have the following conditions:

- The driving speed has to be less than or equal to 60km/h.(This is a hard limitation put there by the regulations, the infrastructure does not need to be designed for this speed, but the traffic conditions should restrict the vehicle to work below the speed limit)
- The opposite flow of the traffic on the road should be separated by a physical barrier.
- The pedestrians and the cyclist should be separated from the traffic. (Need a physical barrier or should not be allowed to use the road infrastructure)

This research assignment is being done in collaboration with RDW [4] who is responsible for licensing the vehicles on the roads of the Netherlands. In the level 3 automation system, the driver is allowed to be out of the driving loop for an extended period but may be asked to enter back into the driving loop within a small time buffer to act as the fallback driver. A literature survey done by Eriksson and Stanton 2017 [14] showed that the mean take-over reaction time is 2.5 when the mean take over lead time is 7 seconds which is within the given lead time of 10 seconds. But with the inclusion of secondary tasks, this time is further going to increase and the quality is further going to deteriorate [37]. Hence it is very important to understand if the driver is ready to take back the control safely. As described in chapter 1(1) the mental model has been identified as one important factor that determines the performance of the driver during the take over request and therefore should have a significant influence on the take over time and quality.

Thus the research question for the thesis is as follows:
“What is the effect of giving good education and training to the driver about the Level 3 ALKS system on the formation and evolution of his/her Mental model and what contribution should be done by the OEM(original equipment manufacturer) to ensure proper development of the driver’s mental model"

Keeping in mind the research question the research will be carried out on a between-subject basis and the participants will be divided into 2 groups primarily based on the training that they receive at the start of the experiment. Henceforth from now on in the report, the group that will receive the elaborate training will be called the **strong group** and the group that receives the brief training is called the **weak group**. This research will require collecting primary qualitative and quantitative data from the participants (users of the automation) regarding their Mental model, trust and acceptance ratings, situational awareness and reaction to the take over request. The methodology of the experiments is described in chapter 3 with the results in chapter 4. Chapter 5 contains the discussions on the results and chapter 6 contains the final conclusions with some recommendation on future projects.

2.2. Hypothesis

The literature survey done on the development and evolution of the mental model suggests that the mental model of the drivers of SAE level 3 automated vehicle depend on the initial training given to them, their trust on the system, acceptance of the system along with the situational awareness of the drivers for the duration when the automation is engaged. The literature survey also explores that the evolution of the mental model with the repetition of the experiments.

With the study topic in mind and the literature review completed, the following four questions hypothesis was created to be investigated.

2.2.1. Training will determine the initial formation level of the Mental model

Justification: The initial education and knowledge help in the initial formation of the mental model of the driver. Therefore, the strong group should have a higher Mental model score as compared to the weak group just after the formation of the mental model has taken place that is after the initial training.

H0: The difference in the initial training will not lead to any difference in the initial (formation) score of the mental model between the 2 group of participants.

H1: The difference in the initial training will lead to the difference in the initial (formation) mental model score between the 2 group of participants.

2.2.2. High trust and acceptance is required for the mental model development of the driver, so there should be a positive difference in the trust and acceptance score of the strong group compared with the weak group

Justification Trust can be defined as the attitude that an agent will help achieve an individual’s goals in a situation characterized by uncertainty and vulnerability [29]. Acceptance can be defined as the willingness to use the SAE level 3 automation irrespective of the trust in the system. A user of the automation may choose to use the automation system even if he/she doesn't have an adequate level of trust in the system in a given situation where he/she has to decrease his mental workload, on the other hand, a user of the automation may choose not to use the automation even if he/she trusts the automation because just because he/she enjoys the pleasure of manual driving. Therefore in the context of reinforcement of the mental model the user of the automation should undergo repetitive use of the automation to reinforce his mental model and for that the trust and acceptance of the user of the automation system in the automation system should be high. The difference in the trust with the difference in the mental model for vehicle automation system has been studied by Beggiato M[8] in which he has shown that the initial level of trust is the same for both the groups of the mental model but for the stronger group it increases whereas for the weaker group it decreases. In the same research, the difference in the acceptance level was studied but no significant difference was found between the acceptance level with the difference in the mental model score.

For Trust

H0: There is no difference in the trust score when there is a difference in the mental model score.

H1: There is difference in the trust score when there is difference in the mental model score.

For Acceptance

H0: There is no difference in the acceptance score when there is a difference in the mental model score.

H1: There is difference in the acceptance score when there is a difference in the mental model score.

2.2.3. Situational awareness is important in the reinforcement of the mental model created after training, so there should be a difference in the situational awareness score if there is a difference in the mental model score

Justification: During the initial phase of the mental model development after acquiring knowledge and training the driver needs to be aware of the surroundings at least during the critical manoeuvre, during the request for the transfer of control and emergency manoeuvres. These events are rare in occurrence but pose critical safety risks if the driver does not react accordingly. The situational awareness is expected to decrease with the trials when comparing each scenario but during the above-mentioned maneuvers the situational awareness should be high so the correct reinforcement of the mental model of the driver takes place. Also as suggested by Zwaan and Graesser 1995 [38] the wrong mental model reduces the situational awareness of the user at the moment when high situational awareness is required and also increases the cognitive load on the driver. The situational awareness is defined as the transient contents of awareness as structured and supported by underlying mental model [23]. As researched by Mogford 1997 [23] pilot trainees in reattaining information about aircraft altitude and direction of flight, maintain a minimum but adequate set of data to help anticipate impending aircraft conflicts. Higher mental model should result in higher score for situational awareness.

H0: There is no difference in the situational awareness score when there is difference in the mental model score.

H1: There is difference in the situational awareness score when there is difference in the mental model score.

2.2.4. Improvement in the mental model score with the repetition of the experiment

Justification: A mental model similar to other human learning behaviour undergoes the learning effect which means that the mental model score of the participants irrespective of the initial training given should increase with the repetitions of the experiment. Beggiatto M [8] studied the learning effect of the mental model when using the level 1 automation system and showed that there is a learning effect in the mental model score. The same effect can be expected with the mental model score of the level 3 automation system.

H0: There is no difference in the mental model score when the first and the last trial are compared.

H1: There is difference in the mental model score when the first and last trial are compared.

3
Methodology

This chapter describes the complete experiment method and setup done to perform the driving experiment in this research thesis. To analyze the mental model performance of the drivers of the level 3 automation system an experiment was designed to be performed in the driving simulator to simulate the driving behaviour of the level 3 automation system fitted when fitted in the vehicle. This experiment was performed on the DAVSi (Delft advanced vehicle simulator) located in the 3ME vehicles engineering lab. For the additional requirement of the experiment, some physical changes were made in the simulator which is shown in Figure 3.5 and later discussed in the section 3.1.5 and section 3.1.8. The driving lap (Figure 3.3) was designed according the dutch traffic infrastructure rules and the ODD of the ALKS level 3 driving automation according to the R.157 rules [25].

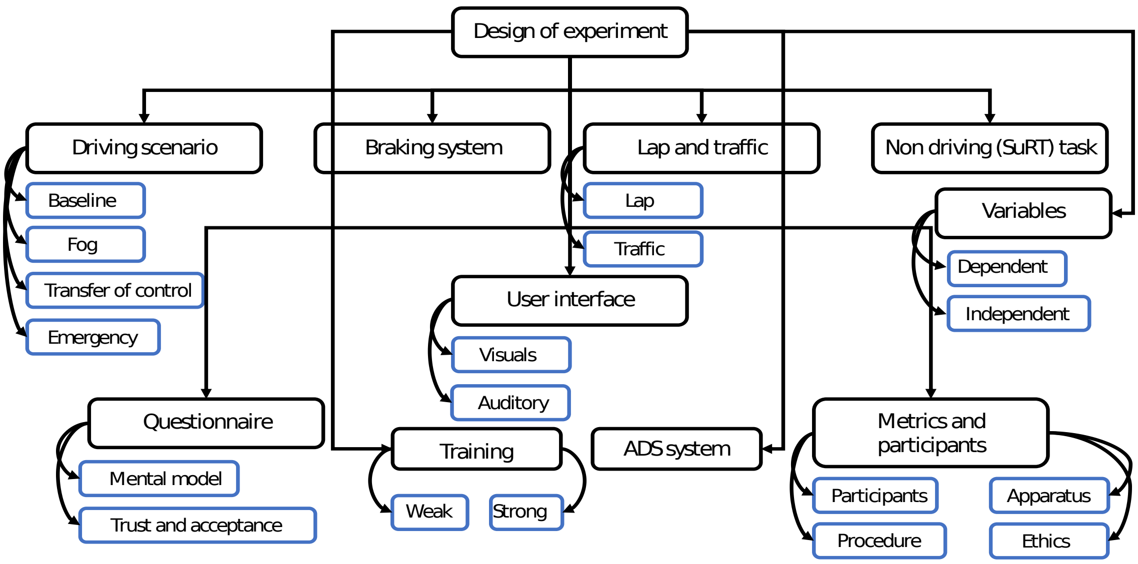
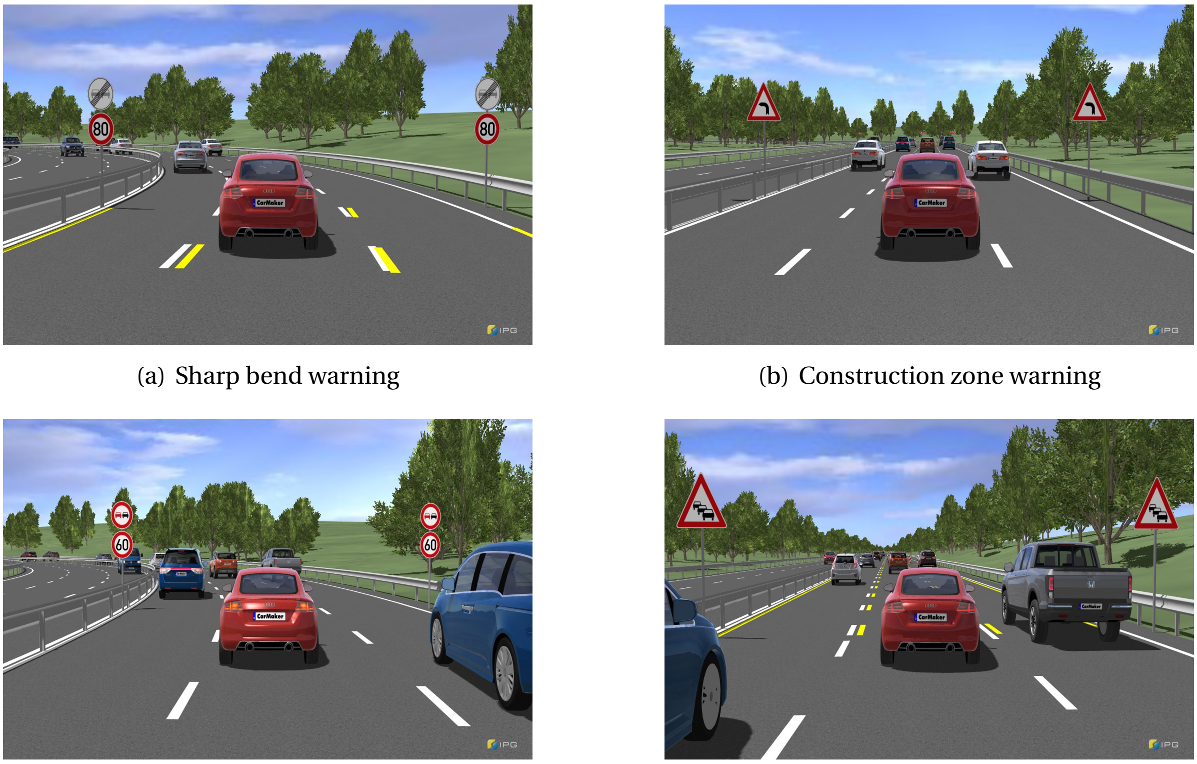


Figure 3.1: Layout of experiment methodology



(a) Sharp bend warning

(b) Construction zone warning

(c) Speed limit change

(d) Construction zone start

Figure 3.2: Lap and traffic signs

3.1. Design of experiment

3.1.1. Design of driving lap and traffic

The main idea behind the modelling of the traffic on the road was to give the participants the feel of the real traffic jam on the highway since the system is meant to be used at 60 $\mathrm{km\,h^{-1}}$ on the dutch highways. The modelling of the traffic was done such that there are no phantom traffic jams and the ego vehicle is always in the motion [3].

An oval track was created as given in figure 3.3 which was 2750 m in length containing sharp bend of radius 50 m after 1500 m of the start point and a construction zone after 2500 m of the start point. In the construction zone the outermost right lane was closed and the zone extended for 250 m, keeping the other 2 lanes free for the flow of traffic. The whole lap had 3 lanes and the width of each lane was 3.5 m as most of dutch highways[3]. The complete lap had been designed with the appropriate road signs that have been placed in the sharp bend and the construction zone along with the speed limits of the zones. The construction zone was also marked with temporary traffic lines. Figure 3.2 illustrates the traffic signs and lane markings.

The speed of the traffic on the left lane was the highest and in the right lane was the lowest. The traffic in all the lanes is flowing at varying speeds. For the left lane, the traffic speed ranges from 70 $\mathrm{km\,h^{-1}}$ to 50 $\mathrm{km\,h^{-1}}$, the traffic in the middle lane flows from 60 $\mathrm{km\,h^{-1}}$ to 40 $\mathrm{km\,h^{-1}}$ and the traffic in the right lane flows from 50 $\mathrm{km\,h^{-1}}$ to 30 $\mathrm{km\,h^{-1}}$. The sharp bend forces all the vehicles to drive at a speed below 40 $\mathrm{km\,h^{-1}}$ so that the vehicle remains in its driving lane. The automation is always driving the ego vehicle in the center lane.

The merging of the cars from the right lane to the centre lane before the start of the construction zone was done in an alternate pattern that is every car in the middle lane allowed one car from the right lane to merge before the start of the construction zone.

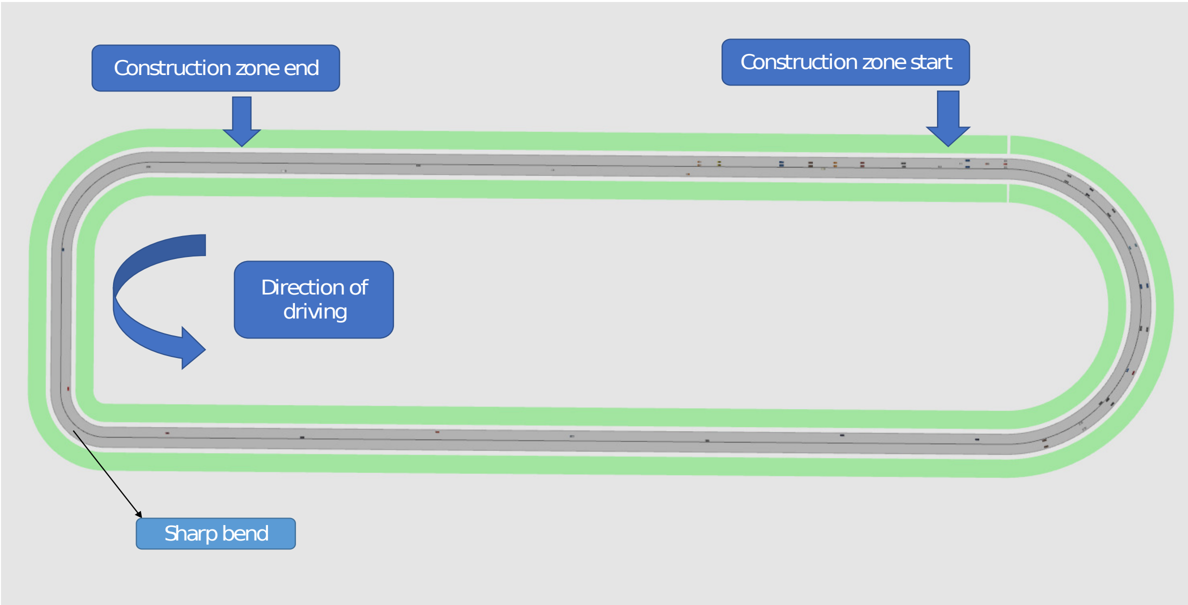


Figure 3.3: Driving lap

3.1.2. Design of driving scenario:

The driving scenarios are designed in IPG carmaker, a software developed by IPG Automotive Gmbh[2]. A passive simulation is used for the experiment which means that the ego vehicle, lead vehicle and behaviour of all the traffic vehicles are preset before the start of the experiment. The scenario was designed keeping in mind the ODD condition [25] which states the road should be a highway with the opposite flowing traffic separated by a physical barrier and no cyclist or pedestrians allowed on the road. A slow-moving traffic jam was simulated which ensured that the driving speed never exceeded the hard speed limitation of the ALKS (by UNECE regulations) system which is $60\,\mathrm{km\,h^{-1}}$. The baseline scenario was designed to act as the control scenario for comparisons in which the automation system worked perfectly and never went out of its ODD. The fog scenario was designed to simulate the possible out of ODD condition for the automation system due to the decrease in the perception of the sensor, though the automation never ran out of the ODD since the density of the fog is low (The automation is designed to work in a fog density equivalent to visibility of 50m or above). The take over request scenario was designed to simulate the possible automation failure within the ODD condition due to the failure in the hardware/software of the automation system. The emergency scenario was designed keeping in mind the possible behaviour of the ALKS level 3 system within its ODD if the system detected the possible collision condition due to the traffic behaviour on the road. For studying the learning effect of the mental model, the same scenarios are repeated in 3 trials in the same sequence. The traffic behaviour is kept the same for all the scenarios and all the trials except for scenario 4 where the emergency manoeuvre has to be performed and a different lead vehicle is used.

Further description of each of the driving scenarios is given below:[1]

1. **Baseline scenario:** The automation system drives the ego vehicle through the whole lap of the track in clear and bright weather with no take over request or emergency manoeuvre involved. The user is asked to do the NDRT task but still is allowed to look in the surroundings and use the brake pedal only when he feels that the vehicle is doing some unusual behaviour or there are chances of collision.

2. **Fog scenario:** The ego vehicles drive through a single lap of the track in fog condition. The first phase of fog appears 50 m before the ego vehicle reaches the midpoint of the sharp bend and ends 50 m after the midpoint of the sharp bend. The second phase of fog appears 50 m before the start of the construction zone and ends 50 m after the end of the construction zone. The fog is set at the density ratio of 0.03% in the IPG carmaker which translate to the visibility of more than 50 m but less than 200 m from the ego vehicle as seen by the participant. The scenario involves no transfer of control request as well as no emergency manoeuvre.

3. **Take over request scenario:** In this scenario, the ego vehicle drives one lap within the ODD of the automation system. The automation system never experiences any loss of ODD but to simulate the take over request the lap was designed to create a scenario for automation failure by forcing the system to go to automation failure mode. The take over request occurs at 2 positions of the lap, one at the start of the sharp bend and the other at the starting of the construction zone. To inform the participants of the automation failure take over request, the user interface screen and the speaker of the vehicle is used(explained more in section 3.1.8).

4. **Emergency Scenario:** In this scenario, the ego vehicle drives a lap on the track, the weather is clear and bright but the ego vehicle is subjected to traffic conditions such that it performs emergency manoeuvres. The first emergency scenario takes place after the sharp bend of the track in which a vehicle from the right lane makes a sharp cut-inn and the ego vehicle performs the emergency manoeuvre in which it decelerates with peak deceleration of $10.90 m/sec^2$, mean deceleration of $6.52 m/sec^2$ and stops. As soon as the distance of the ego vehicle from the cut-inn vehicle becomes 30 m the ego vehicle resumes the normal automation activity. The second emergency manoeuvre takes place in between the construction zones where the lead vehicle brakes suddenly and automation performs emergency manoeuvre, the ego vehicle decelerates with peak deceleration of $10.44 m/sec^2$, mean deceleration of $7.23 m/sec^2$ and stops. The whole scenario lasts for 280 seconds. This scenario is designed to reinforce the mental model of the user associated with the emergency manoeuvre of the ALKS automation system as well as the trust of the user in the system.

3.1.3. Design of training

The training was designed based on the interview conducted by Strand and Stave 2018 [35] in which a personal interview was conducted with 3 new owners of Volvo level 2 automation system at different points of time from the purchase of the car till a 3 month ownership period. The training developed by Beggiato [8] was also referred for this research.

[1]The scenarios can be accessed via this link https://www.youtube.com/watch?v=1F6ZCFPPdRw&list=PLAhBgxwMEXIKgwnvg83K00zl5Bf6lscYR

To remove the bias for the preference of language spoken the training was available both in English (Weak training :Appendix 7.4, Strong training: Appendix 7.6) and Dutch(Weak training: Appendix 7.3.2, Strong training: Appendix 7.7). It was first developed in English and later translated to Dutch by RDW. The difference in between the training was based on the depth in the information that was provided about the functionalities and the limitations of the system. The knowledge about the user interface was kept the same in both the training. The information about the user interface was provided once in the weak training and twice in the strength training.

1. **Weak training:** The first section of the training contained a brief explanation of the DDT of the level 3 automation system with some information on the OEDR activity that the automation system can handle, all the OEDR activity when the system is activated but also that the driver has to take care of the OEDR when the system asks the driver to take over. The next section contained the description of when the system will not work (bad weather condition and hardware/software failure) but no detail was given on how bad the intensity of the weather is tolerable by the system or what is the actual cause for the hardware/software failure of the system. The next section described the duration for the driver to take over the control of the car after the take over request was given and what will happen if the driver chooses not to respond to the take over request. There was a brief description given on the 2 critical zones of the track, sharp bend and construction zone and was explained briefly that if the automation system is working before the start of these zones then the system will continue to work if the weather condition does not degrade beyond the tolerance limit of the automation or some unexpected hardware/software failure of the automation system. There was a description in detail about the tolerance limit for weather for the automation system. There was a detailed explanation given for the user-interface system, what is the meaning of each symbol that is displayed on the screen as well as what the driver is expected to do when the specific warning for the takeover or the emergency manoeuvre is given by the UI system.

2. **Strong training:** The first section of the strength training was the same as the weak one containing a brief description of the DDT and OEDR of the automation system. Additionally, this section also describes the exact ODD and speed limit of operation for the designed level 3 automation system (speed limit of $60\,\mathrm{km\,h^{-1}}$ and road infrastructure of Autosnelweg) which was not discussed in the weak training.

   The following points below summarize the explanation of the training that was given to the participants of the strong group regarding reaction of automation in different road conditions, special manoeuvres and user interface and were not available to the weak group.

   (a) **Straight Road:** The automation system will follow the time gap of 2 secs from the lead vehicle upto the speed of $60\,\mathrm{km\,h^{-1}}$. If the lead vehicle is not available then it will drive at the maximum speed of $60\,\mathrm{km\,h^{-1}}$.

   (b) **Curved road:** The automation system follows the lane marking and maintains the time gap of 2 sec from the lead vehicle upto the speed of $60\,\mathrm{km\,h^{-1}}$. If the lead vehicle is not available then it drives the ego vehicle at the maximum speed of $60\,\mathrm{km\,h^{-1}}$.

(c) **Emergency maneuver:** Explanations why this maneuver is performed by the system and what is the driver expected to do when it is being executed.

(d) **Take over request:** Conditions under which the take over request might occur, either the weather condition deteriorates below the threshold mark or the automation system (software/hardware) failure occurs. The weather threshold (different density of fog condition) was explained using animation, and the participant were given hint on how to know the following distance of the car by looking at the number of lane lane markings. The automation failure could be recognised from the information given by the UI system.

(e) **Road conditions:** Explanations on how the automation will react before the construction zone and sharp bend.

(f) **User interface:** Complete information was given to the participants about the user interface along with different modes for the transfer of control and emergency maneuver. The explanation was also followed by an animation for the same.

3.1.4. Design of braking system

The sensitivity and the characteristics of the brake pedal have been considered to play a crucial role in the development of the mental model, so the design of the brake controller has been done to simulate the static model of braking as done by Meng and Zhang 2016 ([22]). The model contains the static model of the pushrod, master cylinder, brake fluid, brake hose, calliper and rotor assembly and brake booster. The model is then tested on the simulator to measure the achieved braking deceleration vs pedal travel.

Although the ALKS system[25] has the feature of choosing between the brake, accelerator and the steering control, braking was chosen as the tool to reward the participants if they recognised the scenarios in which they felt that the automation might fail or the automation may lead to accident on the road. Therefore the brake pedal measurement was chosen as a quantitative measurement to understand the knowledge of the participant to understand the capabilities of the system in different scenarios. In addition, it was assumed that the predetermined reward for the participant helped to increase the attention of the participant on the road[31].

To avoid collecting the false positives of the brake pedal travel participants were instructed to use the brake pedal during the request for the transfer of control (scenario 3) and to avoid the use of the brake pedal in the other scenarios(1,2 and 4), but they were also told that if the felt the need of the brake pedal necessary then they could use it (For eg if they felt that the car would run into a collision).

In addition, during the request for the transfer of control they were also instructed to keep the pressure on the brake pedal until they see the sign showing *"RESUMING AUTOMATION"*on the user interface screen.

3.1.5. Surrogate reference task(SuRT):

A distraction (non-driving related task) is needed for the driver to simulate the real environment of level 3 automation as it allows the driver to take the hands off the wheel and eyes off the road but still does not allow to leave the driving position or sleep in the car(both the driver presence and the driver availability criteria have to be satisfied for the automation to work. The driver attentiveness is not necessary. These conditions are also enforced by the UNECE guidelines)[26]. The research was done on the effect of cognitive workload and visual workload during critical tracking tasks suggested that visual distraction is more successful in creating a successful distraction for the driver as compared to cognitive workload hence the visual SuRT workload was created during the driving task[28]. The frequency of the SuRT task will also be used to measure the situational awareness of the driver as done by Beggattio[9]. The task is performed on an app developed by the German aerospace department(DLR) which consist of selecting the left or the right part of the screen depending on the location of the bigger circle among a randomly generated group of 50 circles. 50 circles are generated for each cycle among which there is only one big circle about 66% greater in size as compared to the smaller circle. For the easy recognition of the circles and to reduce the glare of the light in the eyes of the participant the circles are chosen to be white placed on a black background. As soon as the participant touches the screen of the tablet the next set of the circle appears, participants are asked to start playing the task as soon as see the cars in the scenario moving and stop playing after 280 secs of the scenario run-time. They are instructed both by the experimenter to start and stop playing the game.

Research done by Lu and Happee 2019 [5] showed that the handheld device significantly increased the take over request time as compared to using a hands-free device hence it was decided to use the hands-free tablet placed on the right side of the driver on the chair as shown in the figure 3.5 for the doing of the SuRT task. The tablet was shifted slightly for the reach of each participant depending on his/her preference.

3.1.6. Pilot test

After the driving scenario, lap, traffic, training and the questionnaire were designed a pilot test was conducted to check if the combination of training, simulated video of the driving scenario and questionnaire can distinguish between the two mental models, as per the difference in the score.

During a self-driving conference presentation, the employees of the RDW office in Zoetermeer were asked to participate in the pilot test. The employees who gave consent for the pilot test were asked to do the pilot test in a sequence that represented the actual experiment. Due to lack of the participants, a within group study was conducted in which the participants were first given the weak model training and then asked to answer the questions. Next, they were given a strong model training and asked to answer the same questions. The figure below shows the results obtained after the test was done. After the test, feedback was taken from the participants regarding the whole pilot test. The arrangement for the option of questions 8-12 (Appendix7.1.1) was rearranged to keep the correct option as a different option in between the weak and the strong training. The formation of the questions was changed to accommodate the simple terms for referring to the vehicles and the infrastructure of the scene since the participants of the real experiment will not be experts (For example changing the term **lead vehicle** to **car in the front**, changing the term **ego vehicle** to the term **your car**). The traffic signs were added in the different sections of the road and the constant flow of the traffic was changed a varying flow.

Figure 3.4 shows the difference in the mental model score of the pilot test. The weak group scored a mean score of 0.67 with a variance of – and the strong group score a mean score of 0.76 with a variance of –. This clearly showed that the combination of the training and the evaluation method used is able to distinguish between the weak and the strong

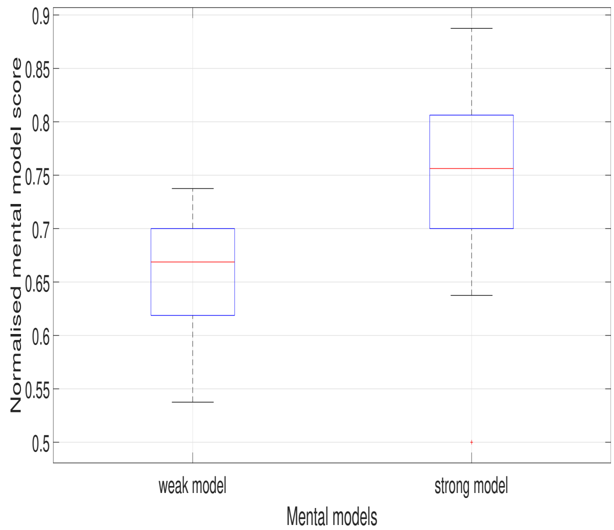


Figure 3.4: Normalized mental model score after pilot test

mental model based on the score obtained.

3.1.7. Design of the questionnaire

The questionnaire was divided into 3 parts, mental model, trust and acceptance. The reading for the mental model questionnaire was taken 5 times during each trial of the experiment, once after the training was given(trial 1) or once just before starting the experiment(trial 2 or trial 3) then after each scenario the mental model reading was taken. For the trust and acceptance questionnaire the reading was taken twice during each day of the experiment, once after the training (day 1) or before the starting of the experiment (day 2 and day 3) and once after the end of the experiment on each day. A seven scale Likert chart was used while answering the question since the number of participants are small and research shows that the 7-point Likert scale produces a better distribution of data as compared to the 5-point Likert scale.

1. **Mental model questionnaire:** This was further divided into 3 sections questions answerable in different formats. The first section is based on the functioning and limitations of automation, answerable using a 7-point Likert scale. The second section contains the questions on transfer of control answerable in single choice correct MCQ format and lastly the third section consist of questions on the expectation of human driver after the automation has asked to take the transfer of control also answerable using the single choice correct MCQ. Appendix 7.1.1 contains the mental model questionnaire.

   The 1^{st}(1) and the 2^{nd}(2) question asks the user about the longitudinal behaviour of the vehicle. The 3^{rd}(3) and 5^{th}(5) question asks about the lane change behaviour. 4^{th}(4) question asks about the engagement in the SuRT task. 6^{th}(6) questions asks about the working of the automation under a fog condition with the given intensity of the fog. 7^{th}(7) and 8^{th}(8) asks about the behavior of the automation when the vehicle from the adjacent lane enters in the lane of the ego vehicle. 5^{th}(5) question asks about the behavior of the vehicle if the driving lane would be blocked. 9^{th}(9) and 10^{th}(10) question asks the participant regarding the transfer of control timing. 11^{th}(11) and

12^{th}(12) question asks the participant regarding how to take them back the control of the car and what they expect if they don't take back the control of the car. The single choice correct MCQ are awarded points from 1 to 7 based on the closeness of the option to the safest behaviour of the vehicle(Appendix 7.2). The arrangement of the questions in the questionnaires was done in a way that the correct answer will not lie at the same end of the Likert scale to keep the attention of the participant while answering (Appendix 7.1.1).

2. **Trust questionnaire:** Research shows that a multi-question based trust questionnaire is better than a single question due to the elimination of the bias from the participants while answering. A single item does not follow the detailed analysis of the trust score due to error of specificity inherent in single items (Appendix 7.1.2). The trust questionnaire was based on research done by Lee in 2004 [20] and on the trust of the human in automation and a trust questionnaire used by Beggattio M [8] to study the trust of the users in the level 1 automation system of the vehicles.

3. **Acceptance questionnaire:** There is no standardized method available to measure the acceptance of the drivers towards automation in vehicles. Having a single question in the acceptance questionnaire is known to have biases so a multi-question questionnaire is needed. This questionnaire is based on the confirmation acceptance theory (Appendix 7.1.3). This questionnaire was based on the technology acceptance model [36] and the acceptance questionnaire developed by Beggattio M [8] for measuring the acceptance of the users while using the level 1 automation system.

3.1.8. Design of the User-interface

For the mental model experiment, the user interface of the automation plays a huge role in the evolution of the correct model as well as the correction of the incorrect model. Figure 3.5 shows the placement of the user interface screen in the car, mounted using a holder from the windscreen, in direct line of sight of the participant and the Surt tablet kept on elevated support in the mockup vehicle for hands-free use.

Both audio and visual modality of the user interface is used for the experiment. Throughout the road, there is an engine sound being played which changes the frequency of the rumble depending on the RPM of the engine. During scenario 1 (No condition) and scenario 2 (fog condition), the user interface remains stationary showing the symbol for the automation on and a music screen (Figure 3.6(a)) on the tablet and plays only the sound of the engine combined with some tire screeching sound if the braking of the car exceeds 0.5G either by the user or by the automation. For the scenario 3 (Transfer of control condition) during the normal driving the music screen (Figure 3.6(a)) is continuously displayed but when the Transfer of control is demanded the screen shuffles in between the music screen, transfer of control (Figure 3.6(b)) screen and minimum risk maneuver screen (Figure 3.6(c)). When the transfer of control screen is displayed the warning tone of frequency 1000 Hz is played with on of cycle of 150 ms for 10 sec. When the minimum risk manoeuvre screen is displayed the warning tone with a frequency of 750 Hz is played with an on-off cycle of 100 ms for 7 sec. After this, a resuming control screen (Figure 3.6(d)) is shown by the automation indicating that the participants should get ready for the automation to start again and release the brake pedal.

Figure 3.5: Setup of the vehicle for the experiment with the user interface tablet in the middle

3.1.9. Variables of the experiment

Independent variables

1. **Training of two groups:** The training given to the participant is varied. One set of participants are given weak training and others are given strength training before they drive in the simulator. This will create a different initial mental model along with a different level of initial trust and acceptance in the participants. This will be used to study the effect of a difference in the training.

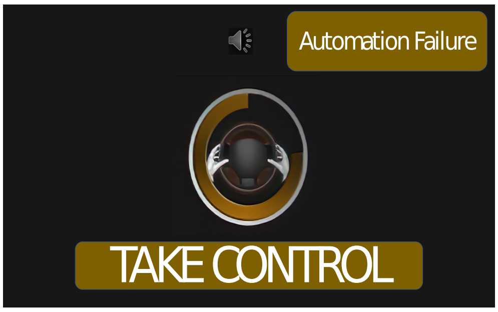
2. **Repetition of trials:** The repetitions of the trials are needed to be kept constant to measure the learning effect on the mental model of the participants. For the experiment, all the 3 trials have been chosen to be done on consecutive days to keep the same gap between the mental model update. This will be used to study the effect of repetition of the experiment.

Dependent variables

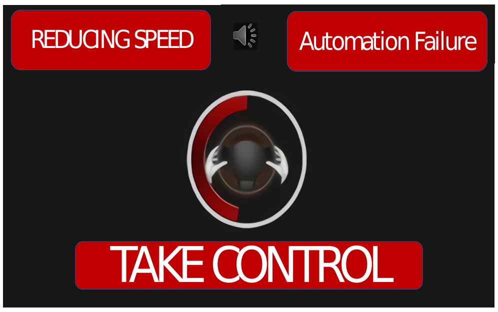
1. **Learning rate:** The learning rate of the participants will depend on which group they are present initially and after which trial number the reading is taken. The learning rate for both the group is expected to be high for Trial 1 and Trial 2 and slowly taper off for Trial 3. The overall learning rate for the weak group is expected to be higher than the overall learning rate of the strong group. The learning rate from Trial 0(measured after reading the presentation) to trial 1 is expected to be higher for the strong group compared to the weak group. The learning rate should also fit the power law of learning. The learning rate can be calculated by fitting a power curve on the data points obtained.

2. **Braking duration:** The participants are instructed to use the brake pedal if they feel that the ego vehicle will run into a situation of collision with the traffic vehicles or

(a) Music screen



(b) Transfer of control screen



(c) Minimm risk manuver screen

(d) Resuming automation screen

Figure 3.6: User interface screens

the road infrastructure or in case of emergency manoeuvres. During the transfer of control request, they are instructed to either use the brake pedal or let the automation do the minimum risk manoeuvre. The braking duration can be calculated from the braking graph obtained from the braking data.

3. **SuRT task frequency:** The frequency of the SuRT task will determine the amount of attention that the driver is paying on the road. For reducing the number of variables, it is assumed that the driver if not playing the game will be looking on the road. The SuRT data can be obtained from the task data saved in the drive of the SuRT tablet.

4. **Mental model score:** This will depend on which group the participant belongs to the number of trials that the participant has undergone. It is expected that the stronger group should show a higher mental model score for all the trials when compared to the weaker group. The final mental model accuracy of the stronger group after 3 trials should be more than the weak group but the difference should not be large. Also, the Mental model accuracy of the strong, as well as the weak group, should be close to the ideal correct mental model. The mental model score can be calculated using the mental model questionnaire (Appendix 7.1.1)

5. **Trust and acceptance score:** This can be measured using the trust (Appendix 7.1.2) and the acceptance(Appendix 7.1.3) questionnaire.

3.1.10. Experiment metrics and participants

A between-subject study was done with the participants. 7 subjects were be placed in the weak mental model group and 7 subjects were placed in the strong mental model group.

Participants

To focus more on the drivers who drive on the road and highways of the Netherlands, the participants were selected from the neighbourhood of Delft Using the Next-door App. Finally, 15 participants (male = 10, female = 5) were selected using the app. To avoid the ageing effect in the study drivers were selected from the age group of 19 and 60 who had the driving license for more than 3 years. The mean and standard deviation of the age was 33 and 10.48 years respectively. The mean and standard deviation of the average driving per month was found to be 250 km and 50 km. The mean and standard deviation for the duration for holding the driving license was 12.55 years with a standard deviation of 9.79 years. No participant had previous experience with Level 1 or level 2 automation.

Procedure

All the participants were initially informed about the basic outline of the experiment steps before they came on the day of the experiment. They were first asked to read and sign the consent form. Thereafter depending on the group that they belonged to, they were asked to read the presentation and the time duration was noted. Before entering the car, they were asked to fill in the Mental model as well as the Trust and acceptance questionnaire. Thereafter they were asked to enter the mockup vehicle, sit in the driving position with the seatbelt fastened and a trial of the braking behaviour of the mockup vehicle as well as instructions to play the SuRT game was given. Participants were instructed that they were free to look outside instead of playing the game and use the brake pedal from time to time if they felt the need for it. After that the experiment was started, the mental model questionnaire was filled after every scenario, the brake pedal data and SuRT task data was recorded. Trust and acceptance rating was taken again after scenario 4 before the end of the experiment session. The experiment was conducted over 3 days to keep the session of the simulator less than 30 mins since the research done by Brooks and Goodenough 2010 [10] showed that the sessions longer than 30 mins have resulted in motion sickness in the participant due to the presence of visual cues but an absence of motion cues. with the first session lasting for 90 minutes (20 mins in the simulator) and days 2 and 3 lasting for 25 minutes (20 min in the simulator).(Figure 3.7). This was due to the introduction, training and practice of the braking and SuRT task which took place on the first day of the participant's arrival.

Apparatus

The experiment was conducted at the Delft Advanced Vehicle simulator (DAVSi) located at the vehicle engineering lab. The display screen of the simulator covers 200° field of view. The simulator does not have any facility to make real-time use of the rear-view mirrors. The mockup vehicle placed in the simulator is a 2013 Toyota Yaris. The mockup vehicle consists of the driver and passenger seats along with the instrument cluster that can display the speed and the RPM of the engine. For simulating the automation screen of the ADAS an iPad was used. IPG movie was used to display the graphics of the scenario at 25 FPS. IPG carmaker was used to generate environment, traffic of the scenarios as well as ALKS controller of the vehicle. The brake controller of the vehicle was designed on Simulink which was linked to the IPG driver for the real-time braking of the car.

Ethics statement

All participants provided written informed consent before participation. The experimental protocol was approved by the ethical committee of the Human Research Ethics Committee

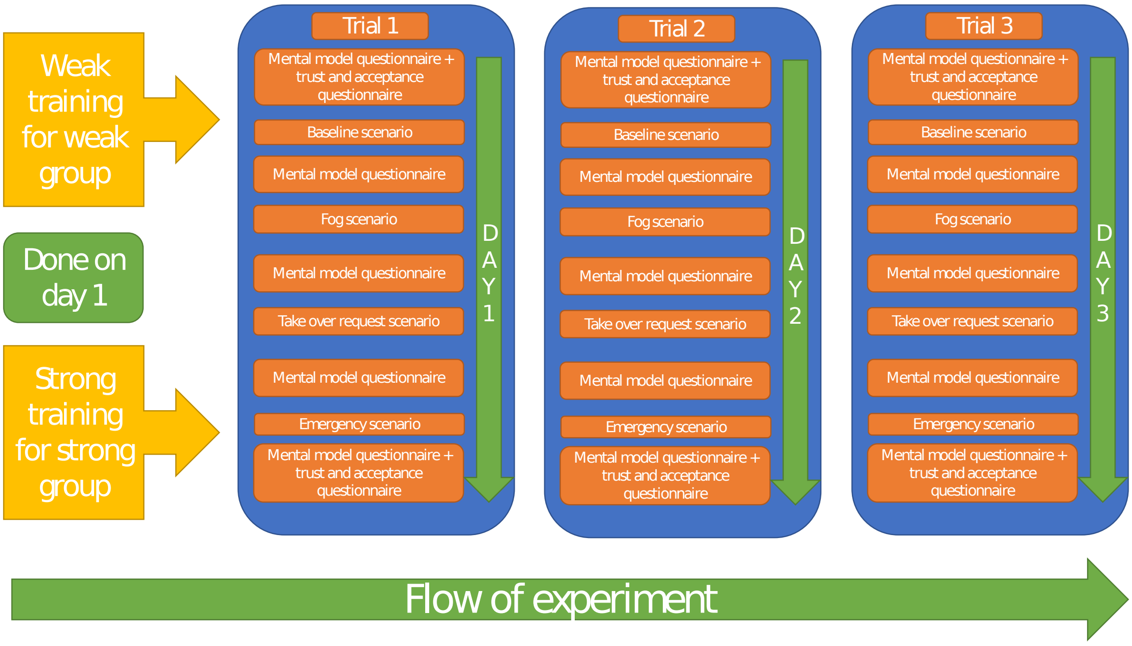


Figure 3.7: Flow sequence of the experiment

of TU Delft, The Netherlands, under application number 1582.

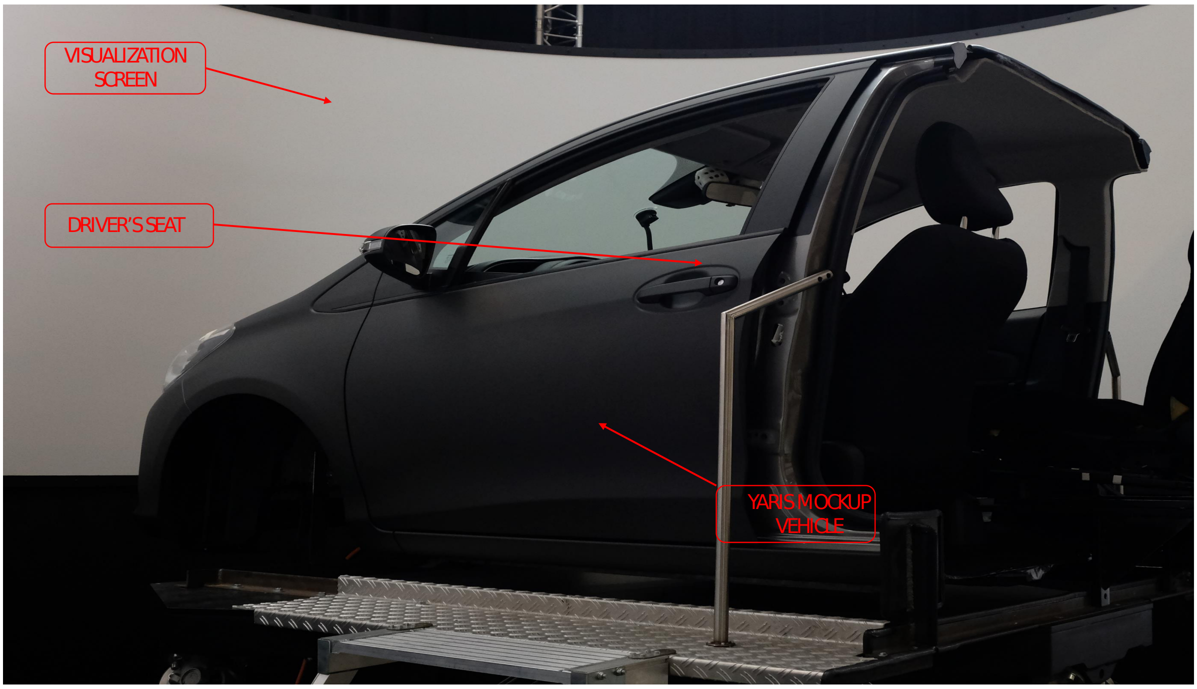


Figure 3.8: Driving Simulator

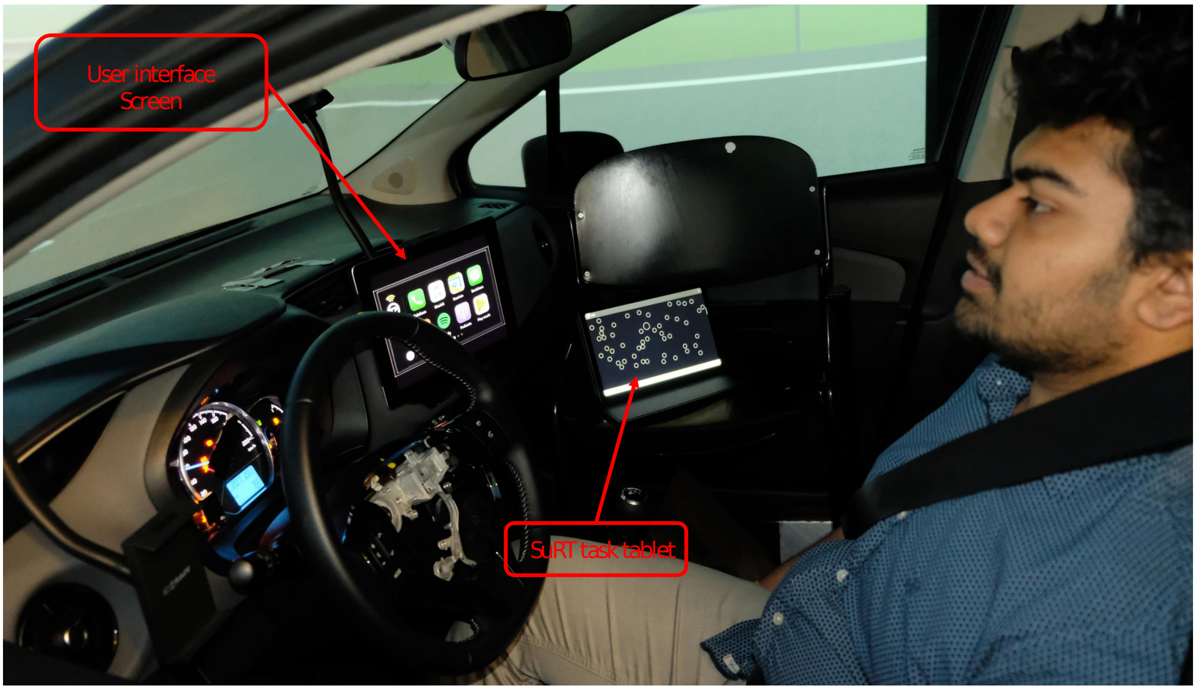


Figure 3.9: Setup of the experiment with participant

4

Results

This chapter reports on the final results obtained after experimenting. This chapter will discuss the results obtained on the mental model data, Brake application data, Surt task data, trust and acceptance data.

4.1. Mental model results analysis

The mental model performance is analysed differently for every scenario since the set of questions being affected by each scenario is different. For trial 1 the first measurement is taken after the training is given, then the reading is taken after each of the scenarios is experienced by the participant that is 4 times during the experiment. For trials 2 and 3 the first reading is taken before the start of the experiment and 4 readings are taken after each scenario is experienced by the participants.

Every scenario affects the different set of mental model question and they are mentioned below (Appendix 7.1.1):

- Scenario 1 effects question 1 2 3 4 8
- Scenario 2 effects question 1 2 3 4 6 8
- Scenario 3 effects question 1 2 3 4 8 9 10 11 12
- Scenario 4 effects question 1 2 3 4 7 8

The score of the question in each of the scenario is averaged out for the participants and normalized on the scale of 0 and 1(4.1). The table 4.2 shows the coefficients and the errors of each of the fitted power learning curve in the figure(4.1). The learning power curve are fitted based on the power law of learning [7]. The fitted curve is in the form of $P(N|a,b,c) = a + b * N^{-c}$ and the coefficients are mentioned in the table 4.2

One tailed t-test has been performed on the mental model score data. For any given scenario the data for the strong group and the weak group has been combined separately. The power curve was fitted on the mental model score points with 95% confidence. For scenario 1 (p = 0.01),scenario 2 (p = 0.01) and scenario 4 (p = 0.01) the strong mental model performs better than the weak model. For scenario 3 the mental model shows a difference in the performance between the two groups but the difference is not statistically significant.

(p = 0.29). Combining the data for all the scenarios and comparing the mental model score between the weak and the strong group results in a statistically significant difference(p = 0.02).

Since multiple statistical tests have been applied on the same set of data, the Bonferroni test has been conducted to include the family-wise type 1 error rate. Applying the Bonferroni test with the reduced alpha of 0.0125. With this test Scenario 1, 2 and 4 passes the statistical test of being different from one another with the stronger group scoring more but scenario 3 is not able to pass. A significantly more number of participants are needed to statistically signify the difference in the strong and the weak mental model for scenario 3.

A within-group comparison was done to study the effect of the repetition of the trials. For the given scenario the data for the after training trail for both the weak and the strong group is combined. Similarly, the data for the third trial of both the strong and the weak groups are combined. Scenario 1(p = 0.08), scenario 2(p = 0.07) and scenario 4(p = 0.09) performed close to the required p-value of 0.05 as compared to the scenario 3(p = 0.33) which was not able to give statistically significant differences in the performance in between the trials.

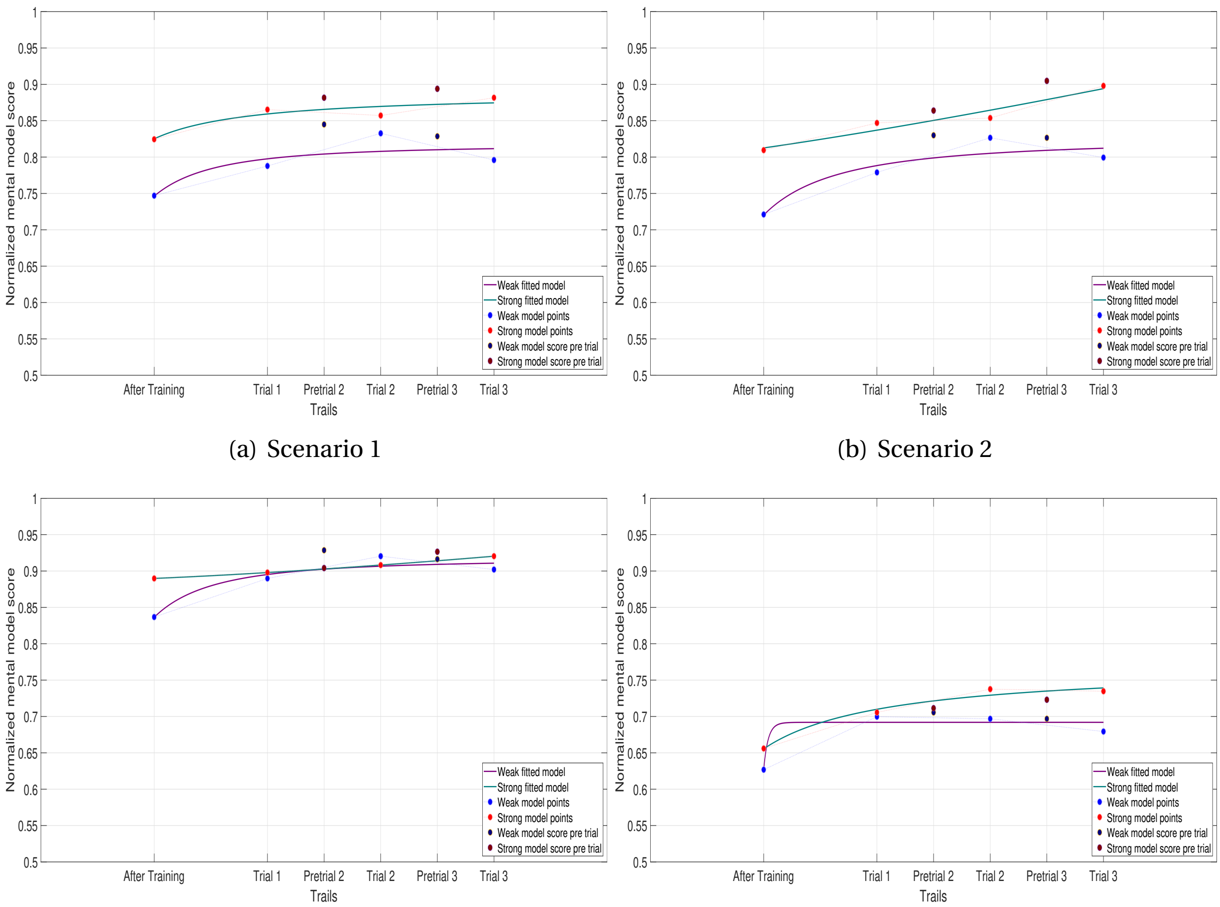
Combining the overall data from all the scenarios and comparing the mental model score just after the training (weak model + strong model) to the mental model score just after the trails 3 (weak model + strong model) gives a normalized score difference of 0.06 with a statistical significance(p = 0.04).

	After training			Trial 1			Trial 2			Trial 3		
	Weak	Strong	Diff	Weak	Strong	Diff	Weak	Strong	Diff	Weak	Strong	Diff
Scenario 1	0.746	0.824	0.078	0.787	0.865	0.080	0.832	0.857	0.025	0.795	0.881	0.086
Scenario 2	0.721	0.809	0.088	0.778	0.870	0.092	0.829	0.894	0.065	0.806	0.891	0.085
Scenario 3	0.836	0.889	0.053	0.879	0.893	0.014	0.916	0.904	0.012	0.883	0.918	0.035
Scenario 4	0.626	0.656	0.003	0.699	0.705	0.006	0.696	0.737	0.041	0.679	0.734	0.055
Mean	0.732	0.794	0.055	0.785	0.833	0.048	0.818	0.848	0.035	0.785	0.856	0.065

Table 4.1: Normalized score of the mental model

	Model	Power terms	R2 error	RMSE error
Scenario 1	Weak	$0.81 - 0.07 * x^{-1.87}$	0.741	0.031
	Strong	$0.88 - 0.06 * x^{-1.16}$	0.859	0.015
Scenario 2	Weak	$0.82 - 0.10 * x^{-1.51}$	0.881	0.026
	Strong	$0.79 - 0.01 * x^{-1.22}$	0.939	0.015
Scenario 3	Weak	$0.91 - 0.08 * x^{-1.91}$	0.92	0.017
	Strong	$0.88 - 0.004 * x^{-1.47}$	0.999	0.001
Scenario 4	Weak	$0.69 - 0.06 * x^{-25.89}$	0.928	0.015
	Strong	$0.77 - 0.11 * x^{-0.89}$	0.974	0.0105

Table 4.2: Mental model fits & goodness of fits



(a) Scenario 1

(b) Scenario 2

(c) Scenario 3

(d) Scenario 4

Figure 4.1: Mental model score

4.2. Brake application analysis

Brake pedal measurement is the quantitative measurement of the mental model of the driver. The data of the brake pedal travel is captured from the potentiometer sensor mounted with the brake pedal of the mockup vehicle. The data is captured through the dSpace controller board and recorded in the IPG Simulation output along with the time stamp and virtual deceleration of the car. The application of the brake pedal has been divided into 2 categories:

1. **Critical:** The application of the brake pedal is critical to ensure that the mental model of the human can understand the limitations of automation. Although the car can stop itself even if the driver does not respond to the request of the automation to take over the control of the vehicle, the driver is expected to do his part in ensuring the safety of the vehicle. In the experiment, the only way to ensure the safety of the vehicle is by using the brakes to stop the vehicle. The transfer of control scenario is only considered as the critical event for the brake pedal application in this experiment.

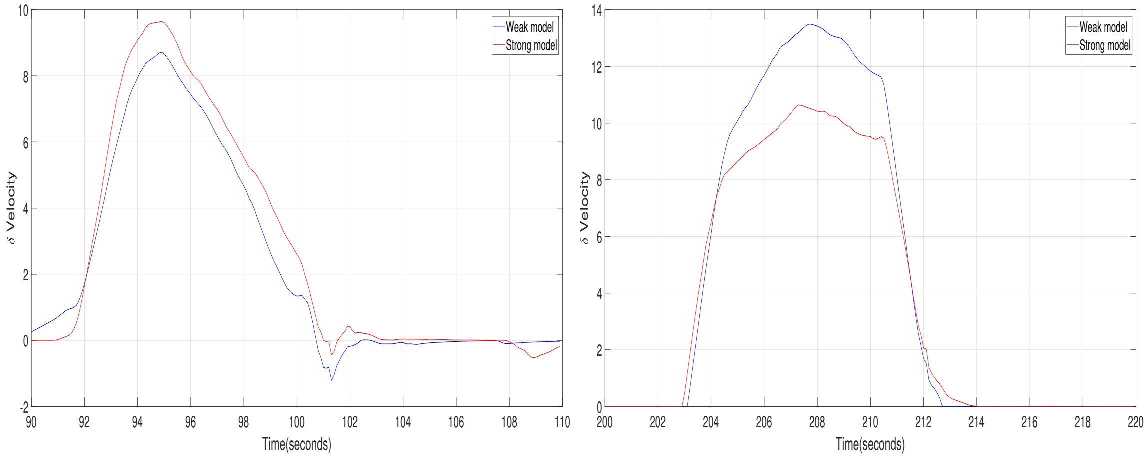
2. **Non critical:** The application of the brake pedal for all the other conditions can be classified as a non-critical condition for braking. The driver has been instructed to use the brake pedal at will if he feels that the car might run into a collision. All the braking manoeuvres performed by the participant in the scenario 1, 2 and 4 can be classified as not critical braking reactions.

Studying the brake application for scenario 3 that is **take over request scenario**, where the application of the braking manoeuvre is critical, the figure 4.2 shows the $\Delta Velocity$ of the ego vehicle which is the mathematical difference between the longitudinal speed of the vehicle when the brake pedal is not used and the longitudinal speed of the vehicle when the brake pedal is used by the participants. Positive $\Delta Velocity$ equates to the application of the brake pedal by the user, the higher the Δ the lower is the speed of the ego vehicle and the higher is the brake pedal force application. On the contrary negative $\Delta Velocity$ equates to the ego vehicle driving at a slower speed when automation is in action as compared to when the driver is taking back the control of the vehicle, hence the brake pedal application by the automation is more than that by the user.

The duration for the take over request is 10 seconds and the minimum risk manoeuvre is performed for another 10 seconds, so the $\Delta Velocity$ is analysed for 20 seconds from the first initiation of taking over request. The first take over request takes starts 167 m(10 seconds @ 60 $\mathrm{km\,h^{-1}}$) before the entry to the sharp bend, second take over request starts 167 m(10 seconds @ 60 $\mathrm{km\,h^{-1}}$) before the start of the construction zone. In both, the case of taking over request the **Transfer of control request** lasts for 10 seconds after which the automation enters minimum risk manoeuvre mode irrespective of the braking done by the participant.

To calculate the statistical significance of the of $\Delta Velocity$ of the 2 groups, a logistic regression was carried on the dataset, combining the data of the 2 take over request and comparing the weak and the strong group, it gave a p value of 0.032.

For the first take over (Figure 4.2(a)) request the $\Delta Velocity$ value is lower for both the groups as compared to the $\Delta Velocity$ of the second take over request (Figure 4.2(b)). Kieras and David 1985 [18] shows that the speed and the accuracy by which the operator



(a) Take over request 1

(b) Take over request 2

Figure 4.2: Delta velocity vs Time

uses the control is directly correlated with the strength of its mental model. Thus the first take over request clearly shows that the strong mental model group has a better understanding of the automation system. Although the same cannot be said for the second take over request condition in which the weak model group reacts more quickly and with higher intensity than the strong mental model group. One possible reason might be that the strong mental model group is well aware of the time allowed for the take over request (10 seconds) which is enough to stop the car even with a light brake pressure from 60 $\mathrm{km\,h^{-1}}$ in case of second take over request.

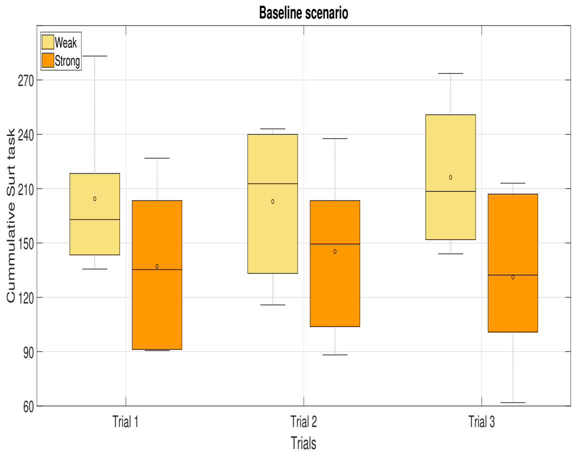
4.3. Surt Task analysis

The SuRT is played using the DLR app as described in section 3.1.5. The frequency of the SuRT task is measured by calculating the rate of the SuRT task done per second. The input was acknowledged even if the participant touched the screen on the wrong side, but the participants were encouraged to score as many correct answers as possible.

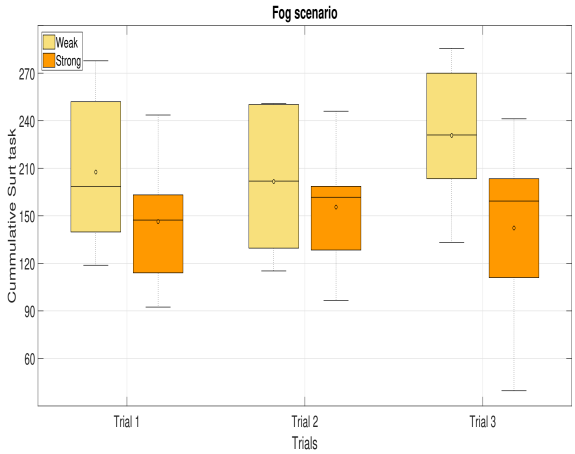
For testing the statistical significance of the Surt data a t-test was performed for the weak and the strong group. On average 217 (SD 109 range 618) SuRT task was performed for the weak group, and 167 (range 437 and SD 86) was performed by the strong group with the significance p-value of 0.01 and t value of 3.91. This gives an average frequency of SuRT task performance as 0.964Hz for the weak group and 0.733Hz for the strong group. The participants were also tested for the ideal SuRT task rate which was found out as 1.43Hz and is high than the task frequency during the experiment indicating that there is a drop in the task frequency and hence increase in the situational awareness [27]. In figure 4.3 the y axis shows the number of Surt task performed by the weak and strong group with the x axis as the trial number.

- For the weak mental model group, the frequency of the SuRT task grows from trial 1 to trial 3. The rate of growth from trial 1 to trial 2 is less as compared to the rate of growth from trial 2 to trial 3. Although in scenario 4 there is a dip in the SuRT frequency in trial 2 in trial 3 the SuRT frequency is higher as compared to trial 1. The dip in the SuRT frequency can be attributed to the learning effect of the driver where initially after the emergency manoeuvre of the 1st trial they were cautious in the 2nd trial but after learning the performance of the automation in the emergency manoeuvre they just let the automation perform and continued playing the Surt task.
- For the strong mental model, all of the scenarios show an increase in the Surt task frequency from trial 1 to trial 2 but a decrease in the SuRT task frequency from trial 2 to trial 3.

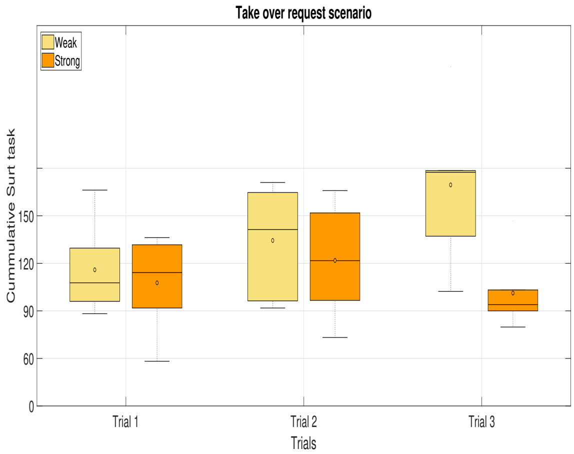
Figure 4.4 shows the plot of the of SuRT tasks done vs time gives us the idea of the increase/decrease in the rate of the SuRT task with the trials at each point in the lap. Fig 4.4(c) has a drop in the surt task as the scenario was split into 2 parts to accommodate for 2 take over requests, as due to the limitation of the passive simulation they could not be done in on go. In all the scenarios the rate of the Surt task is higher for the weak group as compared to the strong group. In Scenario 3 the take over request scenario, for the 1st takeover request there is a drop in the rate of Surt tasks to zero tasks per second, the same is not true for the second take over request although there is a slight decrease in the slope of the SuRT task(this decrease in not statistically significant). For the weak model 14 more tasks are done during the take over request period and for the strong model 22 more tasks are done during the take over request period. One possible reason for the participants to continue doing the tasks during the second take over request is the involvement of feet to respond to take over of control request and not the hands. (Since participants were instructed to maximize the task performance to the best of their ability they chose to continue doing the task even during the take over request, they are still using the brake pedal to stop the car as can be seen in figure 4.2(b).)



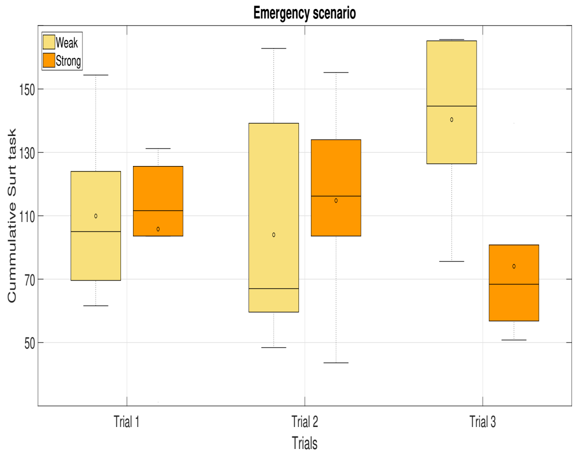
(a) Scenario 1



(b) Scenario 2

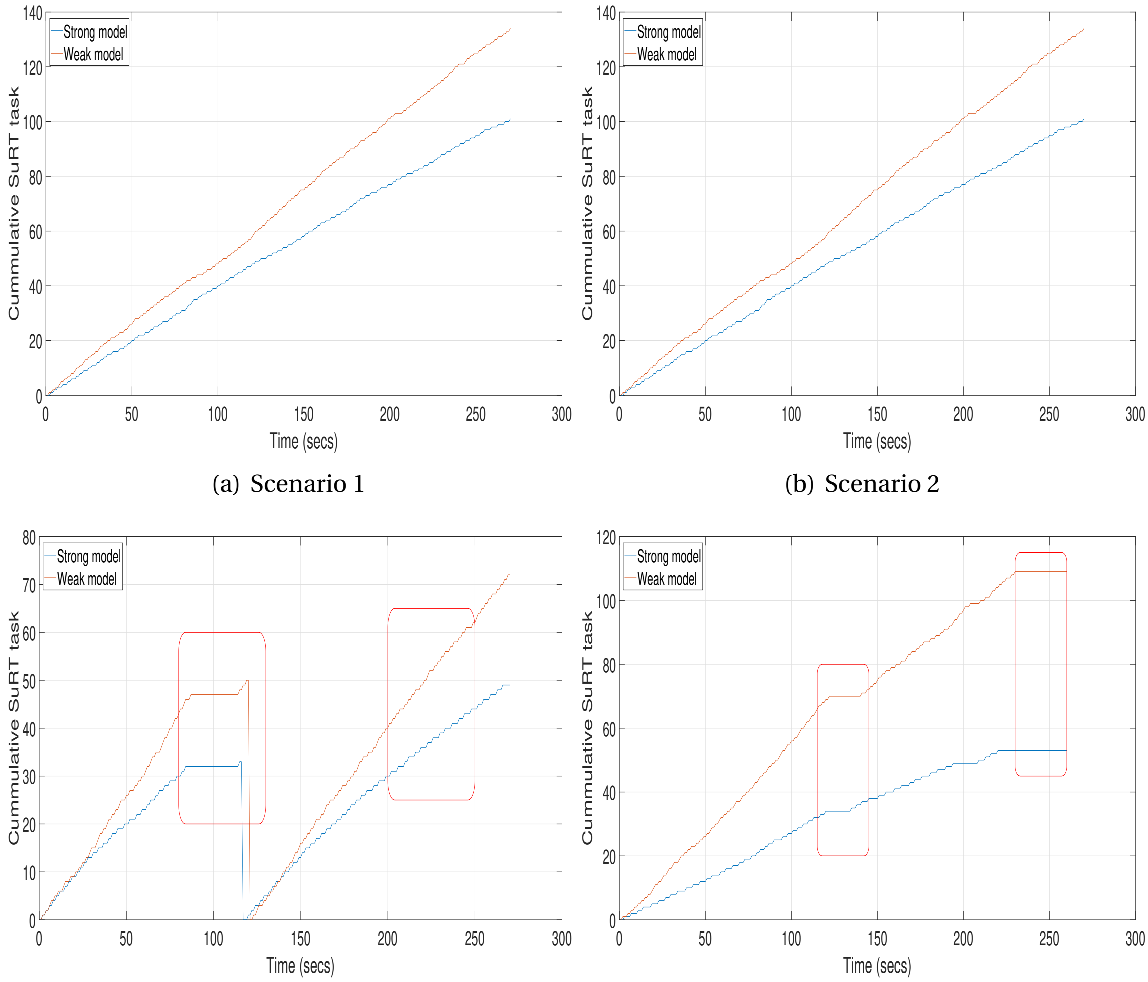


(c) Scenario 3



(d) Scenario 4

Figure 4.3: Total number of SuRT task



(a) Scenario 1

(b) Scenario 2

(c) Scenario 3

(d) Scenario 4

Figure 4.4: Number of Surt task in lap

4.4. Trust and acceptance

To asses the trust and the acceptance level the of the participants during the experiments the reading for the trust and the acceptance was taken using the questionnaire. On day 1 for trial 1 the reading was taken after giving the training and after the experiment was over. For day 2 and 3 the reading was taken once before the start of the experiment and once after the experiment was over. The power learning curve is fitted for both the weak and the strong model and the coefficients of the power curve is listed in the table(4.3).

In the figure (4.5(b)) if we compare the 2 models in terms of trust the weak model has the high rate of initial trust buildup (c = 5.06) as compared to the trust build up of the strong model (c = 0.22), but the asymptotic stability of the trust curve for the strong model takes place at (a = 0.99) as compared to the weak model (a = 0.70). The within subject evaluation of the trust after training and after trial 3 does not show any statistical significance.

In the figure (4.5(d)) if we compare the acceptance curve we can see the rate of increase of the acceptance for the strong model (c = 1.19) is higher as compared to weak model (c= 0.84). Also the stability of curve for the strong model takes place at (a = 0.53) as compared to the weak model (a = 0.51). The within subject evaluation of the acceptance score after training and after trial 3 does not show any statistical significance and almost remains the same through all the trials.

	Models	Power terms	R2 error	RMSE error
Acceptance	Weak	$0.51-0.01*x^{-0.84}$	0.995	0.022
	Strong	$0.53-0.002*x^{-1.19}$	0.999	0.003
Trust	Weak	$0.70-0.001*x^{-5.06}$	0.993	0.035
	Strong	$0.99-0.035*x^{-0.22}$	0.999	0.0103

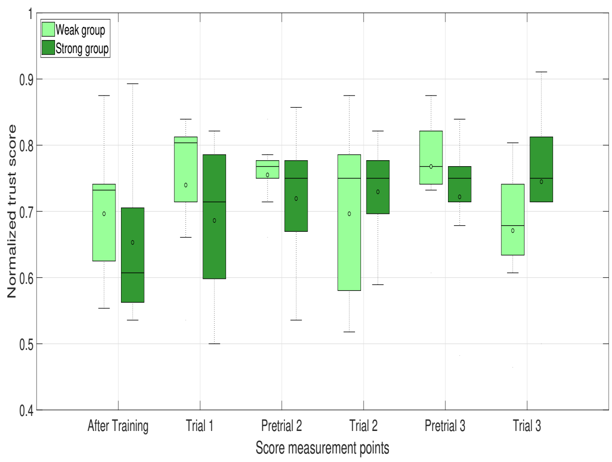
Table 4.3: Power coefficients of trust and acceptance curve

Trust Scores	**Mean - Strong**	**Standard deviation-Strong**	**Mean- Weak**	**Standard deviation-Weak**
After initial training	0.64	0.12	0.69	0.10
After trial 1	0.68	0.12	0.73	0.11
After trial 2	0.72	0.08	0.69	0.13
After trial 3	0.74	0.13	0.67	0.11

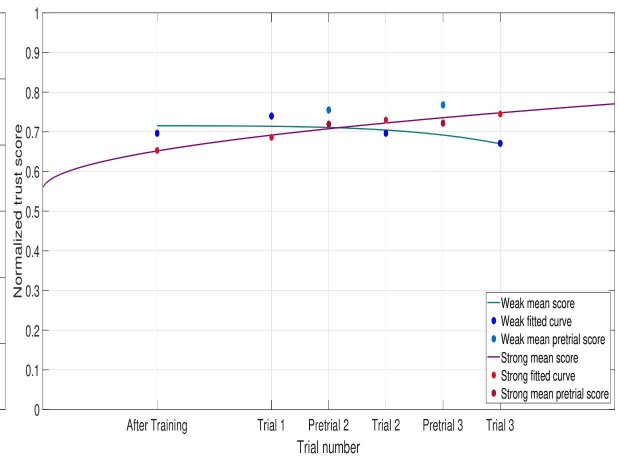
Table 4.4: Mean normalized trust score

Acceptance Scores	Mean - Strong	Standard deviation-Strong	Mean- Weak	Standard deviation-Weak
After initial training	0.53	0.34	0.51	0.18
After trial 1	0.53	0.41	0.48	0.27
After trial 2	0.53	0.29	0.53	0.45
After trial 3	0.53	0.43	0.51	0.29

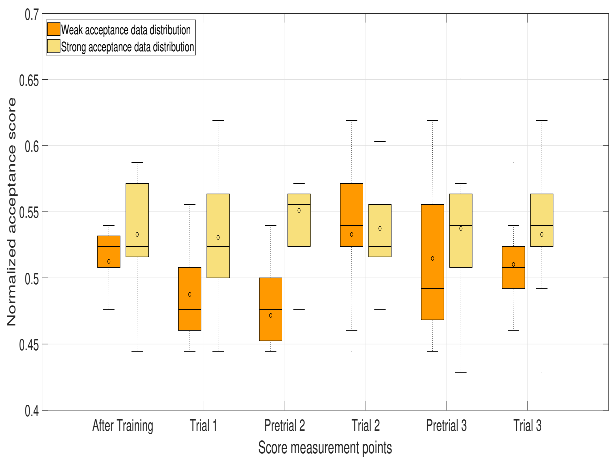
Table 4.5: Mean normalized acceptance score



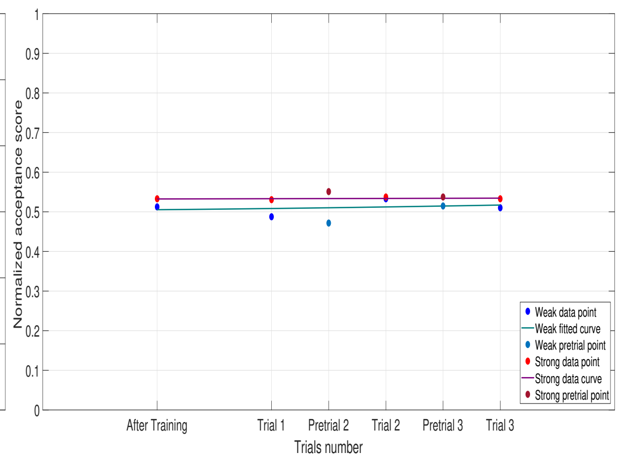
(a) Trust score distribution



(b) Trust learning curve



(c) Acceptance score distribution



(d) Acceptance learning curve

Figure 4.5: Trust and acceptance score and learning curve

4.5. Open ended question

At the end of the experiment on 3^{rd} day 3 open ended questions were asked to the participant to test some perspective of the participants for understanding some general perspective of the participants after they had experienced the level 3 driving automation. The question and responses are stated in the table 4.6. A question was asked on stating the advantage and the disadvantage of the system.

For the 1^{st} question's 1^{st} part the of the use of the automation on the urban (city center kind of scenario) for which only one participant voted in favor from the strong group and none from the weak group. for the 2^{nd} part of the question the for the use of the automation on the semi-urban road 2 of the strong group and 3 of the weak group voted in favor. For the 3^{rd} part of the question of the use of the automation on the highway 6 of the strong group and 4 of the weak group voted in favour.

The 2^{nd} question was regarding the willingness to pay the 5000 euros for ALKS level 3 automation which the participants experienced on the highway. For both the mental model group equal percentage of people voted in favor of paying the extra money for the automation system to be fitted to the car.

Questions		**Strong model**	**Weak model**
Are you willing to use the system on	Urban roads	1/7	0/7
	Semi urban roads	2/7	3/7
	Highways	6/7	4/7
Are you willing to pay 5000 euros extra over the cost of the vehicle to have this system?		4/7	4/7

Table 4.6: Open question answers

5

Discussion

5.1. Effect of initial training on the performance of the mental model

Referring to the results of the section 4.1, for scenario 1,2 and 4 just after the training there is a statistically significant difference in the mental model performance in between the weak and the strong group with strong group performing better than the weak group . The similar trend can still be seen in the mental model results for scenario 3 but the due to low number of participants and small difference in the performance the difference is not statistically significant.

Considering the first research hypothesis discussed in chapter 2 regarding the difference in the formation mental model score due to the difference in the initial training of the user, the alternate hypothesis has been proved. Hence the initial training definitely resulted in the difference in the mental model score of the two group of participants. Table 5.1 shows the average difference in the mental model score over the trials in different scenario, showing that the scenarios that does not contain take over request or emergency maneuver resulted in a less difference than that with the baseline condition or fog condition. As studied by Karla and Paddock 2016 [17] automation on a individual level needs to be driven million of kilometers to experience one edge case scenario. The edge case scenario though is experienced by the participants in experiment but in real life these conditions might take million of kilometers to be experienced. The average difference in the mental model is though less for edge case scenarios, this does not make the initial training as obsolete as during the normal automation working condition the mental model is significantly affected by the initial training.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Average difference	0.06	0.08	0.02	0.024

Table 5.1: Average normalized difference in the mental model score over the trials

Referring to the graphs in the figure 4.1 the absolute score of the mental model is in the order Scenario 3 > Scenario 2 > Scenario 1 > Scenario 4. The take over request scenario has resulted in the best mental model score over the other scenarios, but this scenario cannot be frequent when the automation system is used in the real world, hence the training is definitely needed to get to the high mental model score. Another possible reason for the low difference in the score in scenario 3 can be the similarity of the content of training regarding the take over request. (Appendix 7.4 & Appendix 7.6)

The effect of training is also evident in the use of the control after the take over request is given by the automation. In the section 4.2 the strong group shows more intense and quick reaction to the take over request by slowing down the vehicle more quickly. Though no correlation can be made for the reaction of take over request and increase in the mental model score due to absence of enough data. Also it would be better to include the other controls such as the gas and the steering control in the experiment to allow the user to choose the most appropriate one when the take over request is given as choosing to stop the car in the middle of the highway can lead to chaos and accidents.

5.2. Effect of repetitions of experiment on the performance of the mental model

Referring to the result of the section 4.1, a within-subject analysis is done between the score just after the training to the score just after trial 3. Table 5.2 gives the average difference in between the score after trial 0 and trial 3 for all the scenarios.

Statistical test done on the within subject analysis showed that the results for the scenario 1,2 and 4 are significant but are not significant for scenario 3. Considering the significant results there is increase in the score of the mental model. Scenario 1 shows no edge case scenarios for the automation, scenario 2 offers a close to edge case scenario for the automation where the automation could have stopped working due to bad weather conditions and scenario 4 offers the non edge case scenario where the automation shows how it can handle the emergency situations in which if given the option to the user to control the car can cause accidents due to delay in the reaction time or wrong decision of chosen maneuver.

	Scenario1	Scenario 2	Scenario 3	Scenario 4
Average difference	0.053	0.083	0.003	0.135

Table 5.2: Average normalized mental model score difference between Trial 0 & Trial 3

From the above results it can be seen that all the scenarios show an improvement in the mental model score after 3 trials of the experiment. Statistically significant difference is shown by scenario 1,2 and 4 in which the mental model score after the 3^{rd} trial is more than the mental model score after training. Referring to table 5.2 it can be observed that more the automation handles the difficult and critical driving situations more is the change in the mental model over the time period, but no definitive conclusion can be made regarding this from this experiment since the number of iterations are low so is the case with the number of participants for the experiment.

5.3. Effect of training on the situational awareness of the driver

Section 4.3 shows that there is a sudden increase of the situational awareness in scenario 3 when the take over request was given and in scenario 4 when the emergency manoeuvre was performed in both the groups but there is no significant difference in the increase of the situational awareness during these critical manoeuvres in between the weak and the strong models, so no conclusion can be deduced for the difference in the situational awareness in between the weak and the strong model during the critical manoeuvres.

However, section 4.3 also discusses the statistical difference in the situational awareness of the 2 different groups of users considering all the scenarios and trials, showing that the overall performance of the strong group was better than the overall performance of the weak group for the situational awareness. This relates to the theory that better training which is the static part of awareness has resulted in better situational awareness which is the transient part of the awareness.[34]

5.4. Effect of training on trust and acceptance of the driver

For trust the difference in between the trust level for the two groups is not statically significant but there is a trend in the trust level that can be observed. The starting trust level in the strong group is less compared to the weak group just after the training. But after the end of trial 3 strong group has higher trust level as compared to the weak group. As described in the **literature** humans tend to trust the automation more than fellow humans, if not having the information on the limitations of the automation. If they are well aware of the limitations they will tend to show less trust in automation.

In our research the weak group was not adequately aware about the limitations of the automation thus showed a higher score for the level of trust just after the training. But as they started to experience the limitations of the automation in the driving simulator the trust level dropped. The opposite trend can be seen in the trust level of the strong mental model group, since the strong group is well aware about the limitations of the automation system they have less trust on the system, after experiencing the system in the driving simulator they are well aware that the limitations that they see are the actual limitations and there is no surprise event.

For the acceptance there is a statistical difference of 0.02 in between the weak and the strong mental model group. The trend of the acceptance graph (Figure 4.5(d)) shows that the acceptance level is almost constant for both the group of participants, but the acceptance level is higher in the strong group that the weak group. The acceptance plays an important role in the mental model development of the user of the automation since it determines the frequency and the duration of the use of the automation by the user in the free open world[]. The research shows that the mental model evolution exist and is dependent on the repetitive use of the automation system by the user[20].

5.5. Limitation and scope for future

The experiment is performed using 15 participants out of which 1 participant was not considered for the experiment due to corrupt data and the rest were divided into 2 teams, this resulted in a low statistical power of the results and in depth analysis of the scenario wise results could not be performed. However for adding more statistical power to data will require more number of participants which will be more time consuming for the researcher. Given more budget and time experiment can be performed by recruiting more number of qualified participants from all over Netherlands.

The number of iterations performed per participants could be increases to find the asymptode the learning curves of the mental model as well as the trust and acceptance models.

The number of scenario encountered in the experiment could be increased to accommodate for all the edge case scenarios that are possible while using the level 3 ALKS system in the real world conditions, the mental model depth can also be expanded to cover the complete ALKS level 3 system, later this can also be expanded to cover the complete SAE L3 system. The simulation performed in this thesis lacked the presence of all of the take over control namely the gas and the steering controls which could be added in the future simulations to create a realistic take over request scenario.

A better method to study the situational awareness can be incorporated in the experiment like the use of eye-tracker, SAGAT/SART questionnaire or think aloud protocol etc. These methods can not only capture the quantitative aspect of situational awareness but also qualitative aspects to do in depth analysis of the situational awareness. Trust measurement can also be done using better method like measurement of skin conductance or gaze behaviour using the eye tracking system.

The complete technology acceptance model can be used to do the in-depth analysis of the acceptance of the user in the automation as the continuous use of the automation is the definite requirement for the evolution of the mental model of the user to reach the ideal mental model.[21]

6 Conclusion

This study gives an starting point for the continuation of the study on the mental model of the user of the level 3 automation system and levels above it. This study is strictly based on the ALKS (Automated lane keep assist system) level 3 automation system which has limited features of the general level 3 automated system. This system has very few edge case scenarios but expanding the automation system to the capability of the full level 3 automation system large number of edge case scenarios for which the reaction of the human driver to it will become very important.

This study investigates the effect of training and learning on the mental model of 15 participants. A significant increase in the mental model score was observed when the participants were given detail and elaborate training vs a small and brief training about the ALKS(Automated lane keep assist system) level 3 vehicle automation system. A mean normalized score difference of 0.055 was obtained during the experiment.

The study also investigates the changes in the three major factors that can affect the formation and evolution of the mental model namely the trust, acceptance and situational awareness due to the difference in the training given to the participants. Situational awareness when measured in the terms of number of tasks done resulted in a significant on average a difference of 200 task over all the scenarios. Normalized acceptance score measured all over the scenarios showed a significant difference of 0.03 points. The trust score shows a difference of 0.02 points but the difference is statistically weak.

Considering the learning effect, the study shows that there is a significant change of 0.072 (normalized mental model score averaged over all the trials and scenarios) in the mental model score over the period from initial training to 3 trials in both the group of participants.

This study provides the evidence of how the training effects the initial formation of the mental model of the driver and how it links to the safe interaction of the user of the automation with the automation system itself.

Because RDW is interested in the type certification of cars equipped with the ALKS system, several recommendations have been made for them as well. RDW should as the OEM

- to describe the possible training approach and the evidence of its effectiveness to achieve an adequate initial mental model and learning rate.
- to identify the number of iterations of driving scenarios for the stabilization of mental model and provide evidence on the safe interaction when this level is achieved.

- to provide the evidence based on simulations and real world test to avoid possible bias from the simulation.

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7

Appendix

7.1. Questionnaires

7.1.1. Mental model questions - Answers according to likert scale

1. Automation reacts to the vehicles driving in front in the same lane.(Ans 7)

2. Automation needs a vehicle in the front to work.(Ans 1)

3. Automation will perform the lane change if your driving lane is closed and the adjacent lane is free.(Ans 7)

4. Automation when engaged allows the driver to play games and watch movies.(Ans 1)

5. Automation will stop the car in the middle of the road if your driving lane is closed without asking the you to take the control of the car.(Ans 7)

6. Automation will not work in the sharp bend if the visibility has be reduced due to fog condition. (Visibility in between 50 m and 200 m).(Ans 1)

7. Automation will take care of dangerous cut-inn situations.(Ans 7)

8. Automation will allow the other vehicles in the adjacent lane to merge in your lane if their lane is closed and your lane is free. (Ans 1)

9. How much time is there to take the control of the car if the following screen is displayed.(Ref figure(7.1))(Ans 9-12)

10. How much time is there to take the control of the car if the following screen is displayed.(Ref figure(7.2))(Ans no time 0 seconds)

11. When the automation asks you to take the control of the car what are you supposed to do?(Use the brake pedal)

12. If you do not take the control of the car when the automation asks you, what will the automation do?(Stop with heavy braking)

Figure 7.1: Transfer of control request

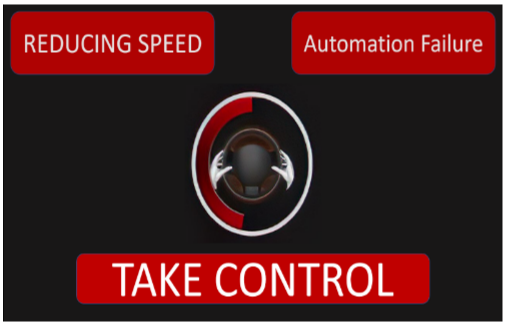


Figure 7.2: Minimum risk maneuver notification screen

7.1.2. Trust Questions

These question were answered on a 7-point likert scale.

1. I trust the system.
2. The system is predictable.
3. I will use the system with caution.
4. I am familiar with the system.
5. The system provides security.
6. The system is dependable and reliable.
7. The system is robust.
8. The outcomes of the system will have unsafe outcomes on the road.

7.1.3. Acceptance Questions

These questions were answered on the 7 point likert scale. How will you rate the system between:

1. Useful/useless
2. Pleasant/unpleasant
3. Bad/good

4. Nice/annoying
5. Effective/Superfluous
6. Irritating/likeable
7. Assisting/worthless
8. Undesirable/desirable
9. raising alertness/ sleep inducing.

7.1.4. Score matrix for the single choice correct MCQ in MM questionnaire

Questions	Option 1	Option 2	Option 3	Option 4
How much time is there to take the control of the car after the automation request for the transfer of control?	Immediately	1-4	5-8	9-12
Score	1	3	5	7
How much time is there to take the control of the car after the automation starts to perform the minimum risk manuver?	Immediately	1-4	5-8	9-12
Score	7	5	3	1
During the transfer of contol request what are the divers supposed to do?	Take the steering as well as the brake control	Take only the steering control	Take only the brake control	Do nothing
Score	7	3	5	1
If the driver does not take the transfer of control what will automation do	Car will keep on moving	Car will change lane	Car will slow down with light braking	Car will slow down with heavy braking
Score	3	1	5	7

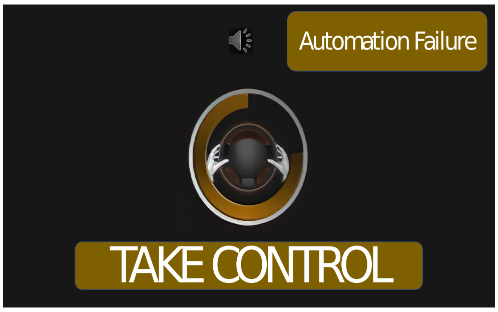
Table 7.1: Score matrix for Single correct MCQ's for Pilot test

Questions	Option 1	Option 2	Option 3	Option 4
How much time is there to take the contro of the car after the automation request for the transfer of control	No time (Immediately)	12-16	5-8	9-12
Score	3	1	5	7
How much time is there to take the contro of teh car after the automation starts to perform the minimum risk manuver	No time (immediately)	1-4	5-8	9-12
Score	7	5	3	1
During the transfer of control request what are the drivers suppposed to do	Steer	Brake	Steer and brake	Steer and accelerate
Score	3	5	7	1
If the driver does not take the trasfer of control what will the auotmation do	Car will keep on moving	Car will change the lane	Car will slow down with light braking	Car will slow down with heavy braking
Score	3	1	5	7

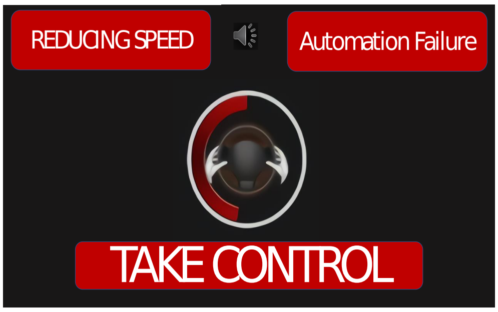
Table 7.2: Score matrix for Single correct MCQ's for the final questionnaire

7.2. User interface screens

(a) Music screen



(b) Transfer of control screen



(c) Minimm risk manuver screen

(d) Resuming automation screen

Figure 7.3: User interface screens

7.3. Training Slides

7.3.1. Weak training in English

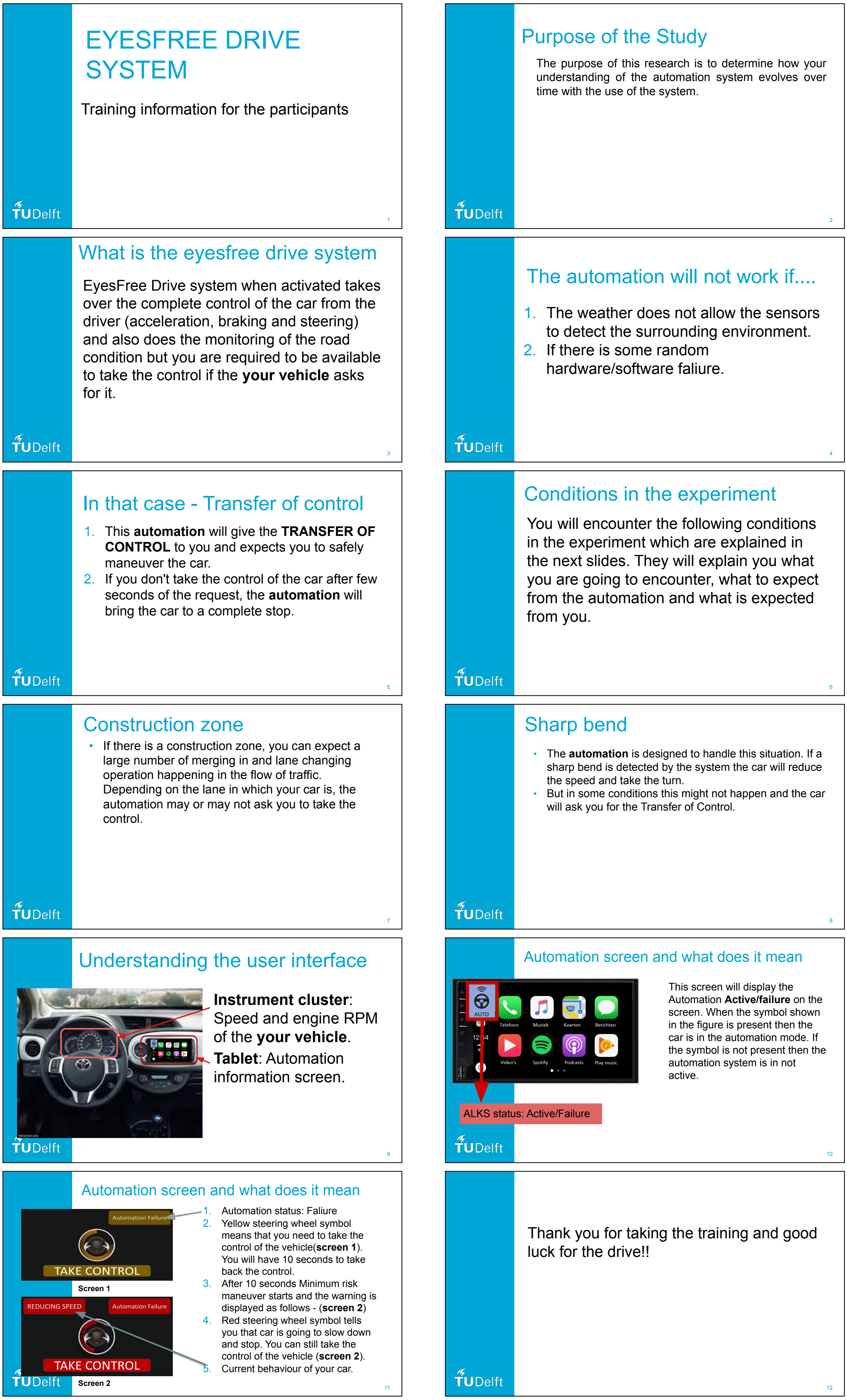


Figure 7.4: Weak training English slides

7.3.2. Weak training in Dutch

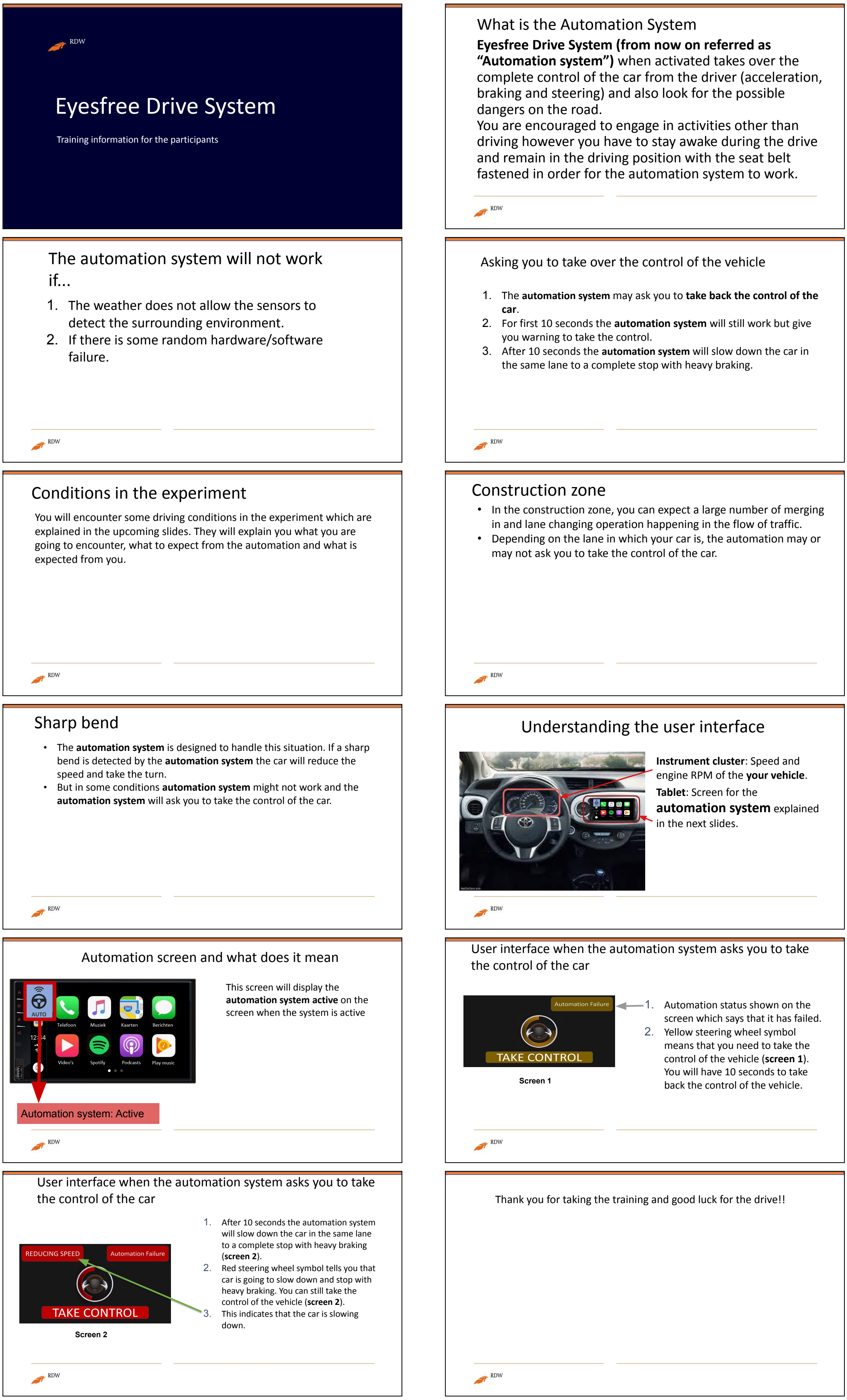


Figure 7.5: Weak Dutch training slides

7.3.3. Strong training in English

EYESFREE DRIVE SYSTEM

Training information for the participants

TUDelft 1

What is the EYESFREE DRIVE SYSTEM

Eyesfree Drive System (from now on referred as “Automation system”) when activated takes over the complete control of the car from the driver (acceleration, braking and steering) and also looks for the possible dangers on the road.
You are encouraged to engage in activities other than driving however you have to stay awake during the drive and remain in the driving position with the seat belt fastened in order for the system to work.

TUDelft 2

Working of the system explained

For this experiment the **automation system** is designed to work by detecting the lane markings **and** the car ahead of you. If there is no car ahead of you then **automation system** will drive the car at the maximum speed of 60 km/h within the lane.

You will have to keep in mind when and why the system will not work for the experiment.

TUDelft 3

Straight road

- The **automation system** detects the front vehicle using the radar sensors.
- It keeps a safe distance of 2 secs from the front car.
- If **no car** is detected ahead the **automation system** will drive on its own at maximum speed of 60km/h.

TUDelft 4

Straight road

Play me

TUDelft 5

Curved road

1. The **automation system** uses the camera mounted in the front and the radars mounted on the sides to recognize the lane marking and make sure that the car never crosses the lane marking.
2. The **automation system** will adjust the speed to the curve for safe cornering.
3. The **automation system** will never make a lane change.

TUDelft 6

Curved Road

Play me

TUDelft 7

Emergency maneuver

- The **automation system** might suddenly apply the brake if it detects some very critical collision risk but it will never steer out of its lane.
- You don't have to worry, this situation is handled on its own. After the risk disappears the car will resume its journey.

TUDelft 8

Emergency maneuver

Play me

TUDelft 9

Transfer of control maneuver

The Automations system will not work in the below conditions and it may ask you to **take over the control** of the car.

- The **weather condition** turns bad. (Heavy fog on the road).
- The next slides will help you to identify the bad weather conditions.

OR

- **Hardware/software** of the automation system is not performing up to the mark.

TUDelft 10

Play me

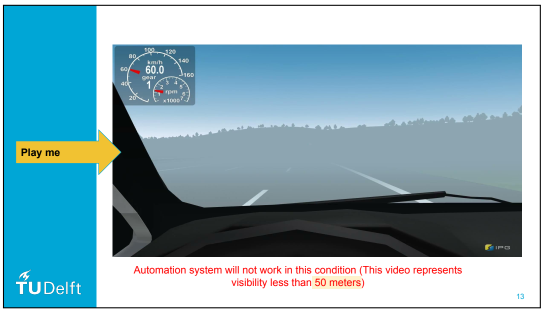
Automation system will work perfectly in this condition(This video represents full visibility without any FOG)

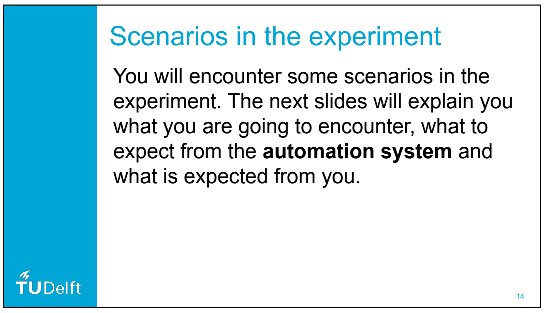
TUDelft 11

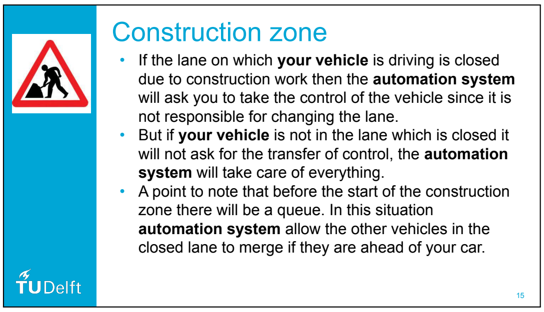
Play me

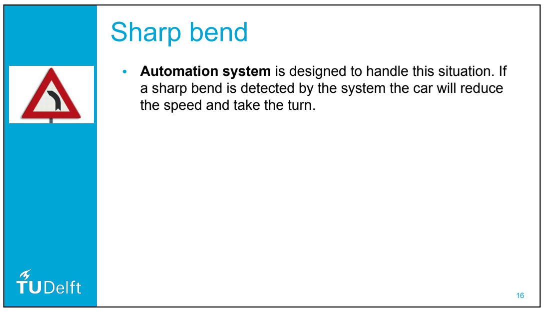
Automation system will work perfectly in this condition(This video represents visibility less than **200 m but more than 50 m**)

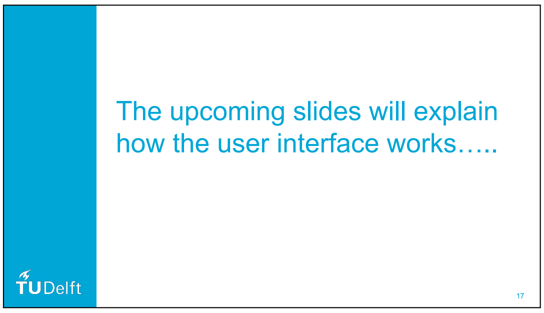
TUDelft 12

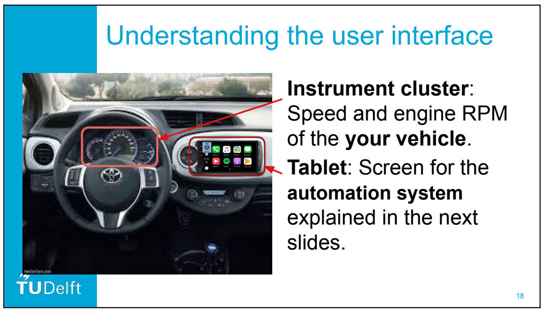

Play me
Automation system will not work in this condition (This video represents visibility less than 50 meters)
TUDelft
13

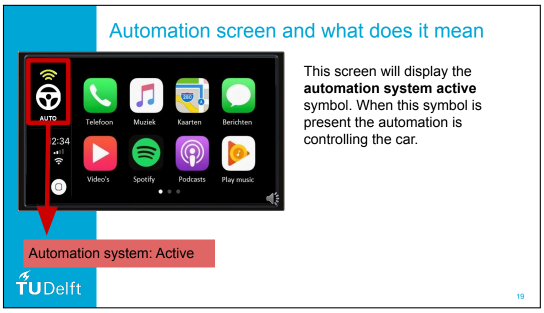

Scenarios in the experiment
You will encounter some scenarios in the experiment. The next slides will explain you what you are going to encounter, what to expect from the automation system and what is expected from you.
TUDelft
14

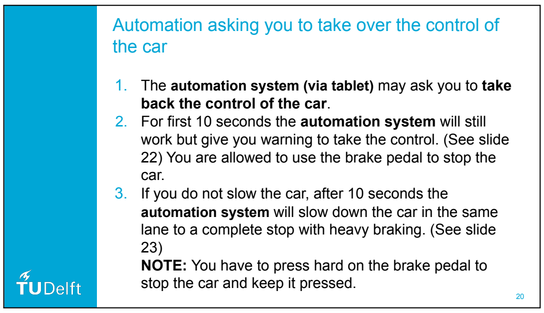

Construction zone
• If the lane on which your vehicle is driving is closed due to construction work then the automation system will ask you to take the control of the vehicle since it is not responsible for changing the lane.
• But if your vehicle is not in the lane which is closed it will not ask for the transfer of control, the automation system will take care of everything.
• A point to note that before the start of the construction zone there will be a queue. In this situation automation system allow the other vehicles in the closed lane to merge if they are ahead of your car.
TUDelft
15

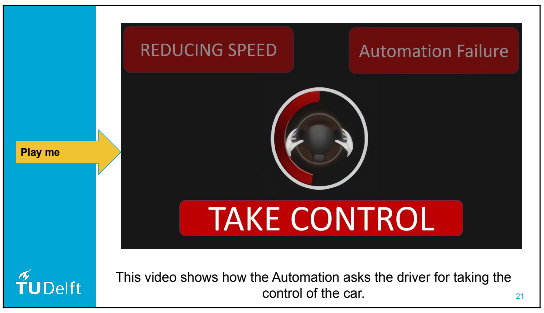

Sharp bend
• Automation system is designed to handle this situation. If a sharp bend is detected by the system the car will reduce the speed and take the turn.
TUDelft
16

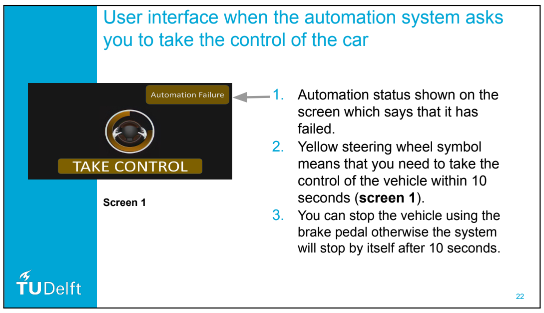

The upcoming slides will explain how the user interface works…..
TUDelft
17

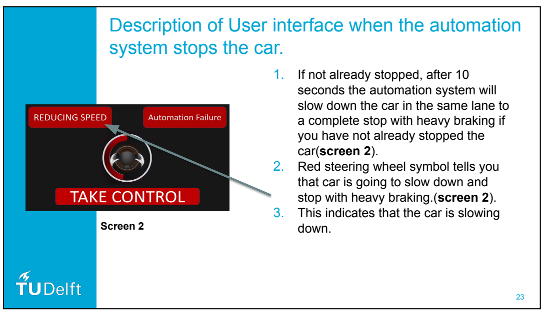

Understanding the user interface
Instrument cluster: Speed and engine RPM of the your vehicle.
Tablet: Screen for the automation system explained in the next slides.
TUDelft
18

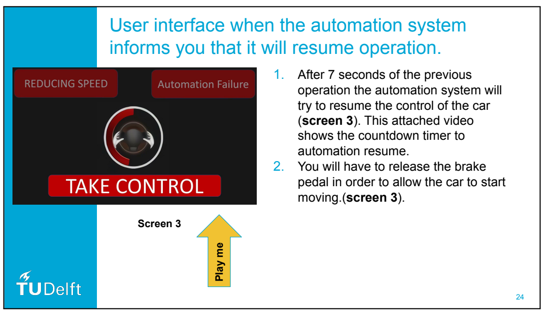

Automation screen and what does it mean
This screen will display the automation system active symbol. When this symbol is present the automation is controlling the car.
Automation system: Active
TUDelft
19

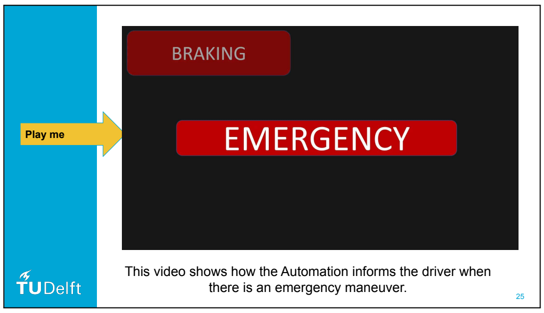

Automation asking you to take over the control of the car
1. The automation system (via tablet) may ask you to take back the control of the car.
2. For first 10 seconds the automation system will still work but give you warning to take the control. (See slide 22) You are allowed to use the brake pedal to stop the car.
3. If you do not slow the car, after 10 seconds the automation system will slow down the car in the same lane to a complete stop with heavy braking. (See slide 23)
NOTE: You have to press hard on the brake pedal to stop the car and keep it pressed.
TUDelft
20

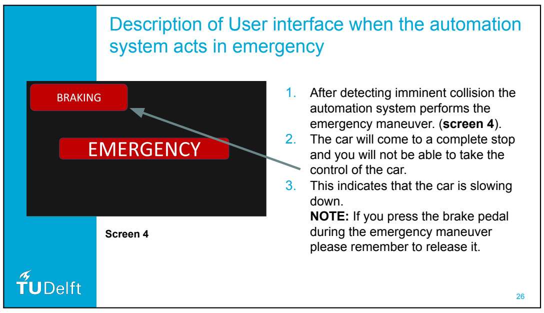

Play me
REDUCING SPEED
Automation Failure
TAKE CONTROL
This video shows how the Automation asks the driver for taking the control of the car.
TUDelft
21

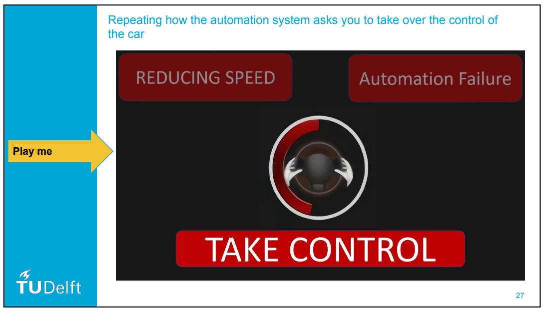

User interface when the automation system asks you to take the control of the car
Automation Failure
TAKE CONTROL
Screen 1
1. Automation status shown on the screen which says that it has failed.
2. Yellow steering wheel symbol means that you need to take the control of the vehicle within 10 seconds (screen 1).
3. You can stop the vehicle using the brake pedal otherwise the system will stop by itself after 10 seconds.
TUDelft
22

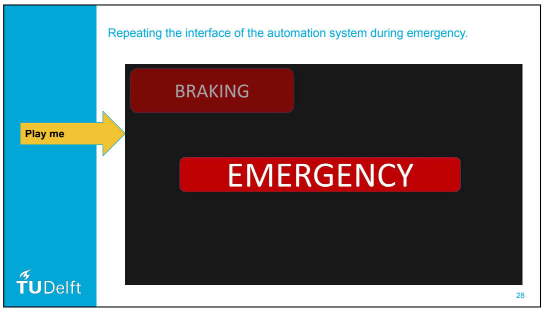

Description of User interface when the automation system stops the car.
REDUCING SPEED
Automation Failure
TAKE CONTROL
Screen 2
1. If not already stopped, after 10 seconds the automation system will slow down the car in the same lane to a complete stop with heavy braking if you have not already stopped the car(screen 2).
2. Red steering wheel symbol tells you that car is going to slow down and stop with heavy braking.(screen 2).
3. This indicates that the car is slowing down.
TUDelft
23


User interface when the automation system informs you that it will resume operation.
REDUCING SPEED
Automation Failure
TAKE CONTROL
Screen 3
Play me
1. After 7 seconds of the previous operation the automation system will try to resume the control of the car (screen 3). This attached video shows the countdown timer to automation resume.
2. You will have to release the brake pedal in order to allow the car to start moving.(screen 3).
TUDelft
24









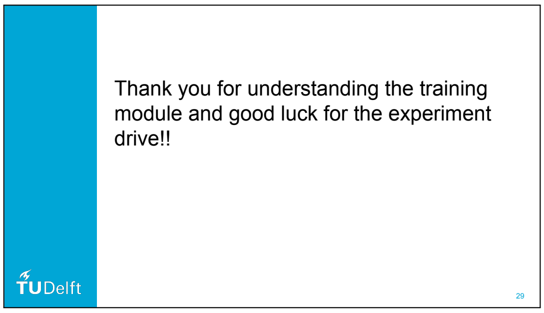


Figure 7.6: Strong English training slides

7.3.4. Strong training in Dutch

RDW

EYESFREE DRIVE SYSTEM

Training information for the participants

What is the EYESFREE DRIVE SYSTEM

Eyesfree Drive System (from now on referred as "Automation system") when activated takes over the complete control of the car from the driver (acceleration, braking and steering) and also looks for the possible dangers on the road.
You are encouraged to engage in activities other than driving however you have to stay awake during the drive and remain in the driving position with the seat belt fastened in order for the system to work.

RDW

Working of the system explained

For this experiment the **automation system** is designed to work by detecting the lane markings **and** the car ahead of you. If there is no car ahead of you then **automation system** will drive the car at the maximum speed of 60 km/h within the lane.

You will have to keep in mind when and why the system will not work for the experiment.

RDW

Straight road

- The **automation system** detects the front vehicle using the radar sensors.
- It keeps a safe distance of 2 secs from the front car.
- If **no car** is detected ahead the **automation system** will drive on its own at maximum speed of 60km/h.

RDW

Straight road

Play me

RDW

Curved road

1. The **automation system** uses the camera mounted in the front and the radars mounted on the sides to recognize the lane marking and make sure that the car never crosses the lane marking.
2. The **automation system** will adjust the speed to the curve for safe cornering.
3. The **automation system** will never make a lane change.

RDW

Curved Road

Play me

RDW

Emergency maneuver

- The **automation system** might suddenly apply the brake if it detects some very critical collision risk but it will never steer out of its lane.
- You don't have to worry, this situation is handled on its own. After the risk disappears the car will resume its journey.

RDW

Emergency maneuver

Play me

RDW

Transfer of control maneuver

The Automations system will not work in the below conditions and it may ask you to **take over the control** of the car.

- The **weather condition** turns bad. (Heavy fog on the road).
- The next slides will help you to identify the bad weather conditions.

OR

- **Hardware/software** of the automation system is not performing up to the mark.

RDW

Play me

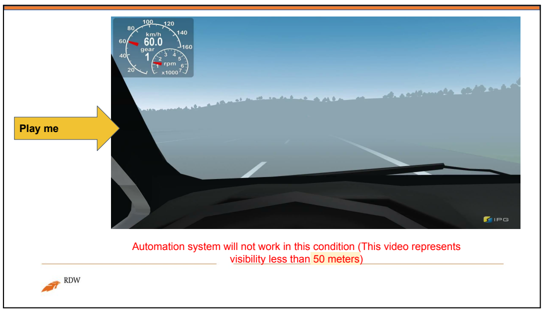
Automation system will work perfectly in this condition(This video represents full visibility without any FOG)

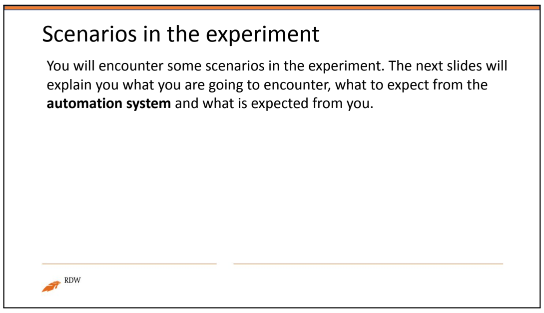
RDW

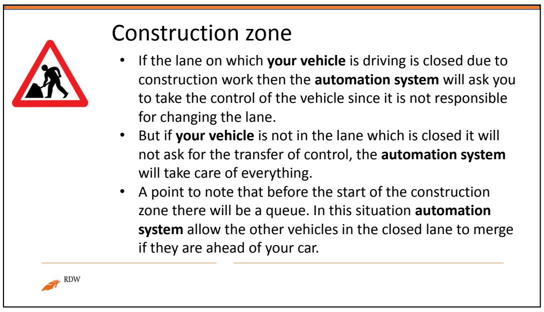
Play me

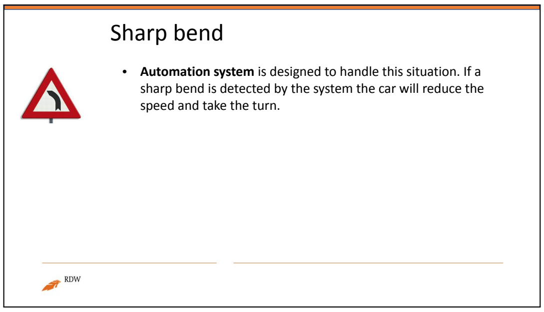
Automation system will work perfectly in this condition(This video represents visibility less than **200 m but more than 50 m**)

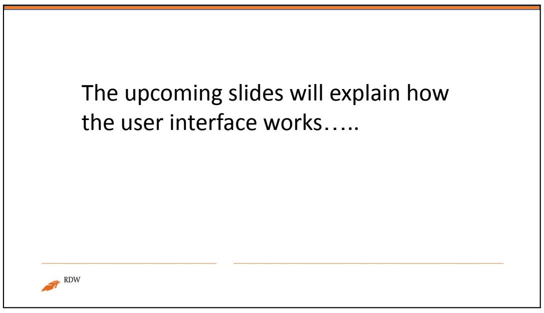
RDW

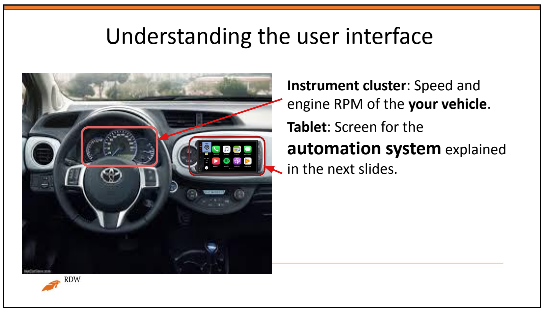

Play me
Automation system will not work in this condition (This video represents visibility less than 50 meters)
RDW

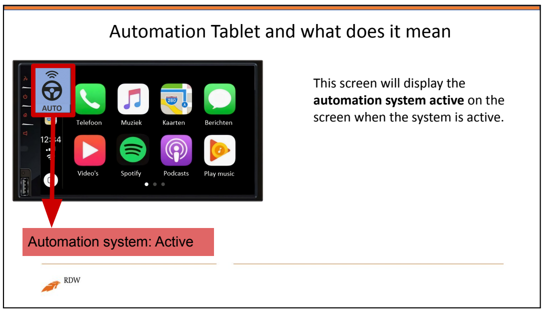

Scenarios in the experiment
You will encounter some scenarios in the experiment. The next slides will explain you what you are going to encounter, what to expect from the **automation system** and what is expected from you.
RDW

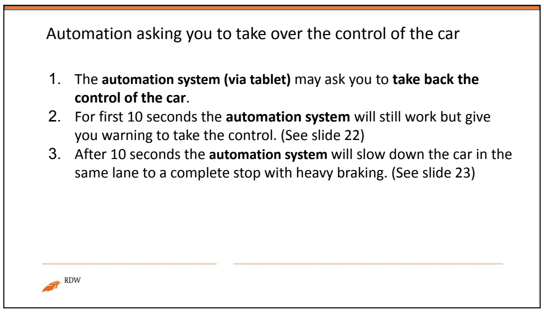

Construction zone
If the lane on which **your vehicle** is driving is closed due to construction work then the **automation system** will ask you to take the control of the vehicle since it is not responsible for changing the lane.
But if **your vehicle** is not in the lane which is closed it will not ask for the transfer of control, the **automation system** will take care of everything.
A point to note that before the start of the construction zone there will be a queue. In this situation **automation system** allow the other vehicles in the closed lane to merge if they are ahead of your car.
RDW

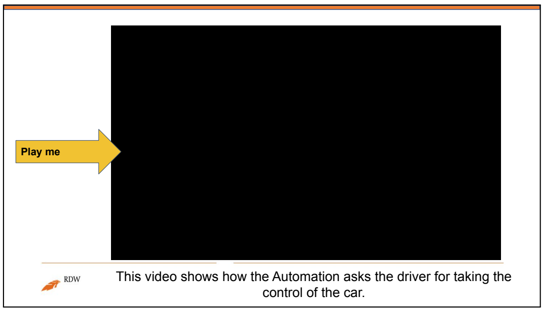

Sharp bend
Automation system is designed to handle this situation. If a sharp bend is detected by the system the car will reduce the speed and take the turn.
RDW


The upcoming slides will explain how the user interface works…..
RDW

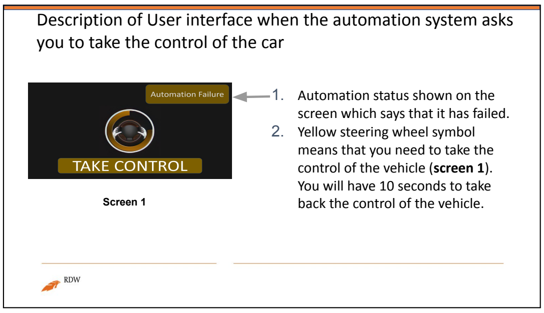

Understanding the user interface
Instrument cluster: Speed and engine RPM of the **your vehicle**.
Tablet: Screen for the **automation system** explained in the next slides.
RDW

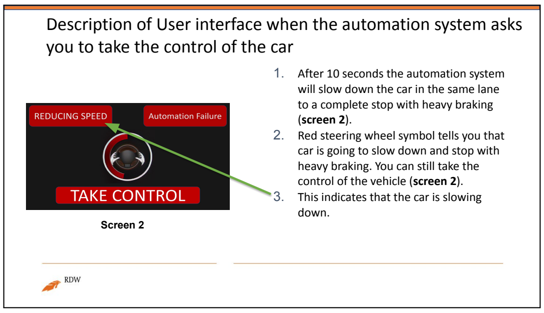

Automation Tablet and what does it mean
AUTO
Telefoon
Muziek
Kaarten
Berichten
Video's
Spotify
Podcasts
Play music
This screen will display the **automation system active** on the screen when the system is active.
Automation system: Active
RDW


Automation asking you to take over the control of the car
1. The **automation system (via tablet)** may ask you to **take back the control of the car**.
2. For first 10 seconds the **automation system** will still work but give you warning to take the control. (See slide 22)
3. After 10 seconds the **automation system** will slow down the car in the same lane to a complete stop with heavy braking. (See slide 23)
RDW


Play me
RDW
This video shows how the Automation asks the driver for taking the control of the car.


Play me
RDW
This video shows how the Automation informs the driver when there is an emergency maneuver.


Description of User interface when the automation system asks you to take the control of the car
Automation Failure
TAKE CONTROL
Screen 1
1. Automation status shown on the screen which says that it has failed.
2. Yellow steering wheel symbol means that you need to take the control of the vehicle (**screen 1**). You will have 10 seconds to take back the control of the vehicle.
RDW


Description of User interface when the automation system asks you to take the control of the car
REDUCING SPEED
Automation Failure
TAKE CONTROL
Screen 2
1. After 10 seconds the automation system will slow down the car in the same lane to a complete stop with heavy braking (**screen 2**).
2. Red steering wheel symbol tells you that car is going to slow down and stop with heavy braking. You can still take the control of the vehicle (**screen 2**).
3. This indicates that the car is slowing down.
RDW

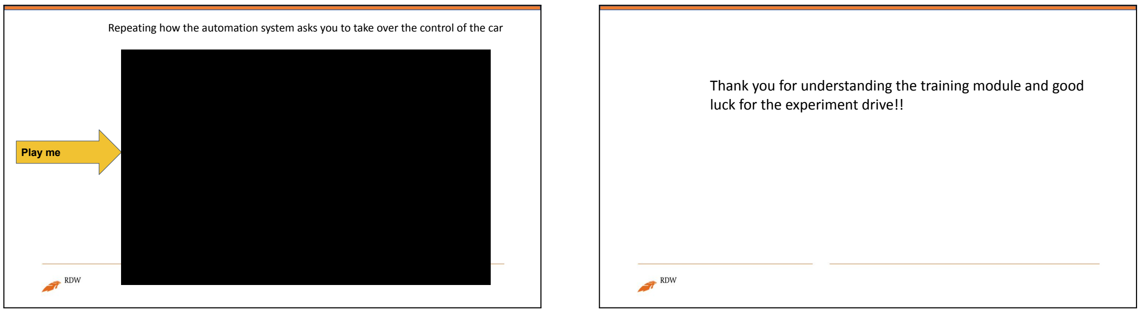


Figure 7.7: Strong training Dutch slides

7.4. IPG Carmaker settings

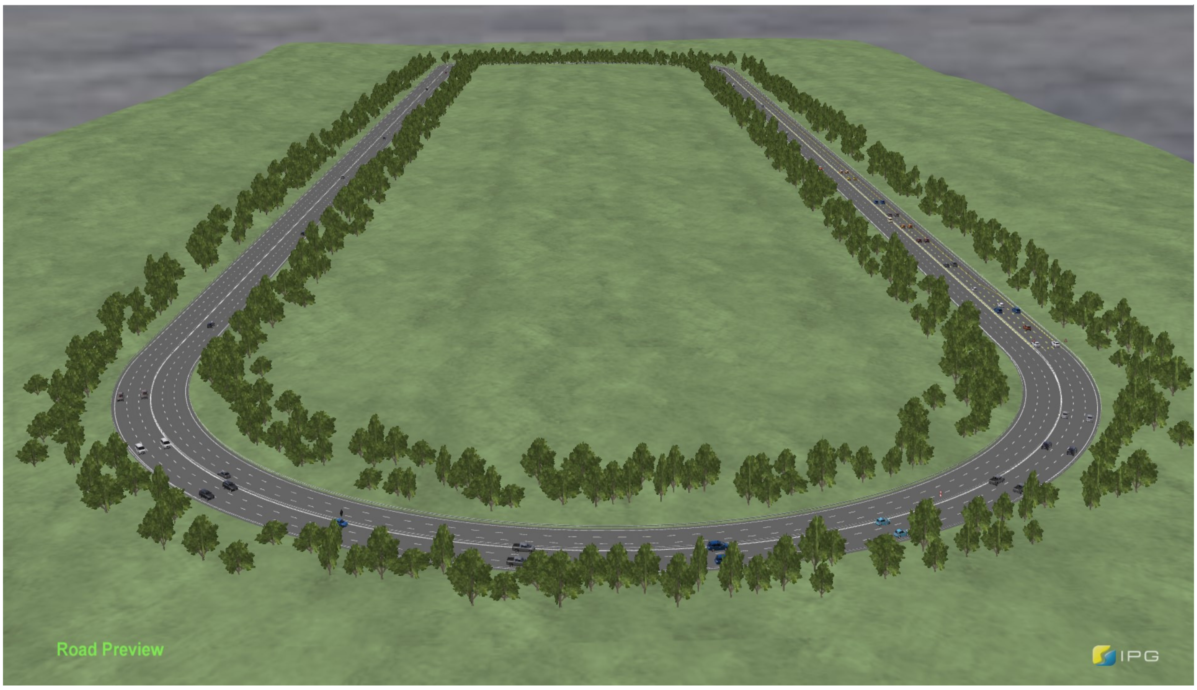


Figure 7.8: 3D track overview

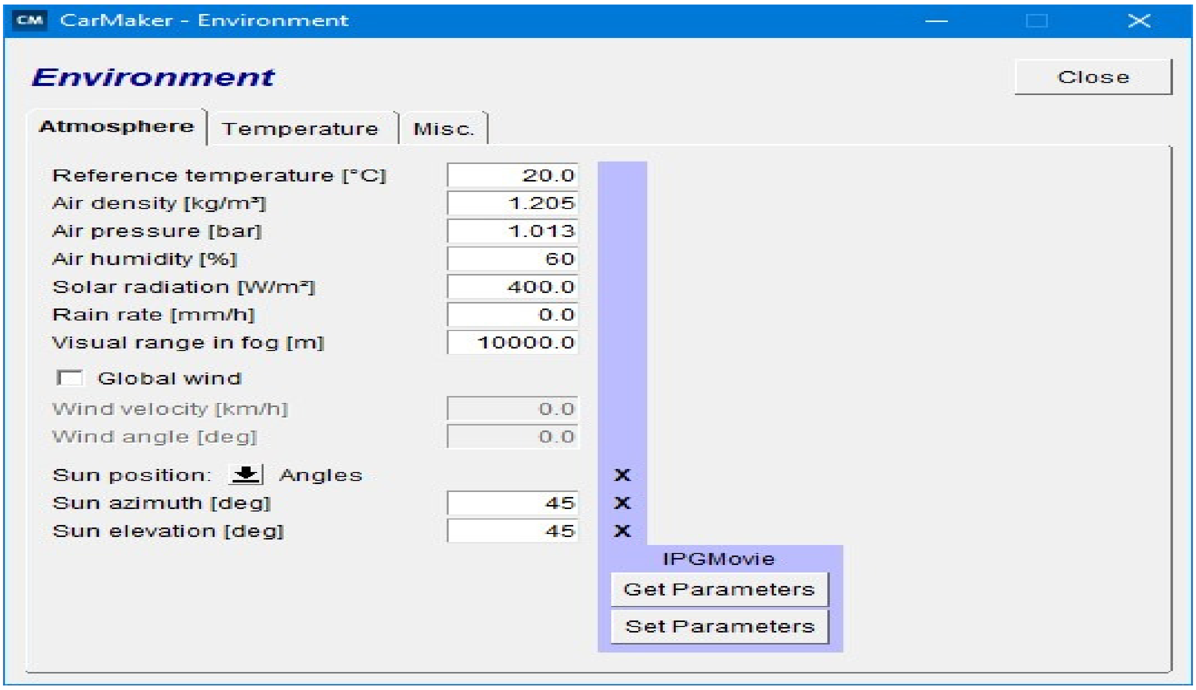


Figure 7.9: Environment setting for the clear weather

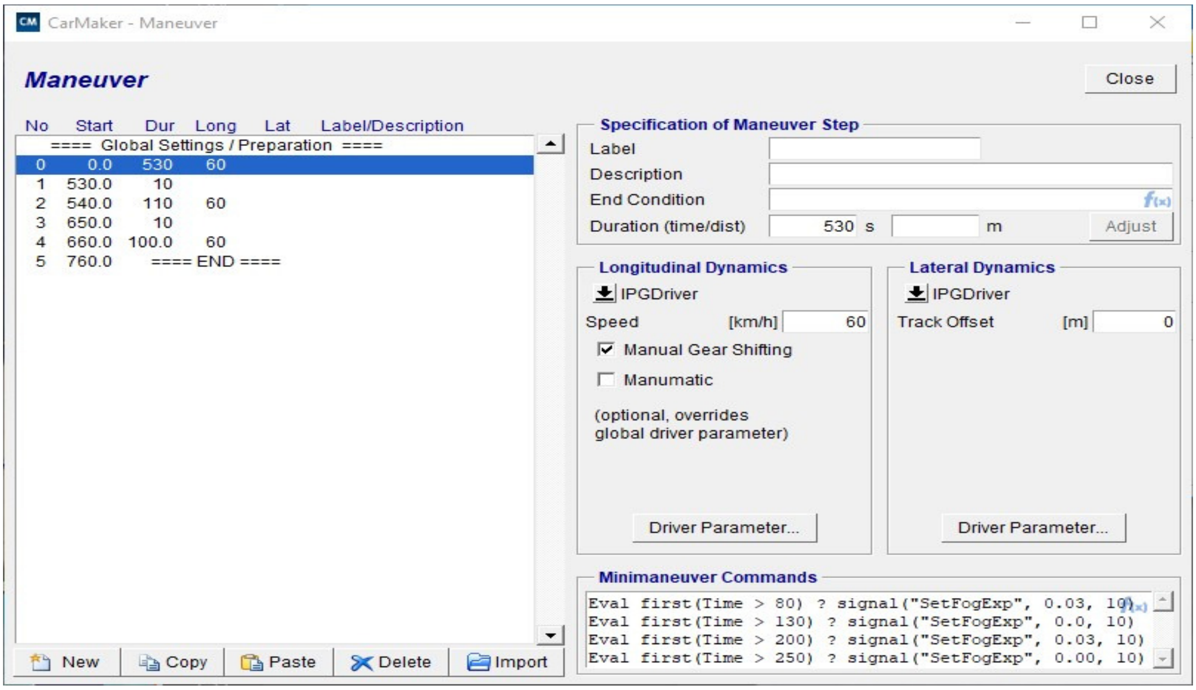


Figure 7.10: Settings to activate fog

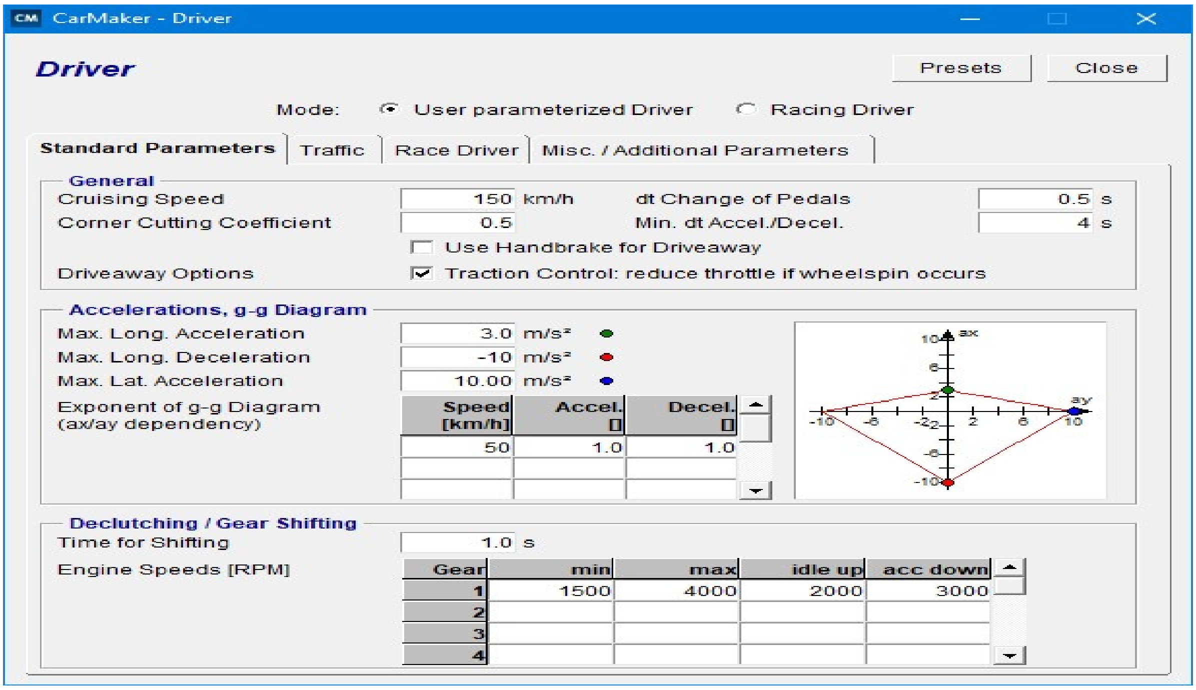


Figure 7.11: Setting the automation limits

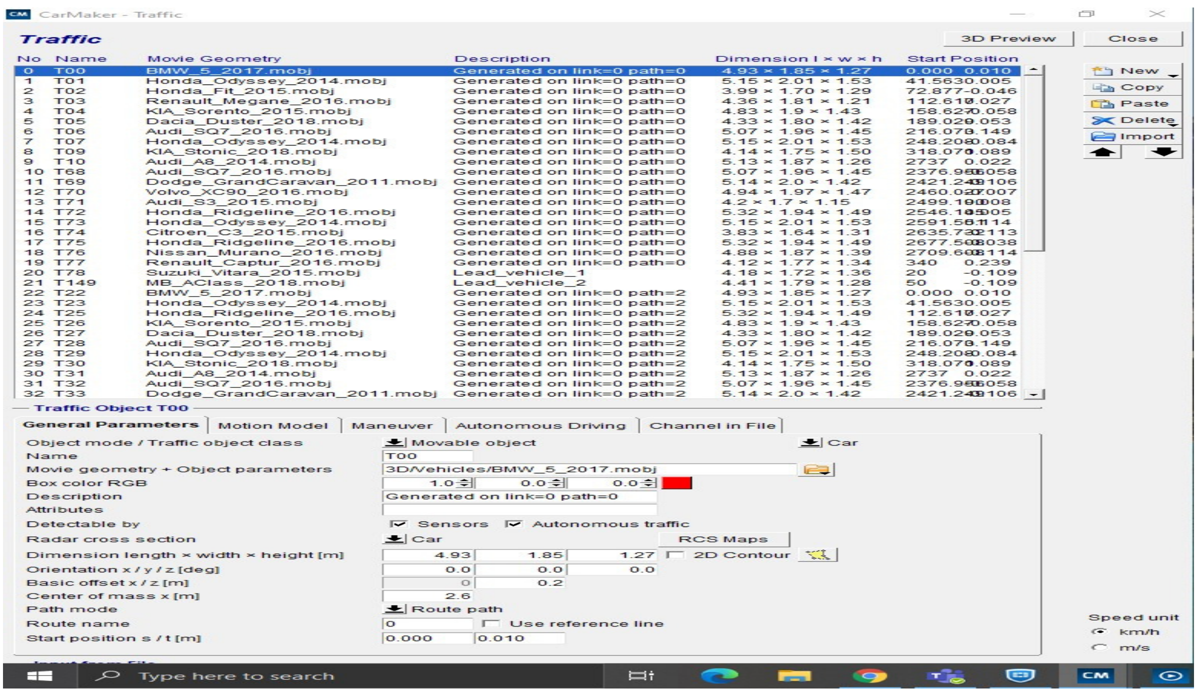


Figure 7.12: Traffic vehicle mix 1

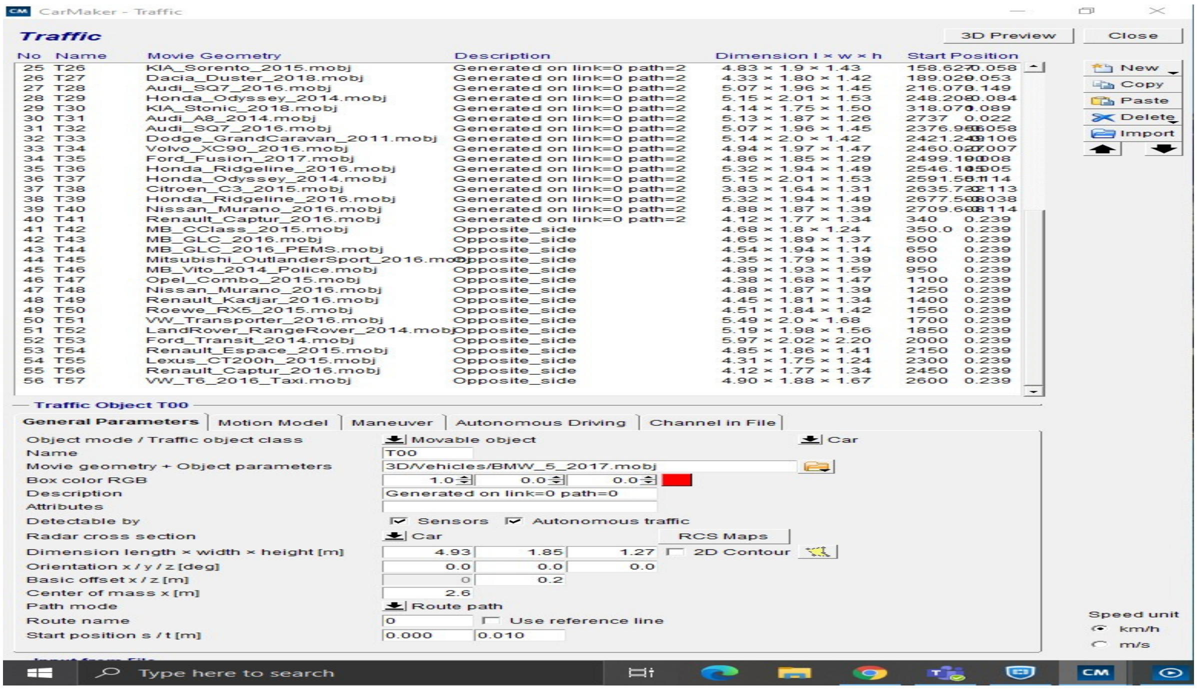


Figure 7.13: Traffic vehicle mix 2