

Enhancing Trust in Automated Driving: A Human Centered Approach

Master's thesis in Automotive Engineering

Krishnachandran Chakkamvilakam Prasannachandran Nair

MASTER'S THESIS IN AUTOMOTIVE ENGINEERING

Enhancing Trust in Automated Driving: A Human Centered Approach

Krishnachandran Chakkamvilakam Prasannachandran Nair

Department of Mechanics and Maritime Sciences
Division of Vehicle Safety
Accident Prevention Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2020

Enhancing Trust in Automated Driving: A Human Centered Approach

[Abstract]

Krishnachandran Chakkamvilakam Prasannachandran Nair

© Krishnachandran Chakkamvilakam Prasannachandran Nair, 2020-01-30

Master's Thesis 2019:109

Department of Mechanics and Maritime Sciences

Division of Vehicle Safety

Accident Prevention Group

Chalmers University of Technology

SE-412 96 Göteborg

Sweden

Telephone: + 46 (0)31-772 1000

Cover:

Trust in Automated Driving

Name of the printers / Department of Mechanics and Maritime Sciences

Göteborg, Sweden 2020-01-30

Enhancing Trust in Automated Driving: A Human Centered Approach

[Abstract]

Master's thesis in Automotive Engineering

Krishnachandran Chakkamvilakam Prasannachandran Nair

Department of Mechanics and Maritime Sciences

Division of Vehicle Safety

Accident Prevention Group

Chalmers University of Technology

Abstract

The automotive industry is aiming for attaining an advanced level of automation by which a vehicle can travel from one place to another without engaging the human driver in any situation during the drive. For attaining this level of automation there are few more levels of automation to be crossed with the help of advanced technologies. As the Society of Automotive Engineers Level 2 Automated Vehicles can be seen on our roads, the next step is to attain Level 3 Automated Driving. Several studies have shown that peoples' trust in Automated Driving is one of the important topics that should be considered for the acceptance of Automated Vehicles in public and for improving road safety. The purpose of this study is to enhance driver's trust in Automated Driving with the help of a newly developed Human Machine Interface that monitors nearby Vulnerable Road Users around the Level 3 Automated Vehicle when it was driven through an urban road and then informs the driver to co-monitor the Automated Driving. This study was conducted in a moving base driving simulator with thirty-four participants. They were divided into two groups accordingly whether they have Level 2 driving experience or not. Each participant drove the Level 3 Automated Vehicle through four different driving conditions, where there is an unexpected pedestrian crossing, in a simulated environment. In each driving condition, they were provided with different automated driving features. Learned trust, dispositional trust, and situational trust were measured. The results show that the group of people who had Level 2 driving experience (learned trust) exhibited higher situational trust when provided with the co-monitoring Human Machine Interface and Forward Collision Warning, also Level 2 experienced drivers performed better in terms of safety. Therefore, it indicates that for achieving a higher level of trust in Automated Driving and improving road safety, a driver should not be inexperienced to previous levels of automated driving when he/she select a Level 3 Automated Vehicle to commute. Furthermore, a Human-Machine Interface which enhances driver's situational trust is highly suggested for a Level 3 Automated Driving.

Key words: Automated Driving, SAE Level 3, HMI, Driver Behaviour, Driving Simulator Experiment, Dispositional Trust, Situational Trust, Learned Trust, VRU.

Contents

Abstract.....	1
Contents.....	3
Preface.....	5
Notations.....	6
1 Introduction.....	7
1.1 Automation today: Focus on Level 3.....	8
1.1.1 Advantages: Safety, comfort, efficiency.....	9
1.1.2 Human Factor issues in Level 3.....	10
1.1.3 Mixed environments: Interaction with VRUs in urban areas.	11
1.2 Automation trust: concept and theories.....	12
1.3 Automation trust problem: Overtrust and Undertrust.....	13
1.4 Automation trust indicators: behavioural and subjective methods.....	13
1.5 Calibration of trust in automation.	14
1.6 Objectives.....	14
2 Methods.....	16
2.1 HMI concept for autonomous vehicles on urban roads.....	16
2.2 Equipment and data acquisition.....	18
2.2.1 Simulator IV.....	18
2.2.2 Scenarios.....	18
2.2.3 Additional task.....	19
2.2.4 Subjective data.....	20
2.1 Participants.....	22
2.2 Experimental design.....	22
2.3 Procedure.....	23
2.4 Statistical analyses.....	24
3 Result.....	25
3.1 The development of co-monitoring HMI concept.....	25
3.2 Descriptive statistics.....	27
3.3 Analysis of collisions.....	32
4 Discussion.....	33
4.1 Limitations.....	34
4.2 Future research.....	34
5 Conclusion.....	35

6. References.....	36
7. Appendix A.....	43
8. Appendix B.....	45
9. Appendix C.....	48
10. Appendix D.....	49
11. Appendix E.....	50
12. Appendix F.....	51

Preface

This thesis is a part of my master program in Automotive Engineering at Chalmers University of Technology, Gothenburg. This thesis work was carried out at VTI, Gothenburg with the supervision of Niklas Strand (VTI, Gothenburg) and Ignacio Solís Marcos (VTI, Linköping) and examiner from Chalmers was Robert Thomson (Chalmers/SAFER, Gothenburg).

This master thesis is a part of the BRAVE Project (BRIdging gaps for the adoption of Automated VEHICLES), funded by European Union's Horizon 2020 research, which aims at the improved safety and market adoption of automated vehicles and to promote an increased confidence in automated vehicles by the society. For this BRAVE project, user validation through realistic testing is carried out by VTI.

I thank especially Ignacio Solís Marcos and Niklas Strand for their steadfast guidance and availability throughout this study. I also thank my examiner Robert Thomson for his highly supportive, guidance, feedback and enthusiastic attitude towards my thesis.

Finally, it should be noted that the tests could never have been conducted without the sense of high quality and professionalism of the staffs, Bruno Augusto, Maytheewat Aramrattana and Andreas Käck who worked for the simulator study from VTI, Gothenburg. The output of the project is achieved because of the smooth collaboration of each of us.

Gothenburg March 2020-01-30

Krishnachandran Chakkamvilakam Prasannachandran Nair

Notations

ACC	Adaptive Cruise Control
AD	Automated Driving
ADS	Automated Driving System
AV	Automated Vehicle
BRAVE	BRIdging gaps for the adoption of Automated Vehicles
CC	Cruise Control
DDT	Dynamic Driving Task
FCW	Forward Collision Warning
GPS	Global Positioning System
HMI	Human Machine Interface
LDW	Lane Departure Warning
LKA	Lane Keeping Assistance
M-HMI	Monitoring Human Machine Interface
NDRT	Non-Driving Related Task
NHTSA	National Highway Traffic Safety Administration
OOTL	Out-Of-The-Loop
PoNR	Point-of-No-Return
RADAR	RAdio Detection And Ranging
RHT	Risk Homeostasis Theory
SAE	Society of Automotive Engineers
SATI	SHAPE Automated Trust Index
TOR	Take Over Request
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Infrastructure
VRU	Vulnerable Road User

1 Introduction

Automation can be defined as the performance of a task by a machine, which was previously carried out by a human (Parasuraman et al., 2000). Automation has different levels, according to the involvement of humans to complete the task. In case of vehicle automation, Automated Driving (AD)/Vehicles (AV) means, a manually driven vehicle is taken under the control by a complex electronic system which perceives, processes and acts according to a pre-defined strategy which is embedded along with the system. Automation is an always-changing topic. As we can see how the starter motor of a car is now considered as machine operation, the preceding way of manually cranking up the engine to start the engine got completely obsolete.

Automation technologies are becoming closer and closer to our day to day life. From the GPS (Global Positioning System) device in a vehicle to the flight control system, these technologies help to ease our everyday tasks and many complex tasks. When a human uses automation there are certain aspects to consider while designing an automation system. A study by Raja Parasuraman et al. (2000) shows the relationship on how humans use, misuse, disuse, and abuse automation. For the appropriate use of automation, the operator must have a better understanding of how automation works. Individual differences of operators (humans) while using automation may lead to inappropriate use of automation. To eliminate this, proper policies and procedures should be considered for whether to use automation or not. It is important to teach the operator to take a rational decision for when to use automation. Automation which consumes less cognitive overhead and workload from the operator gathers more attraction by the operator to use it. Overreliance on automation is one of the major consequences of automation misuse and this can happen because of a high workload which in turn makes the operator fail to monitor automation effectively. The absence of well-established ergonomic design principles can also be a reason that makes the operator fail to monitor automation. Proper feedback about the automation function capabilities to work appropriately in various situations should be conveyed to the operator so that he/she should be able to intervene in automation effectively. Disuse is when an automation function is ignored by considering its previous behaviour of numerous false operations. For example, false activation of alarm for many times. In this case, the decision by the system designer to set a threshold to activate the alarm must be so accurate to avoid its false activation else these situations may make the operator to mistrust automation. Automation abuse happens when an operator's role comes as a by-product of automation rather than considering the capabilities and responsibilities of human performance while implementing the automation function. Automation may be used in a different manner rather than how designers intended to because of the complexities of the operational environment and human operator. These differences should be identified so that an operator can use automation to its best. Automation abuse can lead to misuse and disuse (Parasuraman et al., 2000).

Over the past few decades trust in automation has received much attention in the automobile industry. As the world of automobiles moves towards automation, *trust* is one of the main bridges that connect humans with automation. Enhancing the people's trust in Automated Driving (AD) within a confined amount of time remains a bigger challenge. In the real-world, trust measures an individual's degree of confidence with a stranger or a partner's fidelity with their significant other in a relationship (Hoff & Bashir, 2015). Whereas Mayer et al., (1995) define trust as one's willingness to accept vulnerability. Trust can also be explained on behalf of communities, cultures, society, organizations, etc. Other than explaining trust at an interpersonal level, trust can be

defined in a way how people interact with technology (Hoff & Bashir, 2015). According to Lee and See (2004) trust is a social psychological concept and for the understanding of the human-automation relationship, it is very important.

This thesis is about enhancing drivers (humans) trust in AD on urban roads, by using a newly developed co-monitoring HMI which detects VRUs around the vehicle and informs the driver about them, so that he/she can disengage from other tasks like watching videos, and co-monitor or reengage in driving until it is safe to resume other tasks. For the development of this HMI, design principles from Carsten and Martens (2019) and BRAVE were used. To know how this HMI influenced drivers-trust in the vehicle, different trust measures (learned trust, dispositional trust, and situational trust) were collected and a statistical analysis was carried out with that.

1.1 Automation today: Focus on Level 3

In September 2016, the Society of Automotive Engineers (SAE) released the latest version of SAE-J3016 'Surface Vehicle Recommended Practice: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles'. This standard is accepted by major stakeholders in the automotive field and by the National Highway Traffic Safety Administration (NHTSA) of the US department of transportation.

SAE (SAE J3016, 2016) classified the degree of automation for on-road vehicles with 6 levels, starting from Level 0 to Level 5. In Level 0 there exists no automation and the driver should perform all driving tasks. In Level 1, the driver is supported with some driving assist features but the vehicle should be controlled by the driver. In the case of Level 2, which is partial automation, longitudinal and lateral driving support systems are provided to the driver, but he/she should constantly monitor and engaged with driving.

Automation features are more critical from Level 3 till Level 5 (highly automated drives), allowing the driver to engage in NDRT. SAE Level 3 is defined as a conditionally automated vehicle in which a vehicle performs longitudinal and lateral vehicle control in certain conditions for a limited amount of time by itself (Trimble et al., 2014). When the vehicle is in Level 3 autonomous driving mode the driver does not have to monitor the environment but should be ready to act when the system requests. That is when the autonomous system finds itself that the driving situations are crossing its system boundaries and might lead to a future situation where a system can no longer handle the situation autonomously. For example, lane marking or road networks mismatch with the stored map (Aeberhard et al., 2015). Then the system hands over the driving task to manual driving mode, that is to the driver. This will be implemented by giving a Take Over Request (TOR) to the driver. After the driver receives TOR, he/she must take over the control of steering, braking and /or accelerating the vehicle and take over must happen before reaching system boundary. Therefore, the system must provide a safe buffer for the transition to manual driving control after giving a TOR (Melcher et al., 2015). The TOR strategies include a visual, acoustic and haptic warning. Several studies showed that a buffer time not less than 10 seconds is good enough for a driver to take back control even if he /she is extremely distracted (Melcher et al., 2015; Petermann-Stock et al., 2013; Damböck et al., 2012). Level 4 is termed as high automation, in which the vehicle can perform all driving functions but in specific

driving conditions. For example, in a closed campus as a shuttle feature, high-speed freeway cruising. Full automation is possible by Level 5, where the vehicle will be able to drive autonomously in all driving conditions (*Figure 1*) (SAE J3016, 2016).

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
What do these features do?	These are driver support features			These are automated driving features		
	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met	This feature can drive the vehicle under all conditions	
	<ul style="list-style-type: none"> • automatic emergency braking • blind spot warning • lane departure warning 	<ul style="list-style-type: none"> • lane centering OR • adaptive cruise control 	<ul style="list-style-type: none"> • lane centering AND • adaptive cruise control at the same time 	• traffic jam chauffeur	<ul style="list-style-type: none"> • local driverless taxi • pedals/steering wheel may or may not be installed 	<ul style="list-style-type: none"> • same as level 4, but feature can drive everywhere in all conditions
Example Features						

Figure 1: Levels of driving automation by SAE J3016 (2016).

Studies show that conditionally automated and highly automated vehicles (Level 3 and Level 4, respectively) are anticipated to improve road safety (Bischoff et al., 2018). This study deals with Level 3 automation i.e. conditionally automated vehicles. As the future of AD is aiming for fully automation by keeping the driver out of the driving control loop, there are few other milestones to reach before moving from an assisted driving to highly automated driving (Petermann-Stock et al., 2013; Damböck et al., 2012). Increasing the level of automation also aims at improving safety and fewer emissions (Reimer et al., 2016). In a Level 3 AD, the driver is considered to be a fallback-ready user. When the AD can no more handle the system by itself a human intervention is needed (SAE J3016, 2016) and a real challenge in Level 3 AD is when the driver gets a TOR from the system to react. In this situation, the performance will decline, and the driver will take more time to react when he/she is Out-Of-The-Loop (OOTL) (Strand et al., 2014; Shen & Neyens, 2017; Reimer et al., 2016). When these situations arise, Human Machine Interfaces (HMIs) can be considered to prepare the driver to act on time (Ganzhorn et al., 2013).

1.1.1 Advantages: Safety, comfort, efficiency.

One of the top priorities for the public to adopt automated driving technologies is safety. Various news reports and public agencies reported that more than 90% of road traffic accidents are caused by driver error (Singh et al., 2015). These statements are eye-catching but not reliable. Another study shows that the expectation to attain zero-fatality with self-driving vehicles is unrealistic and in the transition stage, when the conventional vehicles and self-driving vehicles share the same road, the safety might worsen for conventional vehicles (Sivak & Schoettle, 2015). With AD, time-saving and enhanced mobility are possible but depending on the ability of Autonomous Driving System (ADS) to enhance the road capacity, there may be conditions that reduce the

level of comfort expected from the passenger (Rangaranjan, 2016). As the number of AVs on road increases, the driving distance between two AVs may reduce than conventionally driven vehicles. This shortened distance may create unnecessary tension for the passenger. A study conducted by Wadud et al. (2016), showed that (Figure 2) the widespread adoption of AD can reduce energy consumption in different ways. For example, by using connected AV traffic flow can be streamlined and optimized for lower fuel consumption, AVs can do platooning i.e. drive very close to each other on motorways and reduce aerodynamic drag. Different mechanisms affected by vehicle automation on energy consumption are shown in Figure 2 from various data and studies analyzed by Wadud et al. (2016).

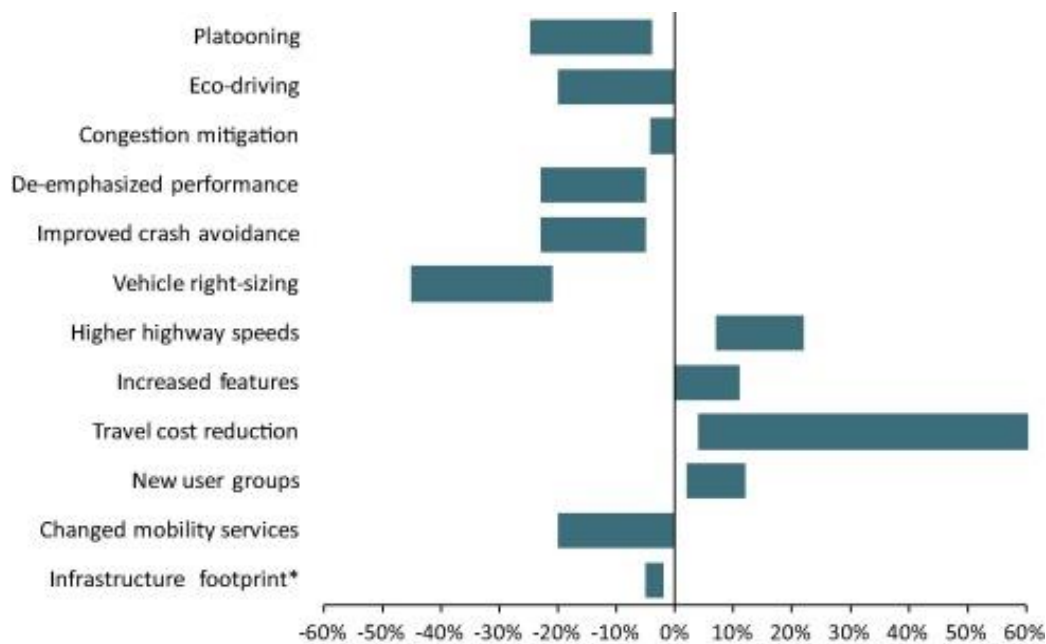


Figure 2: % changes in energy consumption due to vehicle automation, Wadud et al. (2016).

1.1.2 Human Factor issues in Level 3

Automation shifts the human's manual driving task control to supervisory control (Geyer et al., 2011) but only in Level 1 and 2 of AD. When it comes to Level 3 automation it is clearly mentioned by SAE J3016, that the ADS will monitor the Dynamic Driving Task (DDT) when driving automation is engaged. In this case, the driver is considered as a fallback-ready user. That means the driver/user must be receptive to the request from ADS to take over the DDT by ADS to manual control. In Level 3 AD there is no must for a driver to monitor, driving environment and vehicle performance when ADS is engaged. The difference between monitoring and being receptive should be understood. For example, a person who becomes aware of a fire alarm may not be monitoring fire alarms all the time. While driving a Level 1 or 2 vehicles with Adaptive Cruise Control (ACC, Level 1) and Lane Keeping Assistance (LKA, Level 2) the driver should monitor and be receptive to both driving environment and vehicle performance without fail and should not wait for the system to warn. Monitoring also includes being receptive but not vice versa (SAE J3016, 2016). Being receptive to ADS failure in Level 3 AD when the driver is OOTL makes the situation

challenging because of the human factor issues in the domain of driving automation (Endsley & Kiris, 1995). Some of these are issues with:

- *Behavioural adaptation*: a study by Rudin-Brown and Parker (2004) show that drivers who frequently use ACC tend to engage in activities other than driving, also Risk Homeostasis Theory (RHT) states that when there is a change in perceived risk by human, they adapt their behaviour to restore their target perceived risk (Ward, 2000; Wilde, 1988).
- *Erratic mental workload*: automation can increase mental workload in unexpected situations (Lee, 2006) and can decrease the mental workload in routine tasks (Ma & Kaber, 2005).
- *Inadequate mental model of automation functioning*: for example, a driver who doesn't realize the functional limitation of RADAR, i.e. its limited operating range, may fail to reclaim the vehicle control (Stanton & Young, 2000).
- *Overreliance*: it happens when human insufficiently counter check or question automation status (Saffarian et al., 2012).
- *Reduced situational awareness*: high level of automation can degrade human's ability for event detection and response (Norman, 1990; Wickens, 2008). Lack of mode awareness can also happen during high level of automation, which may result in longer response time (Horiguchi et al., 2010).
- *Skill degradation*: automation may cause degradation of cognitive skill to accomplish the task and even it can degrade psychomotor dexterity (Parasuraman et al., 2000).

1.1.3 Mixed environments: Interaction with VRUs in urban areas.

In the near future, Automated Vehicles (AVs) or AD are expected to go through a mixed traffic environment (Schieben et al., 2019). For a safe integration of AVs in a mixed environment, an artificial interaction of AVs should replace the human-human interactions between onboard drivers with Vulnerable Road User (VRU). This leads to a new field of human factor research and HMI designs of AVs (Cacciabue et al., 2014). When an AV interacts with a VRU or other traffic participants plenty of information transfer happens between each other.

While the rapid deployment of AV technologies is happening, one of the biggest challenges faced by human factor researchers, engineers and designers is to incorporate AVs into a mixed traffic environment in a safe manner (Schieben et al., 2019). An analysis was conducted by Schieben et al. (2019) with existing research data on human-human interactions in mixed traffic environments and with preliminary research results from a European project 'CityMobil2', on needs of VRU while interacting with AVs. The CityMobil2 project was conducted in 12 cities in Europe. The analysis reports that certain design considerations are to be taken care of in AVs when VRUs are in their vicinity. This includes providing information about AV manoeuvres, driving mode, perception of environment and cooperation capabilities. Standardizing some of these factors will likely help to ensure appropriate trust, use and acceptance of AV and improve road safety too.

1.2 Automation trust: concept and theories

Trust is one of the major bonds that connect humans with automation. Enhancing people's trust AD in a confined amount of time need more effort. There are many theories that explain the relationship between trust and automation. In a study carried out by Rubin et al. (1994), they see one's trust as a countable factor on the beliefs about others. Whereas Barber (1983) viewed interpersonal trust as a collection of expectations learned socially and it alters based on social order. Some of the authors think trust as a belief, attitude or willingness to accept vulnerability (Meyer et al., 1995). Trust in human-automation depends on the automation system's performance, purpose or process (Lee & Moray, 1992). For the thesis study the author selected 'Trust in Automation: Empirical Evidence on Factors That Influence Trust' by Hoff and Bashir (2015) as the reference for a trust model (*Figure 3*). Their study's main objective was to present a three-layered trust model that correlates existing knowledge of trust in automation by performing a systematic review of empirical research from January 2002 to June 2013. A total 101 papers containing 127 eligible studies were included for their review and a paper was determined eligible if that reported human-subject experimental results, i.e. humans interacted with automated systems to achieve a goal(s). This study comes-out with the three-layered variability in human-automation trust and they are dispositional trust, situational trust, and learned trust. For the thesis study, these three layers of trust were measured. The definition of trust by Lee and See (2004), is that trust is when an agent helps to achieve one's goals in a situation which is characterized by uncertainty and vulnerability. This definition was followed by Hoff and Bashir and as well as for the thesis study.

In general, when trust is described, there exist three main components. First, a truster to give trust, a trustee to accept trust, and something is at stake. The trustee must have some incentive to perform the task. While interacting with technology the incentive could be a designer's intended use of the system (Hardin, 2006). An individual's dispositional trust in the case of automation is referred to his/her general tendency to trust in automation, which is independent of context or that particular system. Dispositional trust is a stable trait i.e. it is a long-term tendency that comes from one's environmental and biological influences. Facts that affect a person's dispositional trust are culture, age, gender and personality traits. Situational trust is when a person's trust development and its significance related to behaviour vary greatly depends on the situation, they are in. This variability is further divided into two. One is internal variability and the other is external variability. Internal variability refers to one's attention capacity, subject matter-expertise, mood. In case of external variability, the type of system, it's complexity and the difficulty of the task in which the system is used matters (Bailey & Scerbo, 2007). Workload, perceived risk, perceived benefits, the framing of the task are some of the significant factors that affect external variability. Learned trust is the one that an operator represents by evaluating the system with his/her previous experience. It is related to the operator's pre-existing knowledge and performance of an automated system. Learned trust is further classified into two, they are initially learned trust, which is one's trust initially on the system while interacting with it, and dynamically learned trust, it is the trust learned during the period interaction. There are studies that show experience with automation or similar technologies makes a user trust or rely automation (Yuviler-Gavish & Gopher, 2011).

In contradiction, there are studies that show that experienced persons show lower trust in automation (Bailey & Scerbo, 2007).

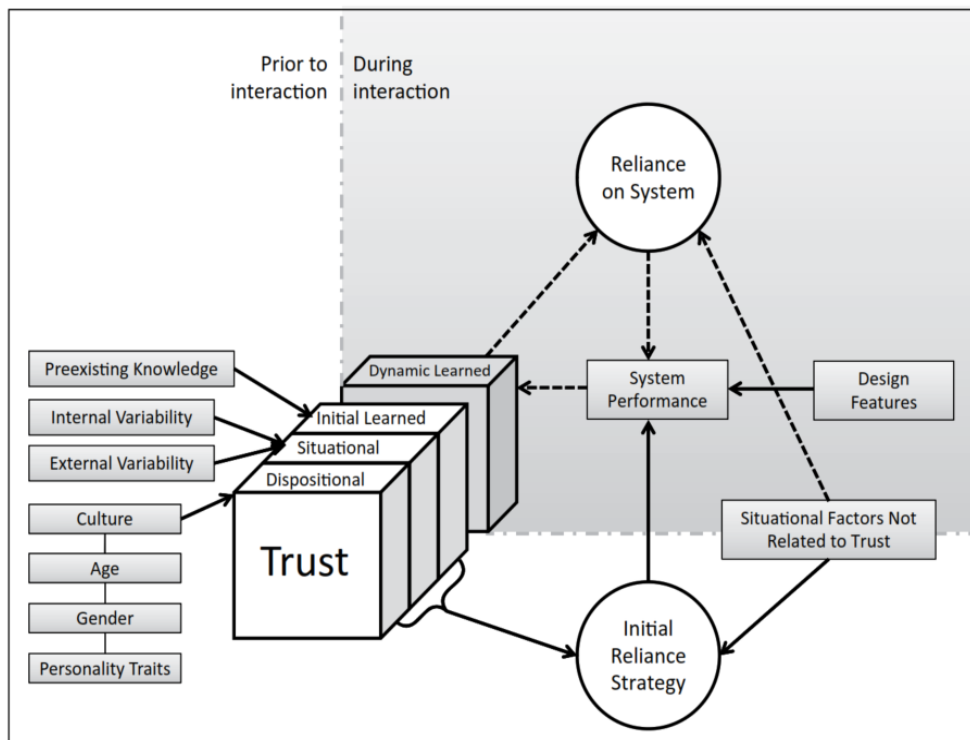


Figure 3: The three-layered trust model (Hoff & Bashir, 2015).

1.3 Automation trust problem: Overtrust and Undertrust.

Research on automation trust focuses on the effects of overtrust and undertrust because of the life-threatening potential when it is unmanaged. When the level of trust overestimates the system capabilities for automation, it is termed as overtrust. Undertrust is when the level of system capabilities for automation are underestimated by the user and this can lead to disuse of automation (Lee & See, 2004). Misuse of automation by overtrusting may lead to accidents. This may happen even by disusing automation as a result of undertrust (Parasuraman & Riley, 1997).

In the context of AD, one could argue that for traffic safety undertrust may be better, since the driver will be more attentive and have higher readiness to take back driving control (Carsten & Martens, 2019) but the driver would compromise comfort for safety.

1.4 Automation trust indicators: behavioural and subjective methods.

According to French et al., (2018), trust is a hypothetical construct that can't be directly measured or observed but can be inferred and says that it is a demanding task to measure trust experimentally. There are different types of trust to examine, like propensity to trust (dispositional trust), history-based trust, experience-based trust (learned trust), cognitive trust, affective trust, etc. Compared to previous ways of measuring trust, as in the starting and end of the session, now many recent studies are measuring trust multiple times during the section and many studies are giving more focus on trust. For measuring trust in automation both subjective and objective scales were used.

Subjective scales are very easy to use compare to behavioural measures, but behavioural measures provide a more potential consistent method of measuring trust and easy to use when it comes to modelling and prediction (Drnec, Marathe, Lukos, & Metcalfe, 2016).

1.5 Calibration of trust in automation.

To accomplish the appropriate reliance of human operators in automation is one of the major goals that a human-automation team needs to achieve (French et al., 2018). In some conditions, a user may depend more than the available automation capability and this may lead to misuse. Under-reliance in automation can increase workload and reduced system performance, which is termed as disuse (Lee & Moray, 1992). To an extent, how well one's trust in automation matches the automation's actual performance decides the user's appropriate reliance on automation (Lee & See, 2004). The relation between human trust in automation and actual automation capability is termed as calibration (Muir, 1987). In Figure 4, when the level of trust matches the automation capabilities, appropriate calibration happens and once this level is achieved he/she can achieve their goal, even if with imperfect automation (Xu, Wickens & Rantanen, 2007), by doing necessary adjustments in the interaction with automation. This helps to achieve optimum performance and safety (Wickens, Gempler & Morpew, 2000).

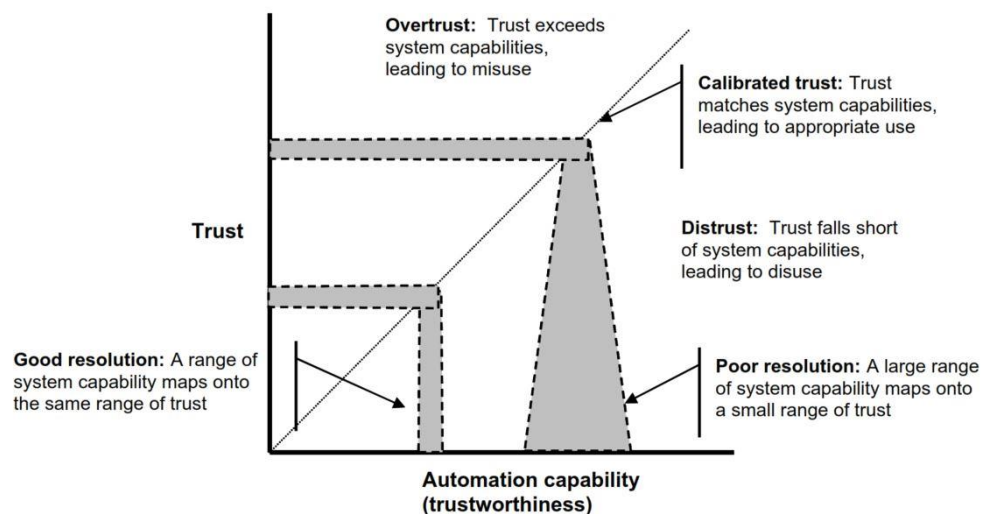


Figure 4: Relationship between automation capabilities and trust (Wicks et al. 1999).

1.6 Objectives

The objective of this study is to develop an HMI that will enhance people's trust in AD and in turn improve the acceptance of AVs on public by considering the requirements from the BRAVE project. The design principles developed from the BRAVE project with a user-centric approach are to be followed. Learned trust, dispositional trust, situational trust can be calibrated to know the impact of this HMI on a driver.

Questions on Trust:

1. What factors influence subjective situational trust (SATI) while driving L3 automated?
 - a. What is the role of dispositional trust?
 - b. What is the role of learned trust?
 - c. What is the role of the type/level of assistance?
(There were four conditions, where the type of assistance/information provided regarding VRU varied, *a*) no M-HMI and no Warning HMI, *b*) only M-HMI and no Warning-HMI *c*) only Warning-HMI and no M-HMI, *d*) both Warning-HMI and M-HMI.
 - d. Do dispositional trust, learned trust and type/level of assistance interact?
2. How do the above factors (i.e., dispositional trust, learned trust and type/level of assistance) affect each component of situational trust (i.e., SATI items)?

Questions on Safety:

3. How do the above factors (i.e., dispositional trust, learned trust and type/level of assistance) influence safety?

2 Methods

To investigate how and what factors affect a driver's trust in Level 3 AD, specific driving situations and functions are to be tested in real life. Since these driving situations are critical and not safe to be tested on real roads, the study was conducted in a moving-based driving simulator which was made to behave as a Level 3 AV which drives through an urban road. When the participants for the simulator study were ready, they went through four different driving conditions in a half an hour drive with a Level 3 AV equipped in the simulator. Various trust measures were collected from them.

Bindewald, Rusnock, and Miller (2018) say that behavioural measurements of trust have more validity than self-reported trust. For driver's behavioural measures in BRAVE driving simulator study, video recordings of driver's upper body movement and foot-pedal operation, use of different steering mounted automation functions, use of NDRT, vehicle position (simulator log data), etc. were collected. For subjective data collection, two self-reported trust scales are used. One is a dispositional trust (propensity to trust) or general trust in automation (Schneider et al., 2017) and situational trust scales (SATI) (Dehn, 2008) are used. To calculate workload, NASA Raw-TLX was used. For this thesis study, only dispositional trust scores and situational trust scores were used as subjective measures. Simulator log data on the driver's reaction to the obstacle was the only data used as a behavioural measure. Gaze behaviour was captured with five SmartEye cameras. This measure comes under the category of psychology and neural measures but not used for this thesis study because of time constraints.

Before the driving experiment started, the participants were informed about the purpose, expected duration, and procedure of the study, their right to withdraw the participation and the consequences that might cause and the limits of confidentiality. Then they were asked to sign the consent form (*Appendix C*) after reading that.

2.1 HMI concept for autonomous vehicles on urban roads.

An HMI's design and functions are very crucial, unless a vehicle is fully autonomous, to ensure that the human and autonomous system collaborates safely. When the driver is out of the loop and engaged in NDRT, the design is even more crucial (Carsten & Martens, 2019). The driver who is in an automated vehicle may not completely understand that the autonomous system cannot work in all situations. It is highly important to make the driver in an autonomous vehicle aware of system capabilities and this can be implemented using HMIs. They play a major role in making the human understand what is expected by a system in terms of monitoring and active intervention. These understandings are considered as a pre-requisite to calibrate trust and for safe and comfortable operation (Carsten & Martens, 2019). For the development of HMIs that establish better understanding between two agents (humans and vehicles), Carsten and Martens (2019) suggested HMI design principles (*Figure 5a*). For developing a new HMI, along with HMI design principles of Carsten & Martens (2019), the design principles formed by BRAVE (*Figure 5b*) through a user-centric approach was also used.

HMI design principles according to Oliver Carsten.

1. Provide required understanding of the AV capabilities and status (minimize mode errors)
2. Engender correct calibration of trust.
3. Stimulate appropriate level of attention and intervention.
4. Minimize automation surprises.
5. Provide comfort to the human user, i.e. reduce uncertainty and stress.
6. Be usable.

Figure 5 a): Design principles by Carsten & Martens (2019).

HMI principles developed by BRAVE with its user centric approach.

1. If the system is in control, drivers do not want to be disturbed.
2. System transparency on what the vehicle does and why can enhance trust.
3. The amount of information provided should be adjustable (e.g. depend on the driver 's trust and experience with the system).
4. To inform the driver about the vehicle and the environment mainly visual feedback should be used.
5. Auditory and haptic feedback should only be used in case a driver reaction is necessary.

Figure 5 b): Design principles by BRAVE.

In an urban traffic environment, it is very common for a vehicle to interact with VRUs, such as bicyclists, pedestrians, other vehicles, etc., numerous times than in highways. When a Level 3 AD pass through an urban road and the vehicle is in automation mode, the driver is likely to be engaged in NDRT. In this scenario, if an unexpected situation happens, for example, a pedestrian broke a traffic rule and crosses the road when it's a red signal for pedestrians to cross the road. The AV may not be able to handle the unexpected situation and ask the driver who is engaged in NDRT (Llaneras et al., 2013) to take back the driving control. In this case, the driver's readiness to take back driving control is questionable. This can lead to automation surprises. The absence of expected actions or presence of unexpected actions is considered as automation surprise (Carsten & Martens, 2019). According to this study, a well-designed automated system should be able to pre-alert the driver about the future situation through prediction to avoid automation surprises. By considering the concept of OOTL, a study from Merat et al. (2019), a driver in an AV can be in two different loops. When the driver is in control loop (in the loop), he/she must monitor automation (both the driving task and the driving environment) and should be ready to take back control, if the system requests, by keeping the foot on brake/acceleration and hands-on steering wheel. In the monitoring loop (on the loop) the driver monitors the automation but is not engaged with manual controls. When the driver stops monitoring and may or may not be engaged with pedals and steering wheel, he/she is considered as OOTL. This case is when the driver is

engaged with manual controls, he/she may not be monitoring the automation because of sleepiness, boredom, tiredness, lack of attention capability, etc. This lack of monitoring reduces situational awareness, which can lead to human error, the reason for most road accidents.

2.2 Equipment and data acquisition

2.2.1 Simulator IV

The study took place in simulator IV at the VTI office in Gothenburg. The SIM IV is a moving base driving simulator (Figure 6 c), which can move longitudinally, laterally and provide rotation along all the axis. Simulator IV uses CORE software which manages the simulator kernel and the VISIR software supports the graphics for the 180° field of view (Jansson et al., 2014). The front and side views from the driver seat are created with the help of eight projectors which show the surrounding of the vehicle including the landscape, road, traffic, pedestrians. Three rear-view mirrors, one on each side and one in the center, which was equipped with LCD screens are used. The cabin of a Volvo XC60 (Figure 6 a) with an automatic gearbox, was mounted for this study. This car cabin is equipped with three cameras: a) one side view, which records participant's upper body movements, b) a front camera recording the front view (Figure 6 b), and, c) a camera recording the driver's feet movement. Five SmartEye cameras were used to record drivers' gaze behaviour. Besides the videos, vehicle dynamics data were also recorded. These include data like lateral and longitudinal vehicle position, speed, braking, steering position and steering mounted controls usage, time, etc.

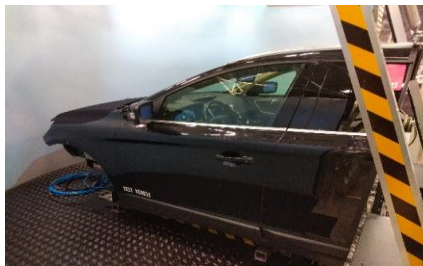


Figure 6 a): Simulator vehicle Volvo XC60



Figure 6 b): View from driver seat.



Figure 6 c): VTI Driving simulator IV

2.2.2 Scenarios

Four different conditions that are used for this study as shown in Figure 7 and they are named as A, B, C, and D. Each condition lasted for 6 minutes and is represented with the long blue arrow. A combination of these four conditions in four different orders has been made using a Latin Square design (Dodge, 2008) to counterbalance and to reduce

the possibility of an order effect. Each set of combinations were considered as one order. So, there were four different orders. Order one is ABCD, order two BADC, order three CDAB, and order four DCBA. Order one is allotted to participant one then orders two to participant two, order three to participant three, order four to participant four and fifth participant will experience order one and this arrangement was repeated until it reached thirty-four participants.

In all the four sets of orders, the participant encountered unexpected crossing of a pedestrian as shown in Figure 7. In condition A the participant didn't get either the support of monitoring HMI (M-HMI) or Warning- HMI (warning). In B, the participant received only M-HMI support before encountering the pedestrian. Condition C is supported with only warning before encountering the pedestrian and this warning was always integrated with a brake-pulse, which acted as haptic feedback in the initial stage of warning. In condition D the participant received both the support, initially from HMI then warning, before encountering the pedestrian. Once the warning was deployed, the driver will get a few seconds to brake and stop the vehicle without hitting the pedestrian. If he/she doesn't brake adequately, the vehicle will hit the pedestrian and that may make the participant uncomfortable. To avoid this situation a point-of-no-return (PoNR) (Strand et al., 2014) is fixed. That is, if the participant (driver) brakes the vehicle 30 seconds before reaching the unexpected pedestrian, he/she can save the pedestrian, if later than 30 seconds, then that is counted as a collision but in this case, the pedestrian appears to accelerate (run) fast. This allows the driver to drive the vehicle without any interruption.

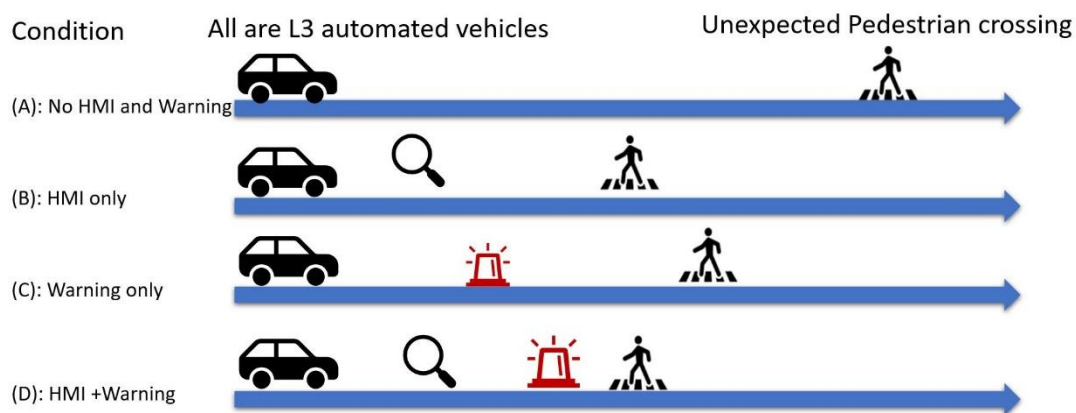


Figure 7: The four different driving conditions tested.

2.2.3 Additional task

A Windows 'LAMINA' tablet was used for this study. This tablet was attached to the center console of the vehicle as shown in Figure 8 and the following popular documentaries were provided: 'National Parks Adventure', 'Explained', 'Street Food', 'Antoine Griezmann En Legend Bur Till', 'The Creative Brain'. These topics were selected from different fields like sports, science, nature, food, culture, etc. on Netflix (Herrmann et al., 2018). The participants were asked to watch the videos whenever they felt comfortable during the drive. Thus, this task was intended to simulate the foreseeable situation in which drivers will divert attention from the driving task to NDRT when they are supported by the Level 3 system. Engaging in the secondary task is the driver's behavioural indicator of trust in AD. These videos were pre-downloaded

to avoid the chance of Wi-Fi interruption during its use. The data from this task are not used for this thesis work but this task was influential for the measured trust scores.



Figure 8: The tablet screen setup inside the simulator vehicle.

2.2.4 Subjective data

2.2.4.1 Dispositional Trust Questionnaire

A general tendency and willingness of a person to trust another are termed as the propensity to trust (Mayer et al., 1995). For a significant prediction of trusting behaviours of participants and perceived trustworthiness in the automation, and adapted propensity to trust scale is considered as the best option (Jessup et al., 2019). Therefore, to measure participant's dispositional trust, a five-point 'Adapted Propensity to Trust in Technology (Adapted PTT)' scale was used (Schneider et al., 2017). In this, participants were asked to rate six statements. A 5-point Likert Scale starting from 1 (strongly disagree) to 5 (strongly agree) and an average of these six rated statements was taken to compute the overall Adapted PTT score of a participant (*Figure 9*).

	1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree
1. Generally, I trust automated machines					
2. Automated machines help me solve many problems					
3. I think it's a good idea to rely on automated machines for help					
4. I don't trust the information I get from automated machines					
5. Automated machines are reliable					
6. I rely on automated machines					

Figure 9: Adapted propensity to trust in technology (dispositional trust) questionnaire (Schneider et al., 2017).

2.2.4.2 SHAPE Automated Trust Index (SATI) Questionnaire

The SATI questionnaire is a part of the SHAPE questionnaire (Dehn, 2008) can be seen in Figure 10. SATI serves the purpose of measuring human trust in Air Traffic Control (ATC) systems and other forms of automation support. In this study, SATI used as a subjective measurement of the situational trust of participants with the Level 3 (L3) vehicle when provided with different driving support systems, that is, across the different conditions. There are six questions in a SATI questionnaire each focusing on a different system property, i.e., reliability, usability, understanding, robustness, confidence, and accuracy. The participants were asked to rate each item on a 7-point Likert scale from 0 (Never) to 6 (Always). Changes were made in the original SATI questions for better understandability of questions and to help participants to relate them with the experimental situation. SATI global score was calculated by averaging the scores from the six items.

Q.1 – In the last drive:	Never						Always
		0	1	2	3	4	
Was the vehicle useful? (I would use it in real life)	0	1	2	3	4	5	6
Was the vehicle reliable? (you relied on the vehicle performance)	0	1	2	3	4	5	6
Did the vehicle work accurately? (the vehicle performed its tasks adequately)	0	1	2	3	4	5	6
Was the vehicle understandable? (the actions/information of the vehicle were understandable to me)	0	1	2	3	4	5	6
Did the Autonomous system work robustly? (the vehicle worked properly in difficult situations)	0	1	2	3	4	5	6
Did you feel confident being in this vehicle?	0	1	2	3	4	5	6

Figure 10: SATI questionnaire (Dehn, 2008).

2.1 Participants

Thirty-four participants were recruited for this simulator study and they were in the age range between 32 and 62 years old ($M= 45.20$, $SD= 8.78$). There were 6 female and 28 male participants. The recruitment process was carried out using the VTI database and with the help of a Facebook advertisement. The participants were divided into two groups accordingly to whether they have SAE Level 2 vehicle driving experience or not (*Table 1*). For each participant in a Level 2 experienced (L2E) group, they had an equal match with Level 2 inexperienced (L2I) group in terms of age similarity.

Selection criteria for being a participant for this study:

1. Valid driving license.
2. At least 5 years of driving experience.
3. Age between 25 – 65 years old
4. No previous tendency of simulator sickness

After the study the participants were rewarded with a present card worth 200SEK for being a part of this study.

Table 1 Number of participants who had experience with different driving support systems.

Description	Number
Total Number of participants	34
Male	28
Female	6
L2 Experienced drivers(L2E)	16
L2 Inexperienced drivers(L2I)	18
Experience with only Cruise Control	11
Experience with only Adaptive Cruise Control	4
Experience with Adaptive Cruise Control and Lane Departure Warning	3
Experience with Adaptive Cruise Control and Lane Keeping System	15
Experience with no driving support systems	1

2.2 Experimental design

A 2x2x2 mixed design was used for this study. Two within-subject factors were analyzed: *a*) M-HMI (not present vs. present), *b*) Warning (not present vs. present). In addition, prior Level 2 experience (yes vs. no) was included as a between-subjects factor. As a result, the study consisted of four conditions combining the presence or absence of the pre-warning and warning systems (Figure 11). Finally, the effects of dispositional trust were also investigated by including dispositional trust as a covariate.

Independent factors	Between group: Level 2 experience	Yes	No
	Within group	No HMI + No warning(A)	
		HMI only(B)	
		Warning only(C)	
		HMI + Warning(D)	
Dependent variable (SATI)	Utility		
	Reliability		
	Accuracy		
	Understandability		
	Robustness		
	Confidence		
Covariant	Dispositional trust		

Figure 11: Experimental design.

2.3 Procedure

Each participant spent around one hour for the entire simulator study. Once the participant arrived at VTI Gothenburg office, the test leader welcomed him/her to the simulator room and made sure that participants had gone through the information sheet (*Appendix A, Appendix B*) that contains details on the general purpose of study, autonomous and monitoring systems used for the study, their task, etc. Then verbal information about how to automate the vehicle and how the new VRU monitoring system (M-HMI) appears during the drive are provided along with figures for their better understanding (*Appendix B*). After that, the participant was asked to sign a consent form and then to fill the dispositional trust questionnaire. After that, they were invited to the driving simulator. In the simulator the participant was seated and asked to get familiar with functions like engine On/Off, automation ‘On’ which means green steering wheel icon on the instrument cluster and automation ‘Off’ is represented as blue also showed the button to operate the automation and ‘ok’ button mounted on the steering wheel. This button had two purposes, one to know that the driver noticed the M-HMI message which appears on the screen and another to confirm that they have answered the questionnaire during the drive, both by pressing ‘ok’.

The four-page questionnaire i.e. one SATI and one NASA Raw TLX survey per each page (*Appendix E*) was handed out and explained that when they get a request to fill the questionnaire during the driving simulator study they have to answer them four times during the experiment. They were also informed that he/she can watch videos on the tablet when they feel comfortable to do so. After that, they were asked if they have any questions. When these initial setups in the simulator are completed, the practice test started.

The participant went through a practice session for six minutes. During this time the participant was asked to try driving by themselves and to try the vehicle automation function. Once the practice section was over the participant was asked to stop the vehicle and asked about his/her comfort to continue with the main study. Then the SmartEye calibration was carried out. Once the calibration was completed the main study started. The participant was asked to drive the vehicle and press the automation button and informed that while the vehicle is in automation mode, he/she can use the Netflix in the tablet to watch a video if they feel comfortable with it. The remaining twenty-four minutes out of thirty was a single stretch of driving through the urban road. This section was further divided into four and each section continued for six minutes. After each case, a request appeared on the screen, ‘Please fill the questionnaire’. Without stopping the vehicle, the participant can fill the SATI and NASA-RTLX and once both the questionnaires are answered he/she should press the ‘ok’ button on the steering wheel. Then the next scenario will be activated by the simulator program automatically (*Figure 12*).

Once all four conditions were completed, they are taken to the discussion table and asked to share their experience, relevant points were noted by the test leader. The participant received an explanation of the study and a gift card worth 200SEK was offered as a reward for their participation.

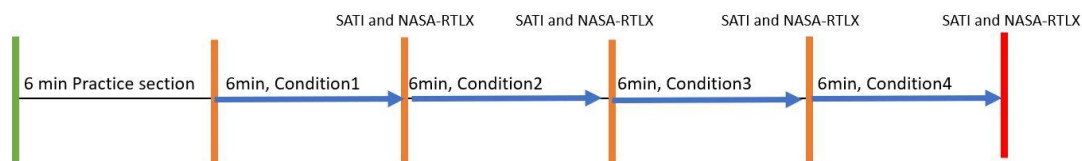


Figure 12: Sequence of event.

2.4 Statistical analyses

Statistical analysis was conducted on IBM SPSS version 25 statistical software. Mean and standard deviations are used for descriptive purposes. A 2x2x2 mixed model ANOVA was carried out to explore main and interaction effects of M-HMI (within-subjects), warning (within-subjects) and Level 2 experience (between-subjects). Dispositional trust was measured as a continuous variable and introduced in the model as a covariate. On a separate section, an analysis of collisions was performed by using Chi-square analyses. Alpha level was set at .05 and corrected using Bonferroni’s method to protect against type-III error. Finally, partial eta-squared was used as effect size.

3 Result

In this chapter, the results of statistical analysis, main effects, interaction effects, and the developed co-monitoring HMI are presented.

3.1 The development of co-monitoring HMI concept.

The co-monitoring HMI (M-HMI) concept was developed for enhancing safety, driver trust in AD and inducing appropriate situational attention levels. For this thesis, this M-HMI is used during Level 3 AD in urban roads, however, this tool may well be used in other contexts not considered here, like rural roads or motorways. The M-HMI conveys driver the information provided by Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication systems (V2V and V2I respectively) regarding the presence of VRUs nearby the vehicle with whom the automated system may potentially interact. This function serves as a preview system of other VRUs that are beyond or out of the driver's view, presumably prompting safer attentional strategies. As an example, drivers may safely engage in watching video while driving Level 3-automated, as long as the M-HMI does not inform of potential VRUs. In other words, drivers may safely remain out-of-the-loop (*Figure 13a*) and benefit from the support provided by the automated system. By contrast, if a VRU that may potentially interact with the driver is detected, the M-HMI will inform and encourage him/her to co-monitor (*Figure 13b*). From the driver role perspective, this situation may resemble a Level 2 driving, where drivers are always expected to monitor. However, the difference lies in that, on the technical side, the system continues the Level 3 mode, as it still monitors the environment and reacts to it. Using Merat et al. (2019) model as a framework, the M-HMI strategically brings the drivers into the monitoring loop (*Figure 13a*), which in turn, should smooth the process of getting back into the control loop (*Figure 13a*). In this sense, the M-HMI, rather than a replacement for the take-over warnings, will complement them but increasing drivers' responsiveness.

It is argued here that the M-HMI may also induce more adequate levels of trust in the system through higher system transparency. In terms of the trust, this may translate into trust levels that match better the system capabilities in a given moment. On the one hand, overtrust and misuse of the system may be mitigated by the system encouraging co-monitoring from the driver. On the other hand, distrust and disuse may be counteracted due to the drivers being better informed of when it is safe to divert attention from the road.

For achieving overall safety, the joint cognitive system, i.e. monitoring by the M-HMI and co-monitoring by the driver/operator, should happen flawlessly. For this, it is made sure that the M-HMI not only provides information to the driver, when attention is needed but also, he/she received the information without fail by collecting feedback. That is, when this M-HMI detects VRUs nearby, it informs the driver with a pop-up message on the screen (*Figure 13 c*). By pressing the 'ok' button on the steering wheel the driver acknowledges that he/she has received the message. Other than driving assistance from M-HMI, the state-of-the-art forward-collision warning HMI (Warning HMI), was also used. With a Warning HMI, the driver initially received a brake-pulse (tactile feedback) and followed by blinking red lights (visual feedback) along with a cabin beep sound (auditory feedback) inside the vehicle cabin. This warning was given in a situation where the driver in the AV must control the vehicle motion safely to avoid a predicted collision.

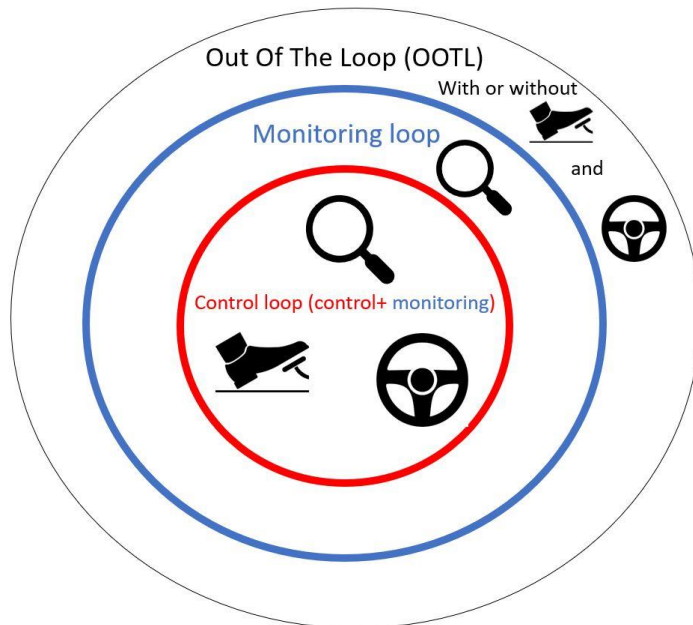


Figure 13 a): Driving automation loop.



Figure 13 b): Instrument cluster showing the M-HMI



Figure 13 c): The pop-up message when M-HMI detects VRUs nearby.

3.2 Descriptive statistics

Table 2: Overall measured Trust scores for L2I and L2E groups.

Condition	SATI & Global	L2_Inexperienced Drivers			L2_ Experienced Drivers		
		Mean	SD	Sample size	Mean	SD	Sample size
Dispositional Trust		3.83	.45	18	3.86	.69	16
C1 No HMI and warning	Utility	2.94	1.76	18	3.66	1.83	15
	Reliability	3.27	1.52	18	2.93	1.94	15
	Accuracy	3.66	1.60	18	2.40	1.63	15
	Understandability	4.55	1.09	18	3.78	1.80	15
	Robustness	3.00	1.74	18	2.00	1.96	15
	Confidence	2.77	1.69	18	2.86	2.19	15
	Global	3.37	1.12	18	3.17	1.57	13
C2 Only HMI	Utility	3.16	1.50	18	4.28	1.48	14
	Reliability	2.88	1.36	18	3.71	1.26	14
	Accuracy	3.05	1.86	18	3.64	1.27	14
	Understandability	4.00	1.49	18	4.71	0.99	14
	Robustness	2.77	1.86	18	3.21	1.31	14
	Confidence	2.66	1.53	18	4.14	1.35	14
	Global	3.09	1.31	18	3.95	1.05	14
C3 Only Warning	Utility	3.66	1.32	18	4.43	1.15	16
	Reliability	3.61	1.09	18	4.18	1.16	16
	Accuracy	3.66	1.08	18	4.25	1.57	16
	Understandability	4.22	0.80	18	4.56	1.59	16
	Robustness	3.83	1.15	18	4.18	1.55	16
	Confidence	3.33	1.08	18	3.81	1.68	16
	Global	3.72	0.70	18	4.24	1.28	16
C4 Both HMI and Warning	Utility	3.88	1.26	17	4.33	1.54	15
	Reliability	3.35	1.22	17	4.33	1.44	15
	Accuracy	3.52	1.54	17	4.80	1.20	15
	Understandability	4.25	1.25	17	4.86	1.18	15
	Robustness	3.47	1.50	17	4.66	1.34	15
	Confidence	3.23	1.09	17	4.33	1.63	15
	Global	3.62	0.96	17	4.56	1.13	15

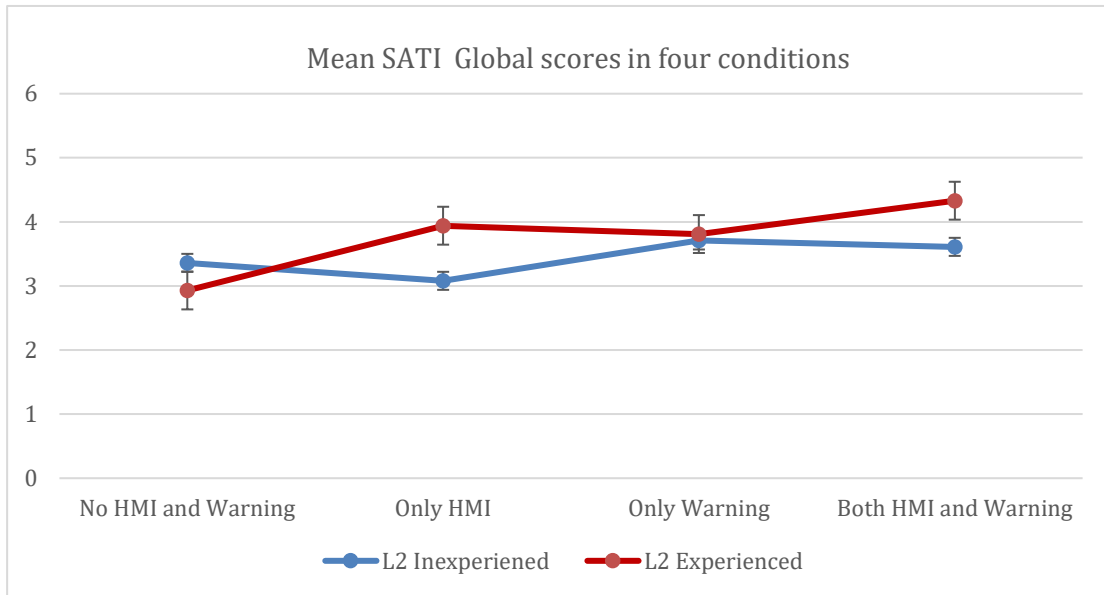


Figure 14: Mean SATI global score in four conditions.

The average scores per group and condition are presented in Table 2. Overall, average scores were moderate-high (roughly between 3-4), showing a certain tendency towards trusting the automated system. Global scores represented in Figure 14 indicate a light increment in overall trust as drivers receive more support. Such increment seems more evident for the drivers with L2 experience. Dispositional trust levels were also rather high for both groups of drivers with scores over 3.8 out of 5.

Table 3: Main and interaction effects analyzed in the mixed ANOVAs. *F*, *P*-values and Partial-eta squared values are presented. Degrees of freedom were 1 and 27 for all the cases.

SATI items		F	P-value	Partial eta-squared	Direction of post-hocs
Utility	HMI	2.80	.11	.094	
	Warning	.01	.93	.00	
	L2 experience	4.71	.04	.15	*Experienced (Exp) > Inexperienced(I-Exp)
	Dispositional trust (DT)	8.49	.01	.24	*Increased DT increases utility
	HMI*Warning	1.22	.28	.04	
	HMI*L2 experience	.01	.93	.00	
	Warning*L2 experience	.17	.69	.01	
	HMI*Warning*L2 experience	1.46	.28	.05	
Reliability	HMI	.15	.67	.01	
	Warning	.24	.63	.01	
	L2 experience	2.34	.13	.08	
	Dispositional trust	2.78	.11	.09	
	HMI*Warning	.05	.83	.00	
	HMI*L2 experience	4.13	.05	.13	
	Warning*L2 experience	.88	.35	.03	
	HMI*Warning*L2 experience	1.91	.18	.07	
Accuracy	HMI	1.68	.20	.06	
	Warning	.68	.42	.03	
	L2 experience	1.40	.25	.05	
	Dispositional trust	4.09	.05	.13	
	HMI*Warning	.00	.99	.00	
	HMI*L2 experience	4.85	.04	.15	a) *When HMI was 'On', Exp > I-Exp b) For Exp drivers, HMI 'On' > 'Off'
	Warning*L2 experience	4.96	.03	.16	a) *When Warning was 'On', Exp > I-Exp b) For Exp drivers, Warning 'On' > Warning 'Off'

	HMI*Warning*L2 experience	.94	.34	.03	
Understandability	HMI	8.02	.01	.23	*HMI 'On' >'Off'
	Warning	.10	.75	.00	
	L2 experience	.53	.47	.02	
	Dispositional trust	1.71	.20	.06	
	HMI*Warning	2.96	.10	.10	
	HMI*L2 experience	7.54	.01	.22	a) *When HMI was 'On', Exp > I-Exp b) For Experienced drivers, HMI 'On' > 'Off'
	Warning*L2 experience	2.42	.13	.08	
	HMI*Warning*L2 experience	5.19	.03	.16	a) *When HMI and Warning was 'On', Exp > I-Exp b) For Exp drivers, HMI and warning 'On' > 'Off'
Robustness	HMI	1.92	.18	.07	
	Warning	.98	.77	.00	
	L2 experience	1.44	.24	.05	
	Dispositional trust	.75	.40	.03	
	HMI*Warning	.35	.56	.01	
	HMI*L2 experience	4.08	.05	.13	
	Warning*L2 experience	2.24	.15	.08	
	HMI*Warning*L2 experience	1.15	.29	.04	
Confidence	HMI	.99	.33	.04	
	Warning	.07	.79	.00	
	L2 experience	5.23	.03	.162	*Experienced > Inexperienced
	Dispositional trust	5.07	.03	.16	*Increase in DT increases confidence.
	HMI*Warning	.41	.53	.02	
	HMI*L2 experience	5.69	.02	.17	a) *When HMI was 'On', Exp > I-Exp b) For Experienced drivers, HMI 'On' > 'Off'
	Warning*L2 experience	.05	.81	.00	
	HMI*Warning*L2 experience	3.40	.08	.11	
Global	HMI	3.78	.06	.12	
	Warning	.02	.90	.00	
	L2 experience	3.66	.07	.12	
	Dispositional trust	5.23	.03	.16	*Increase in DT increases SATI global scores.
	HMI*Warning	.41	.53	.02	
	HMI*L2 experience	7.19	.01	.21	a) *When HMI was 'On', Exp > I-Exp b) For Experienced drivers, HMI 'On' > 'Off'
	Warning*L2 experience	1.72	.20	.06	
	HMI*Warning*L2 experience	4.02	.06	.13	

* < .05; ** < .01

As shown by the mixed ANOVAs, no main effects of *warning* were observed on any of the SATI items. As for the *HMI* factor, this function only increased the understandability perception of the overall system (*Table 3*), however, it did not show any effect on the remaining SATI items. Dispositional trust significantly did covariate with *utility*, *confidence* and *global* scores. These linear relationships are illustrated in *Figure 15*, *Figure 16* and *Figure 17*. As shown, positive linear relationships were found, indicating that higher dispositional trust is reflected in higher trust. Moreover, statistical analyses revealed that drivers with prior experience with L2 systems had a greater perception of *utility* and *confidence* of the simulated L3 system. Differences between L2 experienced and non-experienced drivers became more evident when the HMI and/or the warning was on. When using the HMI, experienced drivers scores higher in *accuracy*, *understandability*, *confidence*, and *global* score. When the warning was active, the L2 experienced driver displayed higher *accuracy* perception. Finally, when both systems were active, L2 experienced drivers reported the system as more understandable. All these interactions effects are shown in *Table 4*, and illustrated in *Figure 19*, *Figure 20*, *Figure 21* and *Figure 22*.

Main effects:

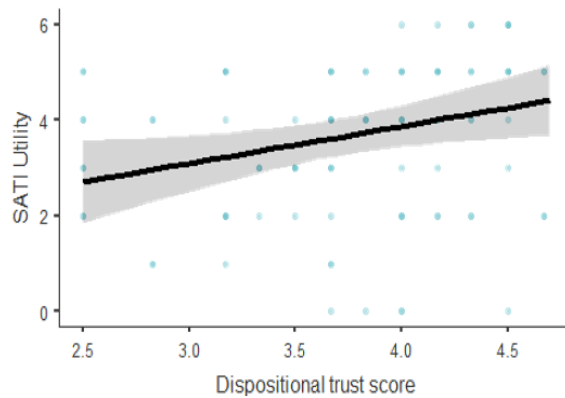


Figure 15: Combining all four SATI scores of all conditions (ABCD) the linear relationship of utility with dispositional trust is noticeable ($p=.01$).

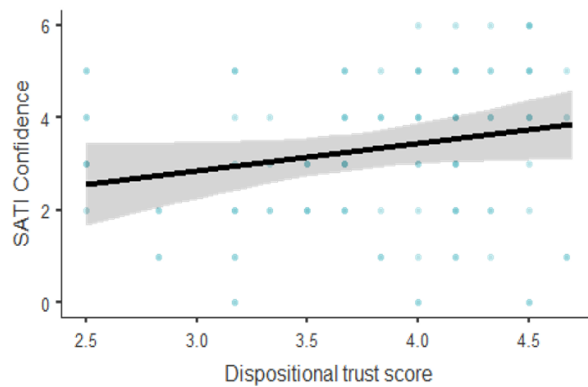


Figure 16: Combining all four SATI scores of all conditions (ABCD) the linear relationship of confidence with dispositional trust is noticeable ($p=.03$).

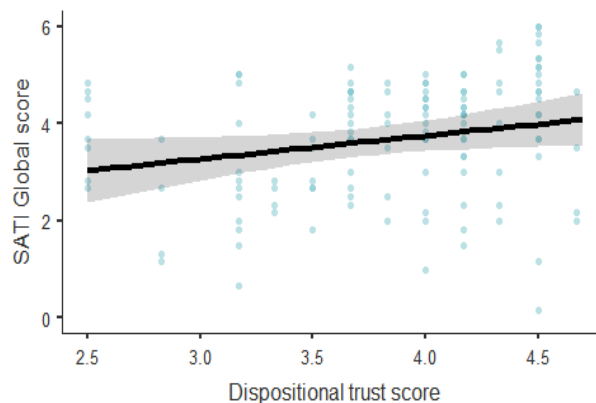


Figure 17: Combining all four SATI scores of all conditions (ABCD) the linear relationship of SATI global score with dispositional trust is noticeable ($p=.03$).

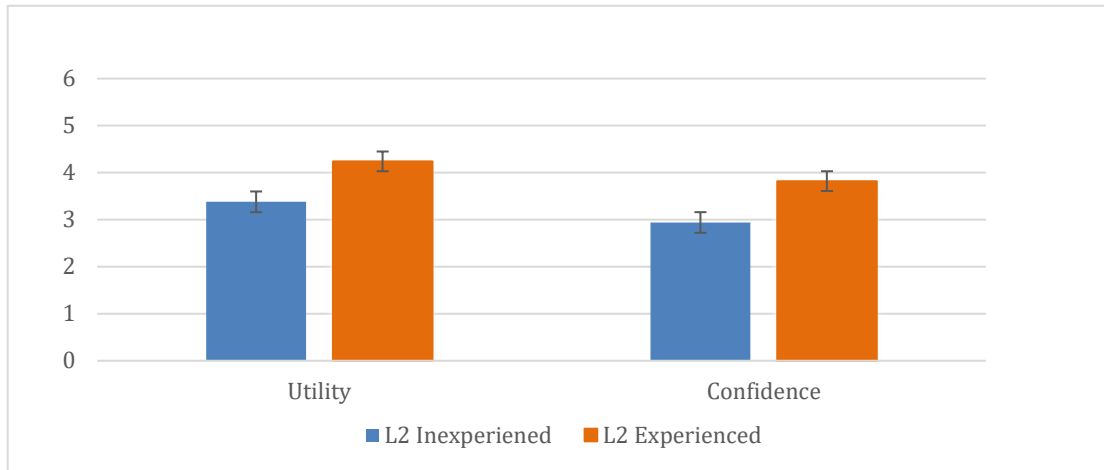


Figure 18: Main effect of SATI utility ($p=0.04$) and confidence ($p=.03$) are shown in the above bar graph. L2E drivers scored higher values in both the cases.

Interaction effects:

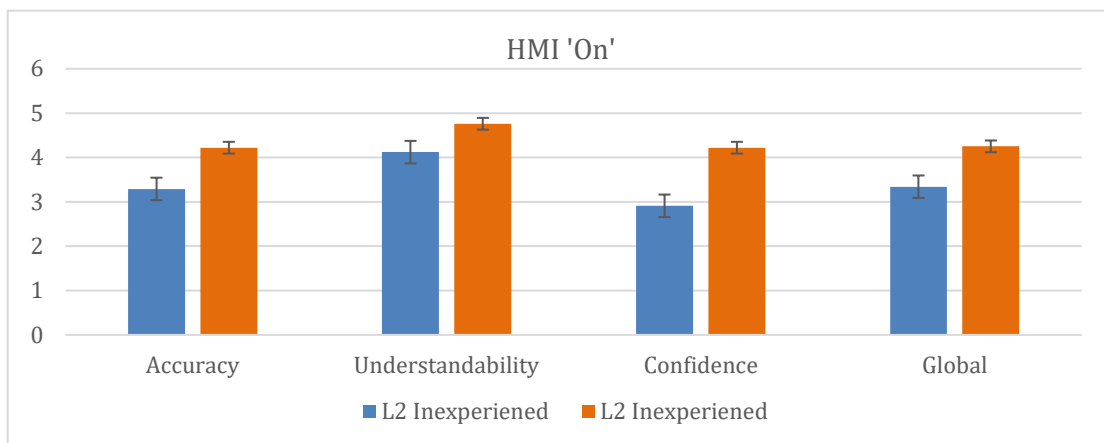


Figure 19: Interaction effect L2E group provided with HMI 'On' showed higher Accuracy ($p=.04$), understandability($p=.01$), confidence ($p=.02$), global SATI ($p=.01$), than L2I group.

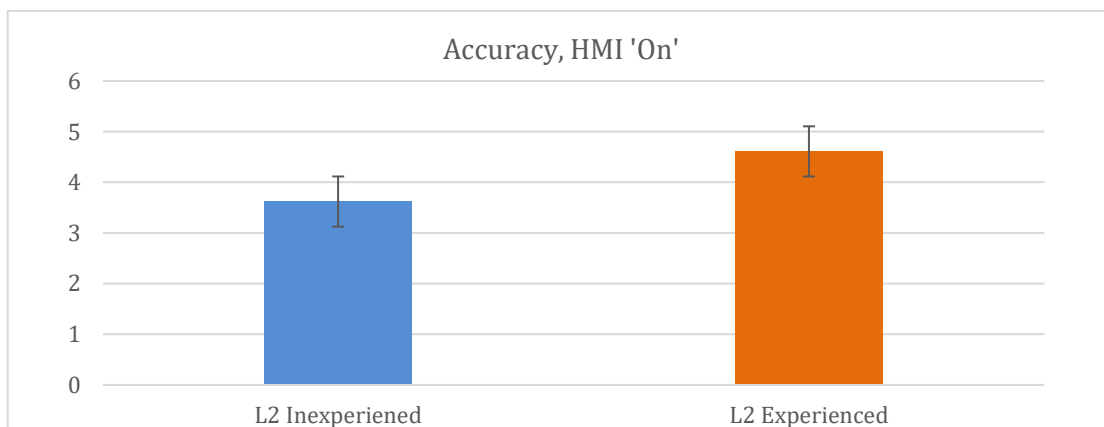


Figure 20: L2E group when provided with HMI showed higher Accuracy ($p=.03$).

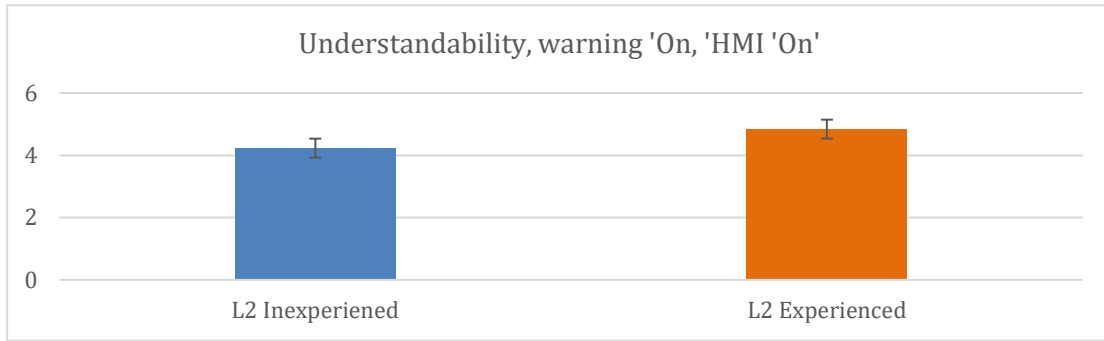


Figure 21: L2E group showed higher understandability ($p=.01$), when warning and HMI was available.

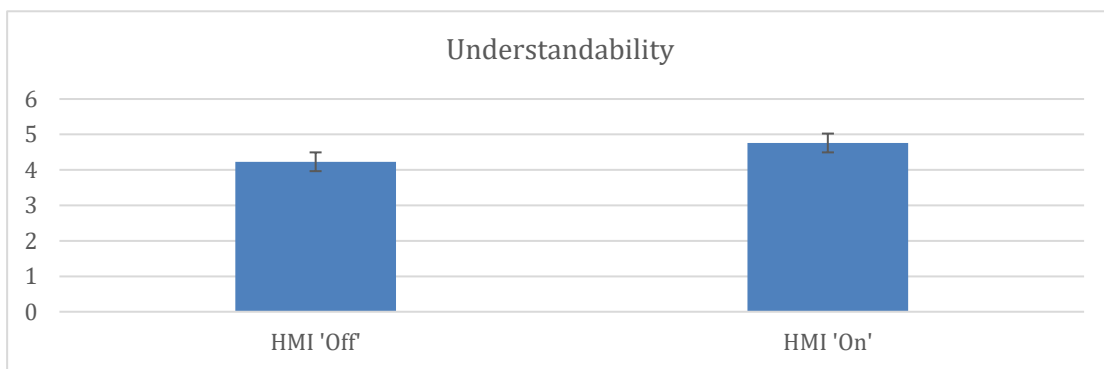


Figure 22: L2E group showed higher understandability ($p=.01$), when HMI was available.

3.3 Analysis of collisions

Categorical analyses (χ^2) revealed that the number of collisions was lower than expected by random chance when the warning was active ($\chi^2=4.23$, $P = .04$), and when drivers had prior experience with L2 systems ($\chi^2= 5,76$, $p = .01$). The frequency of collisions, however, was not dependent on the presence of the HMI ($\chi^2= .47$, $p = .5$). Further categorical analyses exploring dependencies between HMI, warning and L2 experience factors failed to detect significance (Figure 23).

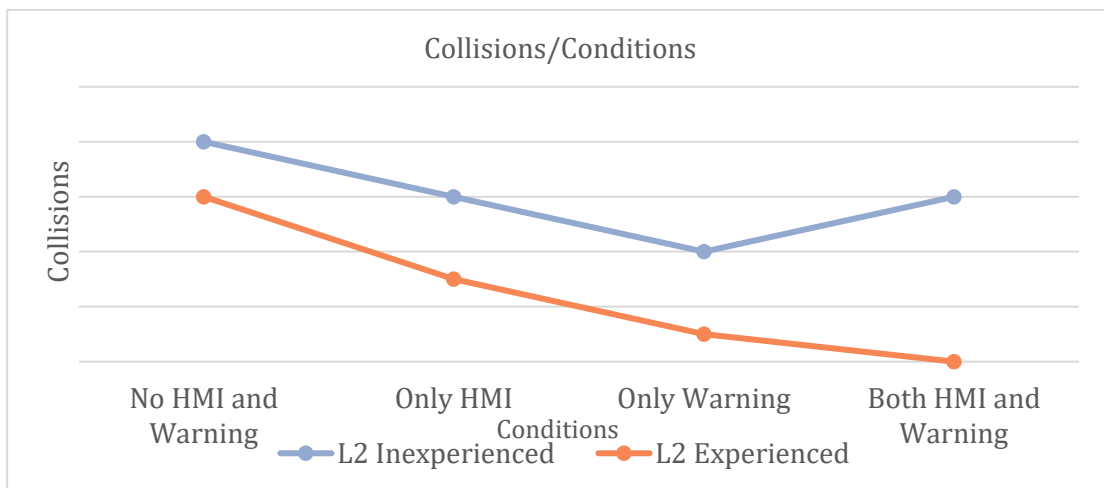


Figure 23: Collision with pedestrians in all four conditions.

4 Discussion

This thesis was conducted to enhance driver's trust in AD by developing and implementing a co-monitoring HMI in a Level 3 AV in a simulation environment. Trust measures like learned trust, situational trust, dispositional trust and simulator log data on collision with pedestrian were collected and used for this study. There were 34 participants for this study, and they were divided into two groups, according to whether they have SAE Level 2 driving experience or not (*Table 1*).

The findings from this simulator study revealed that there is a significant difference between L2 experienced and inexperienced driver groups when they interact with a Level 3 autonomous vehicle (AV). A driver with prior experience with L2 Autonomous vehicle showed more situational trust while driving an L3 AV as compared to inexperienced. Studies from Hoff and Bashir (2015), show that when the operator experiences a novel system (here, L3 AV), they assess the trustworthiness of the system with their previous experience, which is termed as learned trust. Here the drivers who had previous experience with L2 AV are the group with learned trust and they showed more situational trust, which answers study objective 1.b as true. L2E drivers showed the least robustness score while using the vehicle compared to their remaining SATI scores (*Table 2*) when none of the support systems were provided. In the same situation, L2 Inexperienced (L2I) drivers showed a comparably higher score (*Table 2*). This may be because the L2E drivers use advanced support systems or driving assistance systems for driving in their day-to-day life and its absence in this situation leads to low robustness rating. According to studies by Lee and See (2004), learned trust is the one that an operator represents by evaluating the system with his/her previous experience and this answers objective question 1.c that absence of driving support system (i.e. experience factor) will reduce the situational trust. The confidence score of L2E increased significantly when HMI was provided but at the same L2I reported lower confidence to drive the vehicle (*Table 2*). The reason could be that the L2I drivers are naive about these kinds of support systems.

Understandability scores were highest among L2I and L2E drivers and remained almost the same for both the groups when an only warning, and when both HMI and warning was provided (*Table 2*). The warning function appears just before a potential chance of collision with the pedestrian and soon they saw them crossing the road. This instant feedback might increase their level of understanding of the warning system. The analysis of the interaction effect of HMI*warning*L2E also shows significance with understandability. The level of driving support systems affects situational trust. When L2E drivers were provided with both HMI and warning, they showed the highest situational trust in L3 AV. This answers the objective question 1.c and support studies by Yuviler-Gavish and Gopher (2011), which show that experience with automation or similar technologies makes a user trust or relay automation and reject studies by Bailey and Scerbo (2007) that, experienced persons show lower trust in automation.

The dispositional score of both groups of drivers remained the same (*Table 2*). Studies (Hoff & Bashir, 2015) have shown that age plays a significant role with trust in automation but in this study, both L2I and L2E groups are balanced with respect to the age to maintain overall credibility between groups towards the experimental setup. From the results observed in (*Figure 17*), an increase in the dispositional trust will increase the situational trust in conditions where at least one or more support system was provided. An exceptional case is also noticeable in condition 'A' when no support

was provided, the situational trust of L2E drivers reduced as mentioned earlier (*Figure 14*). This shows that a person's propensity to trust automation can be used to predict his/her situational trust unless there is no lack of support than he/she previously experienced.

L2I drivers had a greater number of collisions with pedestrians (*Figure 23*) than experienced in all four conditions. This can be because of the lower sample size and this should be analysed with more data from the study. From categorical analyses (Chi^2) it is visible that the presence of a warning made a greater effect in reducing the number of collisions for L2E, but the presence of monitoring HMI along with warning in condition four did not help much to reduce collision but it did not worsen the situation.

4.1 Limitations

The data analyzed for this study are from the driving simulator which may be different from naturalistic driving data and tend to provide relative validity than absolute validity. This study has some limitations like the low sample size per group of drivers with and without Level 2 driving experience. There can be minor variations in the result because of this reason. A few of the participants failed to fill all questionnaire sheets provided to them. Maybe because of small sample size this might have minor effect on data measured. Analysis of more behavioural data are required to further analyze the situations where there are noticeable deviations in the result. For example, from PoNR we know that L2I drivers would collide with the pedestrian, but the consequences are unknown. The difficulty of getting L2E drivers in the limited study time was one of the reasons for not keeping strict gender equality. More randomness while setting the unexpected pedestrian crossing may make the condition more realistic.

4.2 Future research

The co-monitoring HMI concept can be implemented and tested in furthermore driving conditions. Implementation and testing of this HMI in real life are challenging because it requires precise and accurate V2V and V2I communication systems. For this study, the 'Monitoring Zone!' message was displayed on the simulator screen for minimizing the chance to miss the message by the driver but in real life, this message should be implemented inside the vehicle properly. As a part of BRAVE project, various data are collected like NASA-RTLX for workload analysis, SmartEye for gaze behaviour, data from videos captured, participants self-phased use of tablet for watching videos, SIM IV log data, etc. can be used for verifying the results obtained and figure more interesting facts like unexpected increase in number of collisions when L2I drivers were provided with both HMI and warning. Analysis of participant age on dispositional trust scores may show whether age is a factor that affects one's trust in automation.

5 Conclusion

This thesis work was conducted to develop a co-monitoring HMI and to find how this HMI can enhance driver's trust in Automated Driving. This study was conducted in a moving base driving simulator with 34 participants. They were divided into two groups according to whether they have SAE Level 2 driving experience or not.

The newly designed co-monitoring HMI enhanced a Level 2 experienced driver's situational trust when it was used along with the Forward Collision Warning system. The dispositional trust score remained the same for both Level 2 experienced and Level 2 inexperienced groups. There exists a positive correlation between the increased level of trust in automation and road safety. Level 2 experienced drivers performed better in terms of safety when they were provided with co-monitoring HMI and Forward Collision Warning.

Participants who had higher dispositional trust and previous experience with Level 2 AD showed an increase in utility, confidence and global situational trust scores. In general, Level 2 experienced drivers showed higher utility and confidence. The Level 2 experienced group mentioned higher understandability on the actions and information are taken and conveyed respectively by the Level 3 simulated vehicle better when the co-monitoring HMI was 'On'.

6. References

- Aeberhard, M., Rauch, S., Bahram, M., Tanzmeister, G., Thomas, J., Pilat, Y., Homm, F., Huber, W., & Kaempchen, N. (2015). Experience, results and lessons learned from automated driving on Germany's highways. *IEEE Intelligent Transportation Systems Magazine*, 7, 42–57.
- Bailey, N. R., & Scerbo, M. S. (2007). Automation-induced complacency for monitoring highly reliable systems: The role of task complexity, system experience, and operator trust. *Theoretical Issues in Ergonomics Science*, 8, 321–348.
- Barber, B. (1983). *The logic and limits of trust*. New Brunswick, NJ: Rutgers University Press.
- Bindewald, J. M., Rusnock, C. F., & Miller, M. E. (2018). Measuring human trust behaviour in human-machine teams. *In Advances in Human Intelligent Systems and Computing*, 591, 47–58.
- Bischoff, S., Diederichs, F., Fritz, N., Widlroither, H., Cabaneros, D., Johnsen, A., Sotelo, M. A., Eriksson, A., & Strand, N. (2018). Deliverable D3.1, *Development Methodology Report* (BRAVE Report No. 723021).
- Cacciabue, P.C., Carsten, O., & Vanderhaegen, F., (2014). Is there still a need for CTW?, *Cogn Technol Work*, 16(3), 311-317. <https://doi.org/10.1007/s10111-014-0286-y>
- Carsten, O., & Martens, M. H. (2019). How can humans understand their automated cars? HMI principles, problems and solutions. *Cognition, Technology & Work*. <https://doi.org/10.1007/s10111-018-0484-0>
- Damböck, D., Bengler, K., Farid, M., & Tönert, L. (2012). Übernahmezeiten beim hochautomatisierten Fahren [Takeover times for highly automated driving]. *Tagung Fahrerassistenz*, 15, 16–28.

- Dehn, D. M. (2008). Assessing the impact of automation on the air traffic controller: The SHAPE questionnaires. *Air Traffic Control Quarterly*, *16*(2), 127-146.
- Dodge, Y. (2008). *The Concise Encyclopedia of Statistics*. Springer, New York, NY
- Drnec, K., Marathe, A. R., Lukos, J. R., & Metcalfe, J. S. (2016). From trust in automation to decision neuroscience: Applying cognitive neuroscience methods to understand and improve interaction decisions involved in human automation interaction. *Frontiers in Human Neuroscience*, *10*.
<https://doi.org/10.3389/fnhum.2016.00290>
- Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors*, *37*, 381–394.
- French, B., Duenser, A., & Heathcote, A. (2018). *Trust in Automation—A literature review*. (CSIRO Report EP184082). Canberra, Australia: Commonwealth Scientific and Industrial Research Organization.
- Ganzhorn, M., Diederichs, F., & Widlroither, H. (2013). A holistic approach for measuring driver distraction and inattention. In *3rd International Conference on Driver Distraction and Inattention*.
- Geyer, S., Hakuli, S., Winner, H., Franz, B., & Kauer, M. (2011). Development of a cooperative system behaviour for a highly automated vehicle guidance concept based on the Conduct-by Wire Principle. *IEEE Intelligent Vehicles Symposium*, 411–416.
- Hardin, R. (2006). *Trust*. Cambridge, UK: Polity Press.
- Herrmann, A., Brenner, W. & Stadler, R. (2018). *Business Models', Autonomous Driving*. Emerald Publishing Limited, 311-326.
- Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating Empirical Evidence on Factors That Influence Trust. *Human Factors*, *57*, 407-434.
doi:10.1177/0018720814547570

- Jansson, J., Sandin, J., Augusto, B., Fischer, M., Blissing, B., & Källgren, L. (2014). Design and performance of the VTI Sim IV. Poster session presented at *Driving Simulation Conference*, 128-138. Paris, France.
- Horiguchi, Y., Suzuki, T., Nakanishi, H., & Sawaragi, T. (2010). Analysis of time delay in user's awareness of ACC system mode transitions. *SICE Annual Conference*, 911–915.
- Jessup, S. A., Schneider, T. R., Alarcon, G. M., Ryan, T. J., & Capiola, A. (2019, July). The Measurement of the Propensity to Trust Automation. In *International Conference on Human-Computer Interaction*, 476-489.
- Lee, J.D. (2006). Human factors and ergonomics in automation design. In G. Salvendy (Ed.) *Handbook of Human Factors and Ergonomics*, 3rd Ed., John Wiley & Sons, 1570–1596.
- Lee, J.D., & Moray, N. (1992). Trust, control strategies and allocation of function in human-machine systems. *Ergonomics*, 22, 671–691.
- Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, 46(1), 50–80.
- Llaneras, R. E., Salinger, J. A., & Green, C. A. (2013). Human factors issues associated with limited ability autonomous driving systems: Drivers' allocation of visual attention to the forward roadway. In *Proceedings of the Seventh International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design*, 92–98. New York, Bolton Landing.
- Ma, R., & Kaber, D. B. (2005). Situation awareness and workload in driving while using adaptive cruise control and a cell phone. *International Journal of Industrial Ergonomics*, 35, 939–953.

- Mayer, R. C., Davis, J. H., & Schoorman, F. D. (1995). An integrative model of organizational trust. *The Academy of Management Review*, 20, 709-734.
doi:10.2307/258792
- Melcher, V., Rauh, S., Diederichs, F., Widlroither, H., & Bauer, W. (2015). Take-over requests for automated driving. *Procedia Manufacturing*, 3, 2867-2873.
- Merat, N., Seppelt, B., & Louw, T. et al. (2019). The “Out-of-the-Loop” concept in automated driving: Proposed definition, measures and implications. *Cognition, Technology & Work*, 21(1), 87-98. <https://doi.org/10.1007/s10111-018-0525-8>
- Muir, B. M. (1987). Trust between humans and machines, and the design of decision aids. *International Journal of Man-Machine Studies*, 27, 527–539.
- Norman, D.A. (1990). The ‘problem’ with automation: Inappropriate feedback and interaction, not over-automation. *Philosophical Transactions of the Royal Society of London B*, 327, 585–593.
- Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, 39, 230–253.
- Parasuraman, R., Sheridan, T.B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions of System Man and Cybernetics*, 30, 286–297.
- Petermann-Stock, I., Hackenberg, L., Muhr, T., & Mergl, C. (2013). Wie lange braucht der fahrer? Eine analyse zu übernahmezeiten aus verschiedenen nebetätigkeiten während einer hochautomatisierten staufahrt. [How long does the driver take? An analysis of take-over times from different secondary tasks during a highly automated traffic jam drive]. Paper presented at *the 6th Tagung Fahrerassistenz*, Munich, Germany.
- Rangaranjan, D., (2016). Vehicle Autonomy: What will be the impact, *3rd SIP-adus Workshop*.

- Reimer, B., Pettinato, A., Fridman, L., Lee, J., Mehler, B., Seppelt, B., Park, J. & Iagnemma, K. (2016). Behavioural Impact of drivers' roles in automated driving. In *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 217-224.
- Rubin, J. Z., Pruitt, D. G., & Kim, S. H. (1994). *Social conflict: Escalation, stalemate, and settlement*. McGraw-Hill Book Company.
- Rudin-Brown, C. M., & Parker, H. A. (2004). Behavioural adaptation to adaptive cruise control (ACC): Implications for preventive strategies. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7, 59–76.
- S. A. E. (2016). *Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (J3016)*. Technical report, Society for Automotive Engineering.
- Saffarian, M., De Winter, J. C. F., & Happee, R. (2012). Automated driving: human-factors issues and design solutions. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 56, 2296-2300.
- Schieben, A., Wilbrink, M., Kettwich, C., Madigan, R., Louw, T., & Merat, N. (2019). Designing the interaction of automated vehicles with other traffic participants: design considerations based on human needs and expectations. *Cognition, Technology & Work*, 21(1), 69-85.
- Schneider, T. R., Jessup, S. A., Stokes, C., Rivers, S., Lohani, M., & McCoy, M. (2017): The influence of trust propensity on behavioral trust. Poster session presented at *the meeting of Association for Psychological Society*, Boston, MA.
- Shen, S., & Neyens, D. M. (2017). Assessing drivers' response during automated driver support system failures with non-driving tasks. *Journal of safety research*, 61, 149-155. <https://doi.org/10.1016/j.jsr.2017.02.009>

- Singh, S., (2015). *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey*.
<https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115>
- Sivak, M., & Schoettle, B. (2015). *Road safety with self-driving vehicles: General limitations and road sharing with conventional vehicles*. University of Michigan, Ann Arbor, Transportation Research Institute.
- Stanton, N. A., & Young, M. S. (2000). A proposed psychological model of driving automation. *Theoretical Issues in Ergonomics Science*, 1, 315–331.
- Strand, N., Nilsson, J., Karlsson, I. C. M., & Nilsson, L. (2014). Semi-automated versus highly automated driving in critical situations caused by automation failures. *Transportation Research Part F: Traffic Psychology and Behavior*, 27, 218-228.
- Trimble, T. E., Bishop, R., Morgan, J. F., & Blanco, M. (2014). Human factors evaluation of level 2 and level 3 automated driving concepts: Past research, state of automation technology, and emerging system concepts.
- Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice*, 86, 1-18.
- Ward, N. J. (2000). Automation of task processes: An example of intelligent transportation systems. *Human Factors and Ergonomics in Manufacturing and Service Industries*, 10, 395–408.
- Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors*, 50, 449–455.
- Wickens, C. D., Gempler, K., & Morpew, M. E. (2000). Workload and reliability of predictor displays in aircraft traffic avoidance. *Transportation Human Factors*, 2, 99–126.

- Wicks, A. C., Berman, S. L., & Jones, T. M. (1999). The structure of optimal trust: Moral and strategic. *Academy of Management Review*, *24*, 99–116.
- Wilde, G. J. S. (1988). Risk Homeostasis Theory and traffic accidents: Propositions, deductions and discussions of dissension in recent reactions. *Ergonomics*, *31*, 441–468.
- Xu, X., Wickens, C. D., & Rantanen, E.M. (2007). Effects of conflict alerting system reliability and task difficulty on pilots' conflict detection with cockpit display of traffic information. *Ergonomics*, *50*, 112–130.
- Yuviler-Gavish, N., & Gopher, D. (2011). Effect of descriptive information and experience on automation reliance. *Human Factors*, *53*(3), 230–244.
<https://doi.org/10.1177/0018720811406725>

7. Appendix A

The information, which was sent to participants through E-mail.



Dear participant,

Welcome to our study. Next you will find relevant information about the purposes of the study and the different tasks you will be asked to do. This document also includes practical information regarding VTI location, contact information, etc. We ask you to carefully read the following information and freely ask any question to the contact persons detailed at the end of this document.

GENERAL PURPOSE OF THE STUDY

New automated systems are currently being developed and integrated in standard vehicles. Very soon new vehicles will allow drivers to disengage from the driving task, offering the possibility of engaging in other tasks (e.g. watch videos, read, etc.). Despite this, the system may not be able to react to certain events, like sudden obstacles on the road. In such cases, drivers will be asked to take back control within a few seconds. How drivers will perceive, understand, use and interact with the systems are important questions that need to be answered for a safe and successful deployment of this technology.

This study is part of a European project called (BRAVE – Bridging gaps for the adoption of automated vehicles) coordinated by VTI whose aim is to promote an increased confidence in automated vehicles by the society.

DESCRIPTION OF THE AUTOMATED SYSTEM

During the experiment, you will drive a highly automated car in a moving-base simulator. The automated system will consist of the combination of different functions described below:

- a) Active Cruise Control. This system offers a total longitudinal control of the vehicle. The vehicle maintains the desired speed constant and adjust it to the vehicle in front when necessary, thus, reducing drastically the possibility of crashing. With this system, drivers do not need to use the pedals.
- b) Lane Keeping System (LKS). The system maintains the vehicle within the lane by detecting the lane markings.
- c) Monitoring systems. The simulated vehicle is equipped with sensors that detect and adapt to the presence of other road users around the vehicle such as other cars, pedestrians, cyclists, etc. Nevertheless, the system cannot handle sudden obstacles on the road and will return control to the driver via visual/auditory warnings.

YOUR TASKS

Upon arrival you will be given an overall briefing of the experiment, sign a consent form and fill in some questionnaires. Then, you will receive a short training to become familiar with the simulator and the automated driving.

During the experiment, you will drive highly automated in an urban area while watching a video on a tablet. Meanwhile, cameras and an eye-tracking system will record your behaviour and visual attention. After each drive you will be asked a few questions regarding your subjective experience of the drive you just performed.

The expected duration of the whole session is 60 minutes.

YOUR RIGHTS

You are allowed to stop or quit at any moment from the experiment.

Your privacy will be guaranteed, and your personal information will only appear on the consent form. Only the responsible researchers (Niklas Strand and Ignacio Solis) will have access to such information. All information obtained from the different tasks will be stored in protected server at VTI in an aggregated form.

You will receive a present card (about 200 kr) as compensation for your participation.

DISSEMINATION

The results will be disseminated through different sources just for scientific purposes (e.g. journals, conferences, seminars, etc.). No information that could identify the participants will be shown. Some pictures or video clips may be disseminated, always respecting the identity of the participants.

PRACTICAL INFORMATION

Please, at the experiment day you should be well rested and not have intakes alcohol within the 24 previous hours. Bring contact lenses instead of glasses in case you use them.

Contact people:

Niklas Strand:

Ignacio Solis:

Krishnachand



Location:

VTI (Statens väg- och transportforskningsinstitut)

Address: Regnbågsgatan 1, 417 55 Göteborg ([Lindholmen Science Park](#))



8. Appendix B

Introductory information provided upon arrival.



GENERAL PURPOSE OF THE STUDY

New vehicles will allow drivers to disengage from the driving task, offering the possibility of engaging in other tasks (e.g. watch videos, read, etc.). Despite this, automated systems may not be able to react to certain events, like sudden obstacles on the road. In such cases, drivers will be asked to take back control within a few seconds. How drivers will perceive, understand, use and interact with the systems are important questions that need to be answered for a safe and successful deployment of this technology.

THE AUTONOMOUS DRIVING FUNCTION

You will be driving a vehicle equipped with an autonomous function which controls the vehicle speed as well as its steering. This function can handle the driving task, so it enables you to focus on other activities, however, the system cannot handle sudden obstacles on the road and will return control to the driver. In such cases, the car will issue a visual+auditory warning indicating you must take over control as soon as possible.

The autonomous function is activated and deactivated by pressing a button on the steering wheel (shown later in the simulator). The function can also be deactivated by steering or pressing the brake pedal.

When the function is active, a symbol on the dashboard will turn green, figure 2. When the function is not active, the same symbol will instead turn blue, figure 1.

THE TRAFFIC MONITORING SUPPORT SYSTEM

Additionally, a support system is included in the vehicle that monitors the surrounding traffic and warns the driver when to pay attention to the road. This system will turn on and off automatically, depending on the location of the road. When the system is on, the symbol shown in figure 4 will be shown on the dashboard, and when the system is off, the symbol will disappear.

When this system detects that the driver's attention is required on the road, a message will be shown on the simulator screen, just like depicted in figure 3. By pressing the OK button in the steering wheel, you are acknowledging that you read the message and it will automatically disappear.

THE SIMULATOR DRIVE

The simulator drive will last roughly 30 minutes and is divided in two parts.

In part one, you will have the chance to get accustomed to the simulator and the autonomous function. This will last roughly 5 minutes.

In part two, you will drive in a city environment populated with cars and pedestrians where you will have the opportunity to experience the autonomous function in a realistic driving environment. This last roughly 25 minutes.

During part 2, you will be asked to fill a questionnaire four different times. A message is presented on the screen to let you know when it is time to answer it. The questionnaire will be given to you when get in the car. Please inform the experiment leader every time you complete a questionnaire.

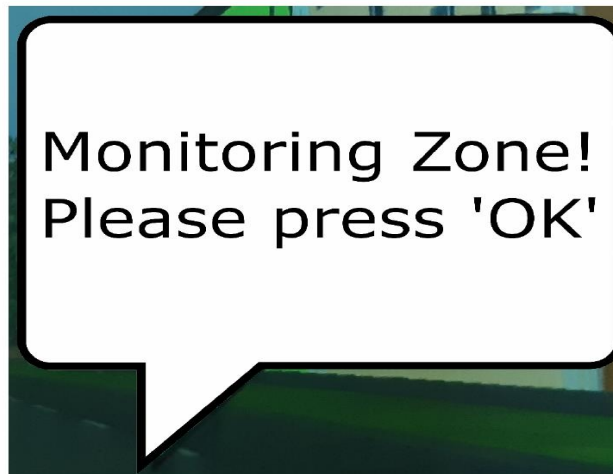


Figure 3 Monitoring Zone message



Figure 4 Monitoring Zone icon



Figure 1 Automated driving OFF



Figure 2 Automated driving ON

9. Appendix C

Consent form filled by participants before the study.



Blankett

Dnr

Samtycke för att delta i forskningsprojekt

Bakgrund

Den här blanketten är utformad för att uppfylla krav om samtycke för att delta i forskningsprojekt enligt lagen (2003:460) om etikprövning av forskning som avser människor. Ett samtycke innebär att du fått information om forskningen och att du därefter gett ett frivilligt godkännande att delta i denna. Du har alltid rätt att när som helst avbryta din medverkan och ta tillbaka ditt samtycke. Forskningsdata som samlats in innan ev. återkallelse får användas i forskningen.

Information om forskningen

Den som utför forskningen, forskningshuvudmannen, är Statens väg- och transportforskningsinstitut (VTI).

Syftet med forskningen är att studera samspelet mellan bilförare och automatiserade körsystem. Resultaten publiceras i enlighet med vetenskaplig praxis. Forskningen kommer utföras genom att försökspersoner får köra i en körsimulator och besvara enkätmaterial.

VTI har bedömt att forskningen kan innebära följande risker eller konsekvenser för dig. Det finns en viss risk för illamående, så kallad simulatorsjuka, på grund av rörelserna i simulatorm. Försöksledaren kommer att övervaka ditt välbefinnande och du ombeds att direkt meddela eventuellt illamående så att simuleringen kan avbrytas. Du är under försöket försäkrad hos Kammarkollegiet. Riskerna bedöms vara mindre.

Jag samtycker till att delta i ovanstående forskning/forskningsprojektet BRAVE		
Underskrift:	Namnförtydligande:	Ort och datum:

Behandling av personuppgifter

VTI kommer att behandla vissa personuppgifter som rör dig, nämligen namn i denna blankett samt videomaterial från körsimulatoren. Anledningen till att VTI har uppgifterna är för att vi behöver ditt samtycke till studiedeltagande samt avser analysera även videodata från körningen. VTI behandlar uppgifterna för att det finns ett allmänt intresse för att VTI ska kunna utföra forskning. Under förutsättning att VTI inte är skyldig enligt lag, så kommer uppgifterna inte att lämnas ut till någon utanför organisationen. Information som ska behållas enligt arkivlagen (1990:782) eller andra tvingade bestämmelser gallras i den mån som följer av gällande rätt. I annat fall kommer dina personuppgifter att tas bort om tio år.

Mer information om hur VTI behandlar personuppgifter och vilka rättigheter som du har i detta sammanhang finns på VTI:s webbplats (www.vti.se).

Övrig information

Som tack för deltagande utgår en symbolisk ersättning med ett värde av cirka 200 SEK.

Kontaktuppgifter

Niklas Strand,

Statens väg- och transportforskningsinstitut (VTI)	Org.nr: 202100-0704
Webbplats: www.vti.se	F-post (reception): vti@vti.se
	Tfn (reception): 013-20 40 00

10. Appendix D

Fill-up form used for collecting participant's dispositional trust.

TP number:

Date:

Test leader:

Group: *Non-experienced* *Experienced*

Propensity to Trust Automated Systems

Instructions: For the below listed items, please read each statement carefully. Using the 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree), select the answer that most accurately describes your feelings.

This questionnaire is to know your general view on trusting the automated machines. In the day-to-day life you might be interacting or using many automated machines, for example a traffic light, ATM, Automated lawn mower etc. Without focusing only on one machine but by considering all together (in general) please fill the questionnaire below.

	1 Strongly disagree	2 Disagree	3 Neither agree nor disagree	4 Agree	5 Strongly agree
1. Generally, I trust automated machines					
2. Automated machines help me solve many problems					
3. I think it's a good idea to rely on automated machines for help					
4. I don't trust the information I get from automated machines					
5. Automated machines are reliable					
6. I rely on automated machines					

11. Appendix E

Form given to participants to fill-up, in the simulator, by the end of each driving condition. In total four copies of the same page were provided.

Page 1

Please fill Q.1 and Q.2

Q.1 – In the last drive:	Never						Always
Was the vehicle useful? (I would use it in real life)	0	1	2	3	4	5	6
Was the vehicle reliable? (you relied on the vehicle performance)	0	1	2	3	4	5	6
Did the vehicle work accurately? (the vehicle performed its tasks adequately)	0	1	2	3	4	5	6
Was the vehicle understandable? (the actions/information of the vehicle were understandable to me)	0	1	2	3	4	5	6
Did the Autonomous system work robustly? (the vehicle worked properly in difficult situations)	0	1	2	3	4	5	6
Did you feel confident being in this vehicle?	0	1	2	3	4	5	6
Q.2 – In the last drive:							
	Low						High
How mentally demanding was the task?	1	2	3	4	5	6	7
How physically demanding was the task?	1	2	3	4	5	6	7
How hurried or rushed was the pace of the task?	1	2	3	4	5	6	7
How successful were you in accomplishing what you were asked to do?	1	2	3	4	5	6	7
How hard did you have to work to accomplish your level of performance?	1	2	3	4	5	6	7
How insecure, discouraged, irritated, stressed and annoyed were you?	1	2	3	4	5	6	7

12. Appendix F

Check list followed for the simulator study.

CHECKLIST

Start of the day (for Bruno / Maytheewat)

1. Projectors on.
2. Graphics on.
3. AC on.
4. Sound on.
5. Restart Smarteye App.
6. Calibrate Smarteye cameras.
7. Restart dashboard.

Prior to arrival

1. Take **participant's folder**
2. **Prepare questionnaires** and make sure there is a pen in the cockpit
3. **Reset** the Netflix video that the previous participant watched to the beginning

Upon arrival

1. Welcome and guide him/her to the simulator (offer toilet, water, etc.)
2. Give them the **information sheet and the figure sheet**.
3. Ask if they have questions about the information sheet.
4. Give them the **consent form**.
5. Ask if they have any questions left.
6. Give them the **initial questionnaire** (Dispositional trust).
7. Take them to the car

In the car (NEW)

1. Tell them to adjust seat.
2. Tell them to put on the seat belt.
3. Show them how to turn on the **engine**. Tell them to wait for you to say it is OK to turn it 'On' since you need to prepare the simulator.

Point to **icons of the function** again.

- a. Automation Off' icon = Blue steering wheel & green = 'On'
- b. 'Cruise control' = automation On
- c. 'Ok' button
- d. Magnifying glass' = Monitoring function.

Tell them the **Smarteye needs to be calibrated** (f, +, emergency button, red plastic dot).

Show them the **tablet** and tell them how to activate the video. Prepare the video.

Tell them "While driving you will be able to watch the video. Watch it for as long as you feel comfortable with it"

Tell them they spend in total 30mins there.

- a. Two sections, first a 5min practice driving section and second a 25 mins main driving section.
- b. The second section consist of four sub section (around 6min each).

Running the experiment – Training

1. Training:

- a. Once the simulator is ready to go, tell them to **start the engine** and drive to 50kph on their own.
- b. Then tell them to do some lane changes.
- c. Then tell them to activate the **autonomous function**.
- d. After a 30 seconds, tell them to activate the **video**.
- e. A message will appear on screen letting them know that they need to stop the car.
- f. Tell them to have the car stopped since it is now time to perform the Smarteye calibration.
- g. **Calibrate the Smarteye system.** On Smart Eye software:
 - Press calibrate button
 - Ask participant to look at the 4 points. For each point, click on the corresponding option and press “train”.
 - Once the 4 points have been trained press Calibrate.
 - If Accuracy values are too high, repeat process.
- h. The experiment can start:
 - Tell the driver the experiment is going to start.
 - Ask if he/she is ready.
 - Ask to start the video
 - Ask her/him to press the throttle and the “Cruise” button 5 seconds after.

1. Normal Drive

- a. There is not much to do here. Just keep an eye on how long they take with the questionnaires.
- b. After each pedestrian event, make sure the driver activates the automation again.**
- c. Make sure drivers **do not press OK button** before completing the questionnaires.
- d. The experiment end automatically and the simulator will stop at the same time.
- e. Ask the participant to switch off the engine.

After experiment

1. Ask if they have any remaining questions or want to discuss about their participation.
Give them more details on the study (debriefing)
2. Ask them not to talk about the study since it may influence other participants.
3. Give present card

End of the day (for Bruno / Maytheewat)

1. Turn off AC.
2. Turn off projectors.
3. Curtains up (white button box next to microphone).

- c. After each sub subsection, a questionnaire request appearing on screen.

Given them the **questionnaires**.

Tell them “In some occasions, an extra support system will inform you whether there are pedestrians/cyclists around, even if you cannot see them. When this system is available, you will see a magnifying glass on the dashboard, and when a pedestrian/cyclist is detected nearby you will get a message on screen that you will need to confirm by clicking OK”.

In other occasions this system will not be available, then you will not see the magnifying glass

Ask is it clear? _____

When there is a warning(audio-visual), you must take back the vehicle control.

Tell them not open the door of the car, you come to get them.

Tell them that they should say if feel uncomfortable (because there are microphones).

Say goodbye and move out.

- a. Close the car door.
- b. Close the gate.
- c. Close the curtain.
- d. Close the door to the bridge.

Before starting the experiment

1. **Curtains** are down (white button box next to microphone).
2. The **Smarteye** (*Smarteye* pc, in the KVMSwitch (click Scroll lock button twice to search for this computer)) profile has been renewed (press new button) and the application is set to track (press track button, only after pressing new).
3. The Smarteye application in the SimKernel (left to the operation panel) pc reports tracking status.
4. Check two top-left boxes running, on SimKernel to verify smart-eye is working.
5. Acknowledge the “**Error Handler**” window in the bosch pc (*motion-bosch*, in the KVMSwitch, (click Scroll Lock button twice to search for computer).

Starting the experiment

1. Do your **monkey** business (*bravewp5/experiment* folder in the desktop of the SimKernel pc).
2. On the operator panel sim4 (to the right of the SimKernel pc), when the green light called “No forced disengage” is lit, press the **start button**.
3. When the two blue lights (top right of the sim4 operator panel) are lit, people **can start driving**.
4. The simulation stops on its own. If you need it to stop before time, use the “stopsimulation” script (*bravewp5* folder in the desktop).