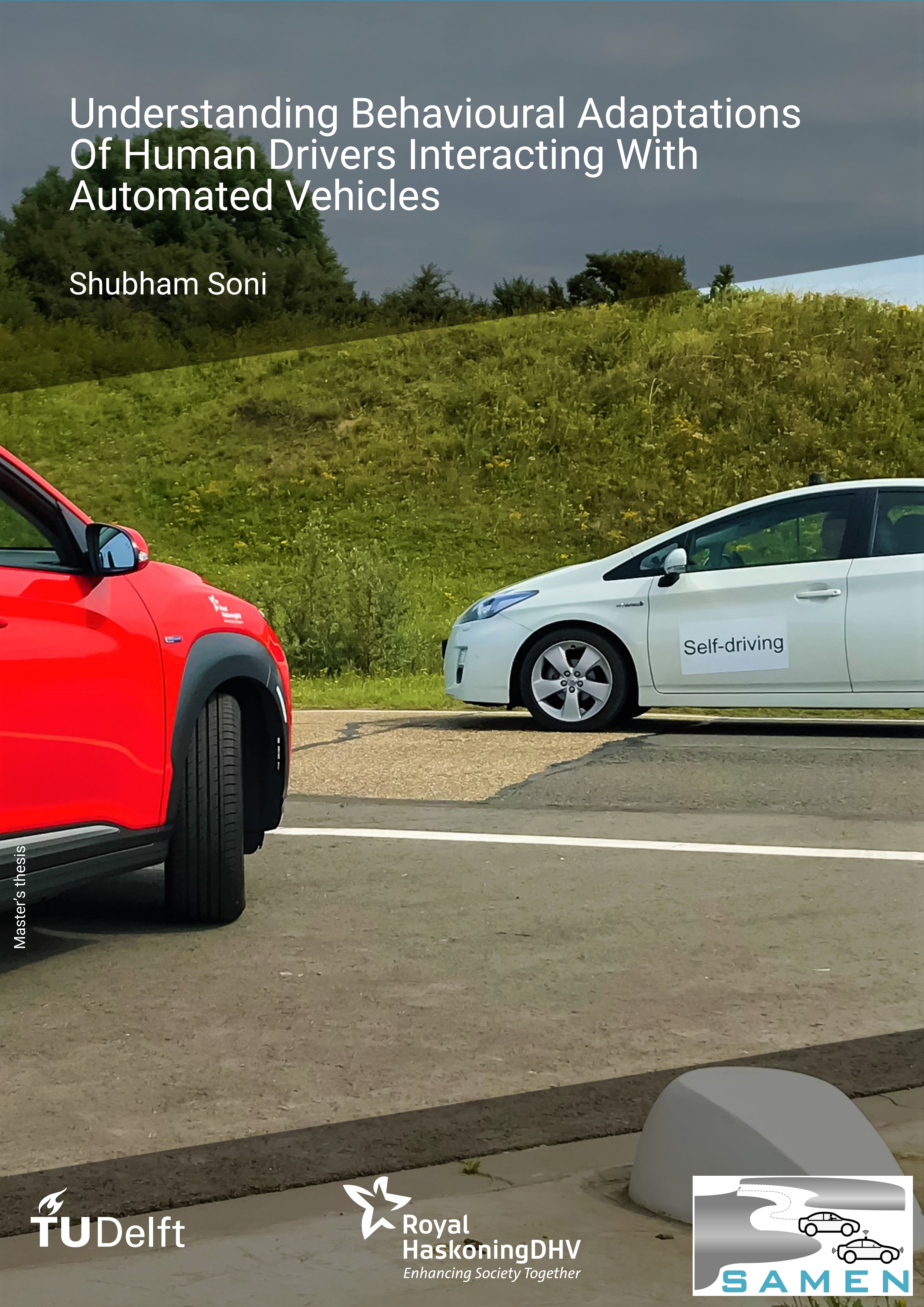
Understanding Behavioural Adaptations Of Human Drivers Interacting With Automated Vehicles

Shubham Soni



Master's thesis

TU Delft

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SAMEN

Understanding Behavioural Adaptations Of Human Drivers Interacting With Automated Vehicles

by

Shubham Soni

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Thesis committee:

Chair	Prof. dr. ir. B. van Arem,	Delft University of Technology
Daily Supervisor	Dr. ir. H. Farah,	Delft University of Technology
External Supervisor	Dr. ir. J. de Winter,	Delft University of Technology
Co-Supervisor	Ir. N. Reddy,	Delft University of Technology
Company Supervisor	Ir. A. Tsapi,	Royal HaskoningDHV
Company Supervisor	Ir. P. Morsink,	Royal HaskoningDHV

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Safe and Efficient OperAtion of AutoMated and Human DrivEN Vehicles in Mixed Traffic

Preface

Ever since my childhood, I have always been fascinated by the influence mobility holds over our lives. It has been one of my dreams to contribute towards innovation and developments in mobility systems which could lead to greater societal benefits. A few years ago, when I heard about Automated Vehicles, I was captivated by the potential benefit if offers in terms of improvements in traffic flow, safety and accessibility. Ever since then, I always wanted to contribute towards the development of this technology. This thesis is not just a part of successful completion of my masters degree but it also fulfils one of my dreams to make a contribution to the scientific community and help to make this world a better place to live. However, my journey would not have been successful without the support and guidance of many people who were involved.

First, I would like to express my gratitude towards my thesis supervision committee. I would like to thank my daily supervisor Dr. ir. Haneen Farah, who constantly supported me and provided her invaluable guidance through the entire course of this research. She entrusted me with this project and has been very actively involved with her endless enthusiasm. She has been a constant source of motivation for me and I heartily appreciate that she was always there to encourage me and provide constructive feedback even during weekends. I would like to thank Prof. dr. ir. Bart van Arem, whose significant contribution and guidance encouraged me to think deeper and perform even better. His words have always been a source of encouragement, enlightenment, motivation, and knowledge. A special thank goes to my company supervisor from Royal HaskoningDHV, Ir. Anastasia Tsapi, for her active involvement during the entire course of this research. Despite her busy schedule, she has been always there to provide her active support and feedback. She ensured that I stay connected with colleagues within Royal HaskoningDHV and have a pleasant working experience despite strange COVID times. I would like to thank my external supervisor Dr. ir. Joost de Winter whose guidance pushed me to develop critical scientific and analytical thinking. His quality feedback and insights helped me to further increase the relevance of this research and provided me with new perspectives. My sincere thank goes to my friend and co-supervisor Ir. Nagarjun Reddy, who was always one call away for any untimely supervision I needed. His creative ideas, practical insights, and quality feedback helped a lot in aligning me with the focus of this study. Last, but not least, I would like to thank my company supervisor Ir. Peter Morsink, who provided me with an opportunity to conduct this research at Royal HaskoningDHV and ensured all practical help I needed to stay in track.

Furthermore, I am deeply grateful to the team who helped me conducting the field test and data analysis. I would like to thank Edwin Scharp and Peter van Oossanen for their exceptional support in providing all technical and practical resources needed to conduct a field test. I highly appreciate their flexibility and support when I encountered some last-minute changes in the field test schedule. I would like to thank my friends Saumyajit Parida, Ishani Baharadwaj, Vinicius Cruz, and Sourabh Dharaneppanavar who volunteered to help conduct the field test despite their busy schedule and deadlines. Without their help, it was not possible to collect data for this research. I would also like to thank my colleague Ir. Anne Marthe Jalvingh who provided her knowledge to help me with statistical analysis.

My deepest gratitude goes to my family, Dr. S.N. Soni (my father) and Sandeepa Soni (my mother) who provided me with immeasurable love and support in every possible way ever since I was born. They have always been there for me as my constant source of strength and confidence. Without them, this journey would not have been possible.

Lastly, I would like to sincerely thank my friends whom I met back in India or here in the Netherlands. They have been always there for me to listen to my stories and complaints. Without my friends, this journey would have been incomplete.

Shubham Soni
Delft, December 2020

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Executive summary

Introduction and research objective

With the advancements in technology, Automated Vehicles (AVs) are becoming a reality. It is not so far in the future when AVs will have a significant penetration rate on our existing road network where they would need to coexist and interact with the Human Driven Vehicles (HDVs) in mixed traffic. The AVs are expected to offer a multitude of benefits to the road transportation system especially in terms of (but not limited to) improvements in traffic flow and safety. Ironically, these benefits are assessed with an assumption that HDV-drivers do not change their driving behaviour while interacting with AVs. However, due to a lack of research, it is not completely known how these different vehicles will interact with each other.

Problem description: Some studies have provided evidence of behavioural adaptation of human drivers due to their interaction with AVs. However, this behavioural adaptation is largely unexplored and there is a requirement to consider the fact that AVs might be able to behave like HDVs in the future. Any change in driving behaviour of HDV-drivers while interacting with AVs will have a direct influence over driving behaviour of AVs. The impact of such a behavioural adaptation on traffic flow and safety could either be beneficial or detrimental, depending upon the type and magnitude of such effect. Behavioural adaptation with positive effects can lead to further improvements in traffic flow and safety. While on the other hand, the negative effects of such behavioural adaptation can lead to problems or even crashes and thus the benefits of automation might not be realised. In that case, the current assessments of potential benefits will become invalid and new strategies, technological design, and policies will be required to counterbalance the negative impacts of such behavioural adaptation. Thus, it is important to understand if there would be any adaptation in human driving behaviour due to the existence of AVs.

Scientific and societal relevance: With a better understanding of behavioural adaptation and the interactions between HDVs and AVs, the scientific community would be able to make better predictions about upcoming challenges and thus several measures such as improvement of technology, training the human driver, changes in infrastructure or changes in policies can be proactively implemented to harvest expected benefits and minimise potential risks that emerge due to AVs. With the knowledge about the magnitude of behavioural adaptation, its impact on traffic flow, safety, and emissions can be quantified. Minimisation of driving risk and increase in predictability of driving manoeuvres would lead to safer interactions between the vehicles in mixed traffic leading towards improvements in traffic safety which leads to greater societal benefits.

Objective: This research aims to study the interaction between HDVs and AVs in a setup of mixed traffic and understanding potential adaptation in driving behaviour of human drivers when they interact with AVs. This research focuses on both lateral as well as longitudinal driving control of HDVs which includes gap acceptance, car-following, and overtaking behaviour. The use case of this research is low speed (with a speed limit of 60 kmph) 2-lane bi-directional straight road sections outside the built-up area with limited overtaking possibilities.

As the objective of this research is to investigate any potential behavioural adaptation of HDV-drivers when they interact with AVs, the main research question in this study is

What are the potential behavioural adaptations of human drivers during their interaction with Automated Vehicles?

To answer this research question, a field test was conducted to collect data which was further processed and analysed to gain insights about the potential behavioural adaptation.

Research methodology

This research aims to focus on three different driving behaviour which was analysed with the help of indicators as shown in table 1. Another objective of this research is to study the learning effect of drivers which involves changes in driving behaviour, stress, and trust over multiple interactions with AVs.

Table 1: Focused driving behaviour and corresponding indicators

Driving behaviour	**Indicator(s)**
Gap acceptance at un-signalised intersections	Critical gap [sec]
Car following behaviour (longitudinal control)	Following time headway [sec]
Overtaking behaviour (lateral control)	Overtaking duration [sec] Overtaking lateral gap [m] Time headway at start/end of overtaking [sec] Relative speed during overtaking [kmph]

In order to study the behavioural adaptation within these focused driving behaviour, a controlled field test was conducted on 21st, 22nd and 23rd July 2020 for data collection. The field test was chosen as it provides insights about real decisions made by drivers. During the field test, participants (driving in the subject vehicle) were made to interact with a test vehicle which was driven both as an HDV or AV (in scenario i-HDV or i-AV where i refers to interaction with test vehicle). The data collection was carried out with the help of field cameras and sensors such as GPS (Global Positioning System), LiDAR (Light Detection and Ranging), and cameras which were instrumented in test and subject vehicle.

The interaction with the test vehicle took place in the following manner. At the start of a run from point A (see figure 1), the subject vehicle takes position at point A and the test vehicle starts driving from point TV1 towards the subject vehicle in approach zone (Blue) at speed of 40 kmph. The participants were asked to first indicate their critical gap (with a hand gesture) for the approaching test vehicle without actually start driving. Once the test vehicle crossed the subject vehicle, the subject vehicle starts driving and follows the test vehicle for the next 1 km at a speed of 60 kmph in the car following zone (green). Later, the test vehicle slowed down to a speed of 40kmph encouraging the participant to overtake within the overtaking zone (red). The run ends when the participant reached its end location point B and the test vehicle reached TV2. At the end of each run, participants were asked to indicate their experienced stress and trust in test vehicle on a scale of 1 to 10. Next run was conducted in a similar fashion from point B to A, where different zones were reversed.

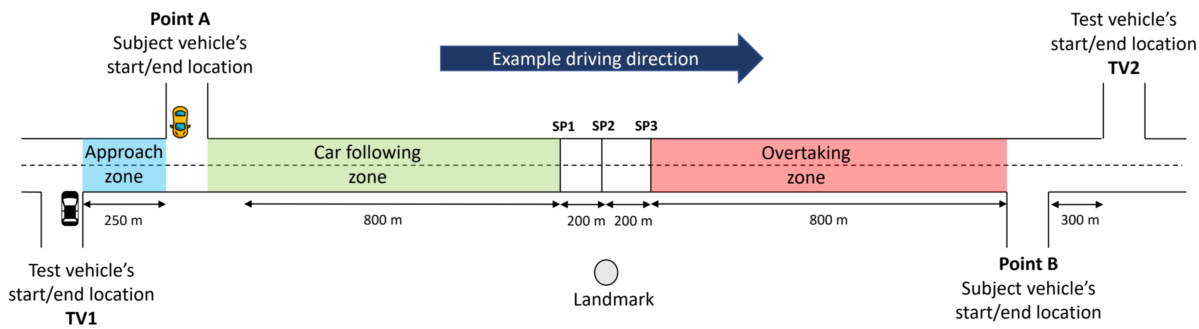

Figure 1: An illustration of different zones in test track for a run from point A to B

A total of 18 male participants (mostly from science and technology background) took part in the field test. As the learning effect over multiple interactions is being studied, each participant interacted with the test vehicle over 10 runs. Each participant within 10 runs interacted 4 times in i-HDV scenario and 6 times in i-AV scenario. An illustration of different scenarios during the field test is given in figure 2.

In this research, the effect of positive or negative information regarding AVs on the driving behaviour of HDV-driver was also studied. Thus in the last three runs of i-AV scenario, a piece of positive or negative information

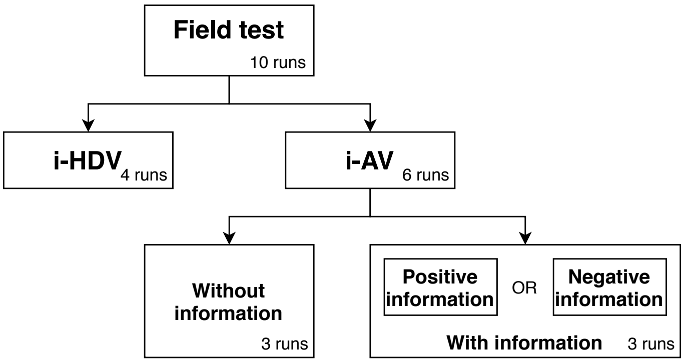

Figure 2: Different scenarios for each participant during field test

regarding the interacting AV (test vehicle driving as an AV) was provided to the participant. The positive and negative information that was provided to the participants are as follows:

Positive information

"The self-driving vehicle you are interacting with tends to avoid risk by driving very safely. It can fully detect its environment and is able to accurately predict the behaviour of other road users, which ensures safe driving."

Negative information

"The self-driving vehicle you are interacting with cannot always fully detect its environment. This may cause it not to correctly predict changes in its environment, leading sometimes to unsafe situations."

The type of information a participant would receive was randomly selected with an aim to achieve equal number of positive and negative information recipients.

Apart from the data collected through sensors instrumented in vehicles, there were questionnaires before, during, and after the field test followed by an interview to gain more insights about the driving behaviour. Table 2 provides an overview of different driving behaviour indicators (and number of observations within them) which were used to gain insights about gap acceptance, car-following and overtaking behaviour.

Table 2: Number of observations (scenarios) for driving behaviour indicators within different scenarios in final database

		Scenario		
Driving behaviour	**Indicator(s)**	**i-HDV**	**i-AV**	**Total**
Gap acceptance	Indicated critical gap [sec]	69	98	167
Car following	Car following headway [sec]	53	75	128
Overtaking	Overtaking duration [sec]	53	79	132
	Overtaking lateral gap [meters]	48	72	120
	Headway at start of overtaking [sec]	51	79	130
	Headway at end of overtaking [sec]	51	78	129
	Relative speed during overtaking [kmph]	52	79	131

From cluster analysis based on the self-reported driving style of participants, it was found that the participants of this research can be divided into two categories: Less aggressive and more aggressive drivers. Also, there were mainly two types of overtaking styles observed during the experiment: Accelerative (when the overtaking vehicle decelerates and follows the overtaken vehicle for some time before initiating overtaking manoeuvre) and Flying (when the overtaking vehicle does not decelerate before initiating overtaking manoeuvre).

Results

In order to gain insights on the potential behavioural adaptation of human drivers during their interaction with AVs, the analysis was conducted to identify the difference in driving behaviour over gap acceptance, car following, and overtaking behaviour. Furthermore, an analysis was also conducted to observe the effect of stress and trust in AVs into driving behaviour of HDV-driver. From the analysis, behavioural adaptation was observed in terms of gap acceptance and overtaking behaviour.

Within gap acceptance behaviour, it was observed that the critical gap of drivers decreased significantly when they interacted with AVs in comparison to HDVs (figure 3 left). The critical gap seems to be decreasing further for interaction with AV when positive information was provided to the drivers (figure 3 right). The positive information also seems to significantly increase the trust of drivers in AV. In contrast, critical gaps were significantly lower with increase in trust in case of an i-AV scenario whereas in contrast, no such significant effect was found in case of i-HDV scenario.

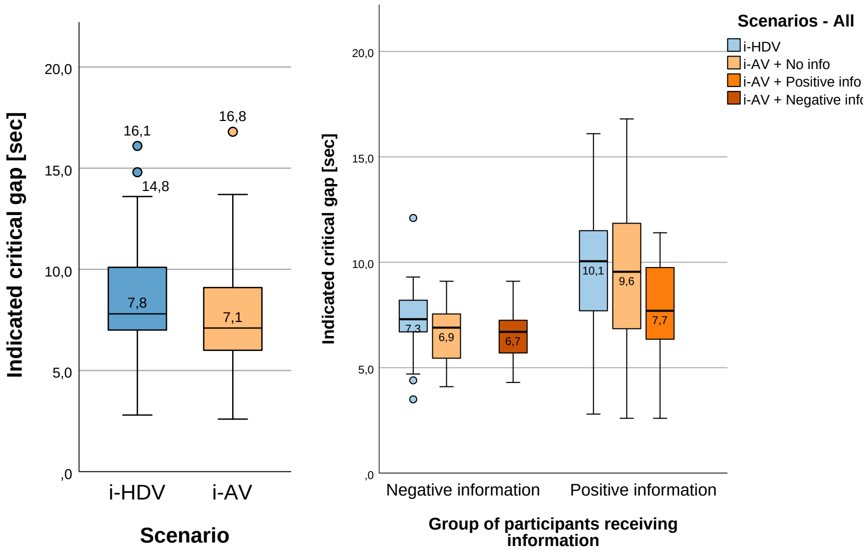

Figure 3: Box plot of critical gap in different scenarios (left) and critical gap within different information recipients (right)

Within overtaking behaviour during interaction with AVs, the headways at the end of overtaking significantly decreased when positive information regarding interacting AV was provided. Within accelerative overtaking style during interaction with AVs, the headways at the end of overtaking seem to decrease significantly over multiple interactions with AV within all information recipients (refer figure 4). Also with increase in trust in AV, the headway at the start of overtaking seem to decrease especially in accelerative overtaking style.

Discussion and conclusion

These findings indicate that drivers, in general, have higher trust in AVs due to which they feel more comfortable performing closer manoeuvres with AVs. Within all different driving manoeuvres, most significant differences were observed within the critical gap and headway at the end of overtaking. Both of these driving behaviours are similar in the respect that in both situations human driver interacts and accepts the gap in front of AV. Thus, it becomes the responsibility of AV to maintain a safe headway from the human-driven vehicle. However, no differences in driving behaviour were observed due to interaction of HDV driving behind an AV.

Positive information regarding the functionality of AV further confirms the driver that AV can detect its environment and interact safely. This leads to even closer interactions with AV. Relating it with insights from questionnaires and interviews, participants also indicated that they trust the driving behaviour of AVs more than HDVs. For the participants who indicated higher stress during interaction with AV, driving in front of it was least stressful. Many participants indicated higher comfort and confidence when AV was driving behind

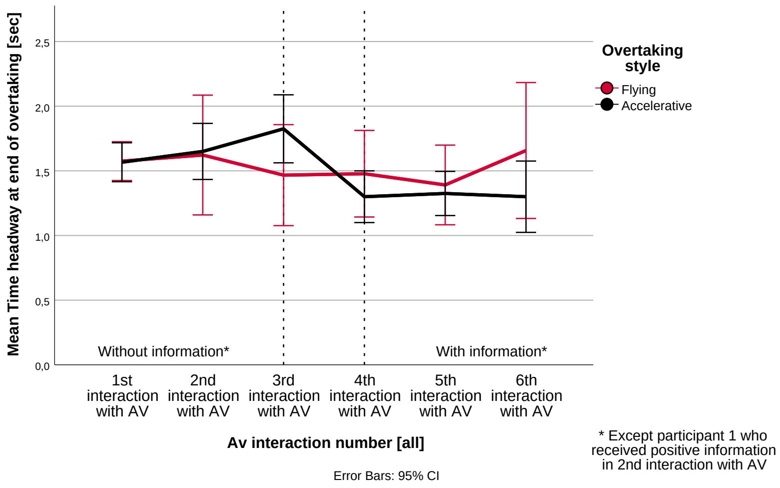

Figure 4: Headway at the end of overtaking over multiple observations (Within different overtaking styles)

them.

Thus, from a behavioural adaptation perspective, it can be concluded that closer interactions in form of abrupt merging in front of AVs and acceptance of smaller gaps in front of AV are expected to take place. Positive information would further improve the confidence and trust in AV leading towards even closer interactions. Thus, it is possible that the technological capabilities of AVs will be exploited especially when AVs are directly responsible to perform safe interactions.

Recommendations

The key findings of this research indicate that lower gaps will be accepted at the un-signalised intersections as well as at the end of the overtaking by HDV-drivers when they would interact with AVs. Several stakeholders such as transport consultants, simulation package developers, road authorities, AV manufacturers, and driving license authorities can use these findings to improve the technology, policies, and implementation road map for AVs.

Transportation consultants can perform assessments to identify potential benefits / disadvantages of such behavioural adaptation on traffic flow and safety. As smaller gaps are being accepted, it is expected that there would be an impact in the capacity of intersections and roads. Microscopic simulations can be performed in order to gain insights regarding traffic flow phenomenons such as shock waves resulting as a side effect of accepting shorter gaps.

Simulation package developers can use these findings to improve or add new features to their simulation software which would ultimately lead to a better understanding of the impact of behavioural adaptation on traffic flow. In current simulation packages, it is not possible to alter the driving behaviour of a vehicle depending upon the type of interacting vehicle. Simulation package manufacturers can incorporate this feature to take into account the behavioural adaptation of HDVs due to their interaction with AVs.

Road authorities can use these findings to improve the design of roads and infrastructure to accommodate the effects of this behavioural adaptation. Furthermore, it is recommended to invest in smart traffic control plans to tackle interaction between AVs and HDVs in the future.

AV manufacturers can use the findings to improve the control and design of their AVs. If the effects of behavioural adaptation are positive, AVs can be made more recognisable to harvest maximum benefits. In case of negative effects, AVs can be designed to look and drive similar to HDVs.

Driving license authorities can use the findings to improve their testing procedure and introduce new courses which can aim towards minimising intention to exploit AV's technological advantages.

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List of abbreviations

ACC Adaptive Cruise Control.

ADAS Advanced Driver-Assistance Systems.

AEB Automated Emergency Braking.

AV Automated Vehicle(s).

FCW Forward Collision Warning.

HDV Human Driven Vehicle(s).

HDV-driver Human driven vehicle's driver.

i-AV Interaction with Automated vehicle.

i-HDV Interaction with Human driven vehicle.

LKS Lane Keeping System.

ODD Operational Design Domain.

OEDR Object and Event Detection and Response.

THW Time Headway.

TV Test Vehicle.

1
Introduction

With advancements in technology, automated driving is becoming a reality and this topic is currently in the limelight of researchers, policymakers, and vehicle manufacturers due to its potential benefits in road transportation. As per Gartner's hype cycle for automotive technologies(2020), automated driving is one of the emerging topic in the automotive industry which has passed the peak of inflated expectations and currently in trough of disillusionment slowly climbing up the plateau of productivity. It is expected that the AV technology will take more than 10 years to reach the plateau of productivity [Gartner, 2020]. However, development of capable and state of the art sensors are leading to rapid development of high-end Automated Vehicle(s) (AV) and making them more capable every day. It is not so far in the future when automated vehicles will have a significant penetration rate on the existing road network. This will lead to a situation of mixed traffic where both AVs and Human Driven Vehicle(s) (HDV) will coexist and interact with each other.

The AVs are expected to offer a multitude of benefits to the road transportation system especially in terms of (but not limited to) improvements in traffic flow and safety. These improvements can be expected due to the technological advantages of AVs such as ability of platoon formation, shorter reaction time and following headways, ability to continuously detect its surroundings, keeping track of all nearby road users, and more smooth, stable and predictable driving. These capabilities are not possible for HDV-drivers who possess slower reaction times and are prone to human error, fatigue and distraction. Due to these differences, AVs are expected to drive and take actions in a different manner in comparison to a HDV-driver. However, with developments in sensing technologies and understanding of human behaviour, it will be possible to bring AVs more close to human-like driving in near future [Matheson, 2019]. This would lead to further changes in driver expectations towards AVs.

The expectations and perception towards AVs is changing and people are forming different opinion towards them. The expectation varies due to different factors such as socio-demographics, education, driving experience and information [Penmetsa et al., 2019]. There have been several unfortunate incidents where AVs were involved in severe crashes. One reported crash involved fatality of a pedestrian after getting hit by a self-driving Uber car [Wakabayashi, 2018]. In another crash, a Tesla model-S car running on Autopilot crashed into a truck and trailer leading to fatality of the driver [Yadron and Tynan, 2016]. The media reports of these crashes can have an influence on people's trust and expectations towards AVs [Feldhutter et al., 2016]. In a recent American Automobile Association's (AAA) annual automated vehicle survey, it was found that 71 % of Americans have lower trust and are afraid of AVs [AAA, 2019]. However, other surveys reveal people's positive attitude towards AVs [Golbabaei et al., 2020]. These studies reveal differences in people's trust and expectation towards AVs.

Given that the AVs are expected to interact differently than HDVs and HDV-drivers may have different opinion and trust towards AVs, it is expected that HDV-drivers might behave differently while interacting with an AV. The HDV-drivers may not be able to react appropriately and thus are expected to change their driving behaviour while interacting with AVs [Rahmati et al., 2019, Trende et al., 2019]. In a study conducted by Rahmati et al. [2019], it was found that driving behind an AV leads to smoother driving with less braking and smoother acceleration. Another study by Trende et al. [2019] indicates that HDV-drivers may try to exploit AVs technical limitations for their benefits during gap acceptance. However, these studies have limited scope and are based on the assumption that AVs differ from HDVs in its driving style. The interaction between AVs and HDVs can be complex and it is crucial to understand how HDV-drivers will change their driving behaviour when they interact with AVs.

1.1. Problem description

In the European Union, approximately 23401 individuals die every year due to road crashes (Eurostat, 2020) out of which 93.5% of the crashes are due to human error [Treat, 1979, Winkle, 2016]. Advanced Driver-Assistance Systems (ADAS) and automated driving have the potential to overcome human error and thus improve traffic safety, flow and efficiency [Aria et al., 2016]. Ironically, these benefits are assessed with an assumption that HDV-drivers will not change their driving behaviour while interacting with AVs. In reality, some studies have provided an evidence of behavioural adaptation of HDV-drivers during their interaction with AVs. However, this behavioural adaptation is largely unexplored and there is a requirement to consider the fact that AVs might be able to behave like HDVs in future.

Any change in driving behaviour of HDV-drivers while interacting with AVs will have an influence on driving behaviour of AVs. The impact of such a behavioural adaptation on traffic flow and safety could either be beneficial or detrimental, depending upon type and magnitude of such effect. Behavioural adaptation with positive effects can lead to further improvements in traffic flow and safety. While on the other hand, negative effects of such behavioural adaptation can lead to problems or even crashes and thus the benefits of automation might not be realised. In that case, the current assessment of potential benefits will become invalid and new strategies, technological design, and policies will be required to counterbalance negative impacts of such behavioural adaptation.

In this early stage of automation, while the technology is continuously developing and penetration rate of AVs is expected to increase marginally, there is a pressing requirement to gain insights about such potential behavioural adaptation and its impacts on traffic flow and safety.

1.2. Scientific and societal relevance

With a better understanding of behavioural adaptation and the interactions between HDVs and AVs, the scientific community would be able to make better predictions about upcoming challenges and thus several measures such as improvement of technology, training the human driver, changes in infrastructure or changes in policies can be proactively implemented to harvest expected benefits and minimise potential risks that emerge due to AVs. With the knowledge about the magnitude of behavioural adaptation, its impact on traffic flow, safety and emissions can be quantified.

For AV manufacturers, the study of interaction between AVs and HDVs would be able to address few concerns: Should AVs drive, interact, and behave like HDVs? Should AVs be easily recognisable to other road users? Should AVs communicate its intentions to other HDVs? and thus ultimately would lead to better design of AVs.

Minimisation of driving risk and an increase in predictability of driving manoeuvres would lead to safer interactions between the vehicles in mixed traffic leading towards improvements in traffic safety. In the end, any improvement in terms of traffic safety, fuel consumption, emissions or traffic flow will lead to greater societal benefits.

1.3. Scope of the research

The main aim of this research is to study the interaction between HDVs and AVs in a setup of mixed traffic with the help of a controlled field operational test. A field test was chosen for data collection as it provides real insights about the driving decisions made by the driver. This study focuses on understanding potential adaptation in driving behaviour of human drivers when they interact with AVs. In order to ensure that change in driving behaviour is due to the fact that interacting vehicle is AV, it is assumed that AVs are clearly recognisable and drives just like HDVs. This research focuses on behavioural adaptation in terms of both lateral as well as longitudinal driving control of the vehicle by HDV-drivers which includes gap acceptance, car-following and overtaking behaviour. Furthermore, this research also focuses on the effect of positive or negative information about AVs on driving behaviour and learning effect over multiple interactions with AVs. The use case of this research is low speed (with a speed limit of 60 kmph) 2-lane bidirectional straight road sections outside the built-up area with limited overtaking possibilities.

1.4. Thesis outline

The rest of the chapters are structured as follows:

Chapter 2 aims to provide a summary of the literature review which was conducted to gain insights about the current state of the art and to find the research gap. The findings from the literature review helped in framing the conceptual framework for this research.

Chapter 3 discusses the research gap and defined the objective of this research. Further, it discusses the conceptual framework for behavioural adaptation of HDV-drivers interacting with an AV. This chapter ends with discussing the research questions of this research, formulating hypothesis and providing insights on research methodology.

Chapter 4 aims to discuss the design of a controlled field operational test to collect data for this research. This chapter ends with a discussion of findings from the pilot test.

Chapter 5 discusses the actual data collection process and provides insights about collecting data from the field test. Finally the process of data processing, cleaning and validation is discussed. This chapter ends with proposing various sub-categorisation criteria for data analysis.

Chapter 6 aims to provide descriptive insights into the collected dataset. Data insights are provided for both questionnaire and sensor data.

Chapter 7 provides the results of statistical testing which was performed to test various hypothesis. This chapter ends with a summary of significant insights gained from statistical testing.

Chapter 8 provides the conclusion of various findings and provides answers to various research questions. This chapter critically discusses the interpretation of various findings and provides the reflection on methodology, state of the art and results. This chapter ends with discussing the contributions of this research and limitations.

Chapter 9 provides recommendations to various stakeholders involved in the development of AV and discusses the scope of further research.

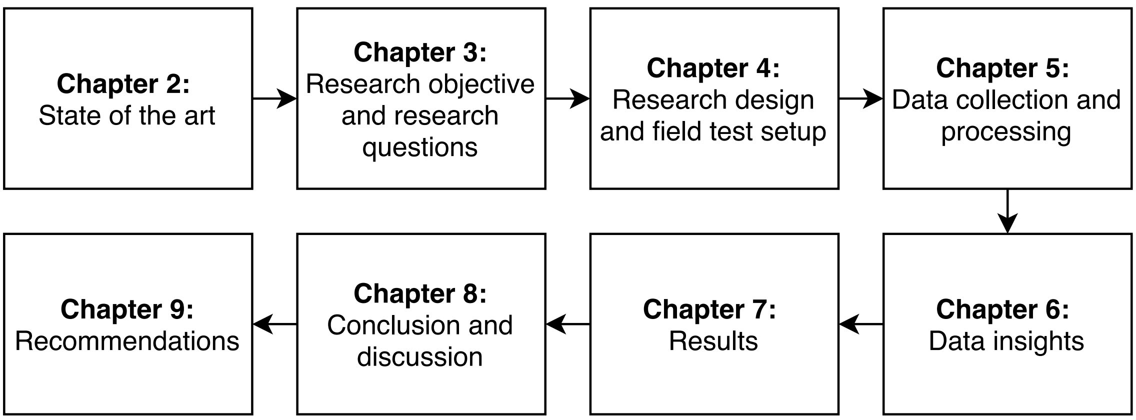


Figure 1.1: Thesis outline

2

State of the art

The AV technology is continuously developing and it is expected that it will have a significant impact on future mobility [Gruel and Stanford, 2016]. Over the past couple of years, this topic has gained tremendous interest from vehicle manufacturers, policymakers and researchers due to its potential impact on road transportation [Beza and Zefreh, 2019]. The expected benefits due to the presence of AVs include an increase in infrastructure capacity (based on market penetration rate), reduction of energy consumption and emissions, reduction of car ownership, promoting shared mobility and most importantly, increase in traffic safety [Beza and Zefreh, 2019]. However, despite all the potential benefits, there are some uncertainties that require the attention of stakeholders [Wadud et al., 2016]. On the technological side, one uncertainty is regarding the AVs capabilities as AVs are affected by a number of limitations that technology has not been able to overcome yet [Robertson et al., 2017]. On the behavioural side, another uncertainty is related to the behavioural adaptation of the AV's user as well as interacting HDV-drivers [Gouy et al., 2014]. This section aims to review the literature with a focus on the behavioural adaptation of HDV-drivers due to their interaction with AVs. In order to understand more about AVs, first, it is important to understand different level of automation.

2.1. Automated vehicles and SAE level of automation

With the advancement of technology, vehicles are equipped with systems that assist drivers in performing their driving task. There are multiple systems which either assist the driver or takes over the driving task from the driver. Based on the capabilities of these systems, the different vehicles can be classified into 6 different levels of automation (SAE, 2018). The different levels of automation vary from level 0 which represents no automation to level 5 which refers to full automation. The other levels of automation (level 1 - level 4) are Operational Design Domain (ODD) specific. Table 2.1 shows a summary of different levels of driving automation.

The ODD refers to the situations/conditions under which a given system is designed to operate (SAE,2018). In the first three levels of automation (level 0-2), the Object and Event Detection and Response (OEDR) is carried out by the driver whereas, in level 3-5, the OEDR is performed by the system. However, level 5 automation is not ODD restricted and refers to a system which can fully operate without the need of a driver. Level 1-4 have limited ODD and require driver intervention on tasks outside the ODD.

This research intends to study the behavioural adaptation of HDV-drivers when they interact with AVs involving a fallback driver. Thus the use case of this research can be related to SAE level 2 or 3 automation. However, it is important to understand the behavioural adaptation in the first place which is discussed in the section below.

Table 2.1: Summary of different levels of automation (SAE,2018)

Level	Name	Narrative definition	*DDT*		*DDT fallback*	*ODD*
			Sustained lateral and longitudinal vehicle motion control	***OEDR***		
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

2.2. Behavioural adaptation in automated driving

The phenomenon of behavioural adaptation is defined as "unintended change in the behaviour of the users with the introduction of a new system against the system's intended designed operation" [OECD, 1990]. Behavioural adaptation generally focuses on negative effects of the phenomenon as it may jeopardise expected benefits of the system [Saad, 2004]. Behavioural adaptation can appear in many different driving tasks such as speed management, change in following distance, way of overtaking, way of lane changing, braking, level of attention, gap acceptance etc. [Draskoczy, 1994].

There are a lot of examples in literature which studies the behavioural adaptation in users of AVs in terms of taking over control [De Winter et al., 2016, Gold et al., 2013] or behavioural adaptation of vulnerable road users with respect to AVs [Fuest et al., 2019, R. Palmeiro et al., 2018, Velasco et al., 2019]. However, research which focuses on the behavioural adaptation of HDV-drivers interacting with AVs is crucial and has not been studied extensively yet. Table 2.2 gives an overview of studies which tried to study the behavioural adaptation of HDV-drivers interacting with AVs.

Table 2.2: Summary of studies focusing on understanding the interactions between road users and automated vehicles

Authors	Title	Approach	Year	Country
Rahmati et al.	Influence of Autonomous Vehicles on Car-Following Behavior of Human Drivers	Field-test	2019	US
Zhao et al.	Field experiments on longitudinal characteristics of human driver behavior following an autonomous vehicle	Field-test	2020	China
Trende et al.	An investigation into human-autonomous vs. Human-human vehicle interaction in time-critical situations	Driving simulator	2019	Germany
Schoenmakers et al.	Automated vehicles and infrastructure design: an insight into the implications of a dedicated lane for automated vehicles on the highway in the Netherlands	Driving simulator	2019	NL
Lee and OH	Lane change behavior of manual vehicles in automated vehicle platooning environments	Driving simulator	2017	Korea
Gouy	Behavioural adaption of drivers of unequipped vehicles to short time headways observed in a vehicle platoon	Driving simulator	2013	UK
Lee et al.	Exploring lane change safety issues for manually driven vehicles in vehicle platooning environments	Driving simulator	2018	Korea
Gouy et al.	Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control?	Driving Simulator	2014	UK
Nyholm and Smids	Automated cars meet human drivers: responsible human-robot coordination and the ethics of mixed traffic	Ethical Assessment	2018	NL
Zhong et al.	Clustering Strategies of Cooperative Adaptive Cruise Control: Impacts on Human-driven Vehicles	Driving Simulator	2019	US
R. Palmeiro et al.	Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment	Wizard-of-Oz Field test	2018	NL
Dey et al.	Pedestrian road-crossing willingness as a function of vehicle automation, external appearance, and driving behaviour	Video based survey	2019	NL
Velasco et al.	Studying pedestrians' crossing behavior when interacting with automated vehicles using virtual reality	Virtual reality simulation	2019	NL
Heikoop et al.	Acclimatizing to automation: Driver workload and stress during partially automated car following in real traffic	Field test	2019	UK

A study by Rahmati et al. [2019] studies the influence of Automated vehicles in car-following behaviour of human drivers by conducting a field test. In this study, two different scenarios were tested. One scenario was when a human driver follows another human-driven vehicle. In another scenario, a human driver follows an automated vehicle. This study uses the simulated speed profile of a HDV and an AV to control the programmable test vehicle Chevy Bolt. The realistic speed profile was generated by using a speed profile of a real vehicle and then programming the throttle of Chevy Bolt to create a speed profile for different scenarios. During the field test, 9 participants with a car were asked to follow the Chevy Bolt running under different speed profiles. After collecting the field test data, outcomes were analysed to adapt a car-following model. Further, using the new car-following model, simulations were run to gain more insights into change in car-following behaviour of human drivers. From the field test, it was found that humans drive closer to their leader when the leader is an AV. Also in case of following an AV, the speed profile was smoother. These findings insinuate towards a more efficient traffic flow due to AV. However, in this study, there was no difference in the appearance of AV but rather AV followed a different speed profile. Also, AV was not driverless in this experiment.

Another similar study was conducted by Zhao et al. [2020] to identify differences in car-following behaviour of human drivers interacting with automated vehicles. In this research, a field test was conducted where the participants were made to interact with an HDV and an AV (with distinguishable and indistinguishable appearance). The AV used in this study differ from HDV in its driving behaviour and used its sensors for longitudinal control. The driving behaviour of human drivers while following AV was compared with driving behaviour while following HDV. The findings of this research indicated a significant difference in car-following behaviour of participants when they interacted with distinguishable AV. The participants were categorised into three groups based on their driving behaviour. AV-believers trusted the technology and maintained smaller gaps, AV-skeptics suspected the technology and maintained larger gaps and other drivers who were insensitive to AV technology. However, no significant difference was found when participants interacted with indistinguishable AV. This study revealed the impact of trust of drivers in AV technology on their car following behaviour. However, the sample size in this experiment was low (10 participants) and the author recommended further investigations in car-following behaviour.

A study by Trende et al. [2019] investigated the gap acceptance behaviour of drivers when they interact with both HDVs and highly automated vehicles in a driving simulator experiment. Their driving simulator experiment consisted of a subject waiting at an un-signalised intersection and trying to merge into the traffic in the perpendicular stream. The crossing traffic consisted of a few opportunities to allow merging into the main stream. The subjects in their experiment can choose to either merge within the available gap or wait for the traffic to cross. This behaviour was tested with and without time constraint. The subjects were also provided with a piece of positive information regarding AVs that they are programmed to defensively avoid collisions. The outcome of this study indicated higher gap acceptance when the interacting vehicle was AV. This result indicates towards the driver's intentions to exploit technological advantages of AV and its ability to perform safer manoeuvres.

A study conducted by Schoenmakers et al. [2019] investigated the behavioural adaptation of human drivers due to the implementation of a dedicated lane for AVs and its impact on traffic flow with the help of a driving simulator experiment. In this research, car-following behaviour of human drivers was investigated when they drove near a platoon of AVs. The simulations were carried out within four scenarios of dedicated lane for AVs: no dedicated lane, continuous access dedicated lane, dedicated lane with limited access separated by a guardrail and dedicated lane with limited access separated by a road marking. The findings of this research indicated that significantly lower time headways were maintained by manually driven vehicles when they drove near a platoon of AVs in continuous access and limited access with road marking separation dedicated lane scenarios. Furthermore, simulations from the finding indicated positive influence in traffic flow at a penetration rate of 15-20% in continuous access and 30-35% in limited access dedicated lanes.

A study by Lee and OH [2017] studied the behavioural adaptation of HDVs in platooning environments using a simulation experiment. In their experiment, the participants were asked to drive near the platooning environment of AV in different market penetration rate scenarios. During the experiment, they were investigated in their workload using NASA-TLX assessment. From the research, it was found that the participants experience more psychological burden while driving near the platooning environment leading to an increase in lane change duration. The lane change duration kept on increasing with the increase in penetration rate of AV in different scenarios. However, in their research the sample size of 30 participants (15 males and 15 females) was not adequate and more research was needed to consolidate the findings. No field operational test has been conducted so far that confirms the findings from this experiment.

Gouy (2013, 2014) conducted several driving simulator studies to study the behavioural adaptation of drivers while driving next to the platoon with short Time Headway (THW). These studies focused on measuring the adaptation in THW kept by participants when they are provided with certain situations. From the studies, it was found that the preferred THW of the unequipped drivers remained the same however the adopted THW of the drivers changed as per different driving scenarios. It was observed that the unequipped vehicle drivers adapt their behaviour while driving near the platoon of shorter THW and tend to reduce their head-ways near the critical THW threshold of 1 second. It was also observed that the drivers spend more time under their critical time headway threshold.

Another research by Zhong et al. [2019] studied the impact on different clustering strategies of automated vehicles on human-driven vehicles using a driving simulator experiment. In this research, different scenarios with different penetration rates were tested. As an indicator, authors used hard braking (acceleration less than -3m/s^2) to indicate hazardous traffic situations. On the behavioural adaptation side of the experiment, a change in the pattern of hard braking was observed with a different market penetration rate of connected automated vehicles. The probability of hard braking increased when the penetration rate is increased up to 10-30 %. Another striking observation was regarding the lane change behaviour where the average lane change frequency increased in presence of connected automated vehicles when the market penetration rate was increased up to 30%. This behaviour indicates that the behavioural adaptation of human drivers in HDV is more prominent when the penetration rate of Automated vehicles is lower.

A similar trend was observed in a study by Lee et al. [2018] which studied the lane change behaviour of the human-driven vehicles driving near the platoons of AV. In this study, it was found that the lane change preparation duration increases with an increase in the penetration rate of the AV. Also, the steering to change lane was more intense leading to probable unsafe driving.

In a study by Nyholm and Smids [2018], the ethical perspectives of designing the Automated vehicles were presented keeping in mind its interaction with the human drivers. Due to some differences between human and automated driving, the interaction between them is challenging and might have some coordination issues which might compromise traffic safety. One suggestion that was made to improve the safety in mixed traffic conditions was to make the robotic driving more like human driving. This is also confirmed through a study by Oliveira et al. [2019].

Another point that is made in this research is that if the automated driving is considered to be a safer alternative, then a human driver might show behavioural adaptation in form of a moral duty to either switch to AV or use extra precautions while using manual vehicles in mixed traffic. Another reverse behavioural adaptation might appear when the driving behaviour of fully AVs are not known properly or are considered unsafe, then the drivers in HDV might be extra cautious while driving near an AV. It is also being studied that trust in these systems increases over time [Oliveira et al., 2019].

All these studies indicate the existence of behavioural adaptation of human drivers when they interact with AVs. However, there is a lack of literature which aims to study the one to one interaction between HDVs and AVs. A lot of studies focuses on behavioural adaptation while driving next to a platoon of AVs, however, in early phases of automation, platooning might be a rare phenomenon. A lot of studies are based on a driving simulator and there is a lack of studies which collects data from real-world driving.

The reviewed papers also investigate the behavioural adaptation from different perspectives. Many studies seem to investigate the car following and lane change behaviour, however, there is a dearth of studies which aims to investigate gap acceptance behaviour.

2.3. Driving behaviour: Gap acceptance, car-following and overtaking

Driving is a complex task and it involves multiple levels of interactions to successfully perform it. As per Michon [1985], the driving task can be divided into three levels: Strategic, Tactical, and Operational. The strategic level deals with overall goals and planning of the trip. The tactical level deals with decisions regarding driving manoeuvres such as overtaking, gap acceptance etc. Whereas on a control level, instantaneous driving actions such as braking, lane change, speed change takes place.

When an HDV-driver encounters an AV on road, behavioural adaptation takes place in tactical and operational level. However, over time, when more information about AVs is obtained, the behavioural adaptation becomes more consistent on a long term strategic level [Sullivan et al., 2016].

The driving behaviour can be studied over multiple interactions. The interactions in terms of gap acceptance, car-following and overtaking behaviour are discussed below.

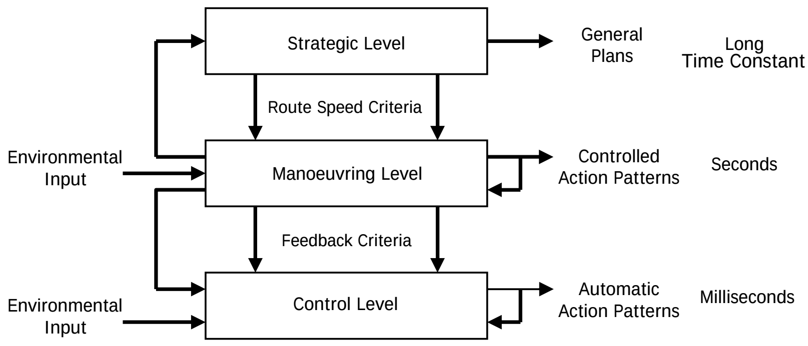


Figure 2.1: A hierarchical model of the task of driving (Michon, 1985).

2.3.1. Gap acceptance behaviour

Gap acceptance is an important component in microscopic traffic characteristics which is used in the determination of capacity and movements at an uncontrolled intersection [Vinchurkar et al., 2020]. The gap acceptance behaviour is generally studied in terms of critical gap of drivers which is defined as the smallest gap that a driver in the minor stream is willing to accept in order to merge into the major stream traffic [Luttinen, 2004].

2.3.2. Car following behaviour

Close car following accounts for 24% of all accidents involving two or more vehicles in USA in 1990 [McGehee et al., 1992]. However, Advanced Driver-Assistance Systems such as AEB reduced the rear-end frontal collisions by 27% [Isaksson-Hellman and Lindman, 2016]. It is expected that AVs would lead to a further decrease in car-following collisions.

In literature, car-following behaviour is generally studied in terms of distance and time headways [FULLER, 1981]. Distance headway defined as a bumper to bumper distance between lead and following vehicle whereas time headway also takes into account the speed of the following vehicle and can be calculated as distance headway divided by the speed of follower [Van Winsum and HEINO, 1996]. There are several factors that influence the choice of time headway. Several studies have associated choice of headways with personal characteristics of drivers.

Some studies have tried to differentiate between car following and free flow state. Vogel [2002] estimated the threshold to determine free flow state from car following on an urban intersection with a speed limit of 50 kmph. The data was collected with the help of pneumatic tubes at 4 measuring stations for 6 consecutive days (24 hr per day). It was found that headways larger than 6 seconds fall into free flow regime.

2.3.3. Overtaking behaviour

Overtaking is a fairly complex driving manoeuvre especially on undivided two lane roads where vehicles overtake slower vehicles using the opposite lane with a presence of oncoming vehicles from opposite directions [Asaithambi and Shravani, 2017]. Wilson and Best [1982] identified different styles of overtaking manoeuvres as flying, accelerative and piggy-banking. Flying overtaking takes place when the overtaking vehicle doesn't follow the overtaken vehicle before the start of overtaking. In case of an accelerative overtaking, the overtaking vehicle follows the overtaken vehicle before overtaking generally in pursuit of an opportunity to overtake. Piggy-banking takes place when overtaking vehicle overtakes along with another overtaking vehicle.

There are several methods used in literature to study overtaking behaviour. The overtaking behaviour is generally studied in terms of overtaking duration [Asaithambi and Shravani, 2017, Vlahogianni, 2013], relative speed during overtaking Asaithambi and Shravani [2017], headways at start/end of overtaking [Asaithambi and Shravani, 2017, Wilson and Best, 1982] and lateral gap while overtaking [Dutta and Vasudevan, 2020, Pal and Chunchu, 2019].

2.4. Influencing factors: Driving style, trust, stress and appearance of AVs

Several models of behavioural adaptation have been proposed which identified various factors which have an influence over behavioural adaptation. In an early version of qualitative model of behavioural adaptation proposed by Rudin-Brown and Noy [2002], driver characteristics such as trust, reliability, personality and mental model have an influence over the driving task. Within this model, external factors such as type of vehicle, road and environment also played a role in behavioural adaptation. A Joint Conceptual Theoretical Framework (JCTF) of Behavioural Adaptation proposed by Wege et al. [2013], also included cognitive, motivational and energetic processes of the driver along with external factors and driver characteristics. Some influencing factors which keep appearing within different behavioural adaptation models and have an influence over driving behaviour are discussed below.

2.4.1. Driving style

There are a couple of research which has investigated the relationship between socio-demographic characteristics such as age, gender, driving experience etc and personality traits such as skill, attitude, control etc. on the involvement in car crashes [Beirness, 1993, Garrity and Demick, 2001, Jonah, 1997, West et al., 1993]. From these studies, it was found that driving style differs between individuals and plays a major role while performing different driving manoeuvres. Interpersonal differences between individuals result in a difference in driving style among drivers and several methods have been proposed in the literature to identify and assess difference in driving style among individuals.

One of the most famous ways to capture differences in driving style is with the help of self-reported questionnaire [Westerman and Haigney, 2000]. Many scales have been constructed in past years to capture different aspects of driving styles. For example, Driving Style Questionnaire (DSQ, French et al. [1993]) focuses on factors which are known to have involvement in accidents and risky driving behaviour. The Driving Behaviour Inventory (DBI,Gulian et al. [1988]) focuses on the driver's stress and frustration while driving. On the other hand, Driving Behaviour Questionnaire (DBQ, Reason et al. [2011]) takes into account errors, mistakes and violations made during driving task.

However, since these scales are specific to driving behaviour related to accidents, a more generalised scale was proposed by Taubman-Ben-Ari et al. [2004] known as multidimensional driving style inventory (MDSI) which can capture a large range of driving styles. Within MDSI, four broad driving styles are : (a) reckless and careless driving style, (b) anxious driving style, (c) angry and hostile driving style, (d) patient and careful driving style which can still be further expanded into 8 categories of driving styles. This scale is based on a self-report questionnaire which consists of 44 questions and can be answered within a 6 point scale. The answers of multiple questions can be multiplied by a proposed factor loading to identify different scores of different driving styles.

2.4.2. Trust in AVs

People's trust in AV technology may have a great influence on how they interact with AV on road. A study by Feldhutter et al. [2016] showcased how the trust in automated vehicles varies due to media influence and personal experience. From this study, a significant change in trust level was found when the participants received basic information about AV, read media articles, and personally experienced AV in a simulator. Another important gender-related difference found was that male participants showed significantly higher trust in AV technology in comparison to female participants. However, as the participants experienced AV in a simulator, their trust while experiencing AV in real traffic can be totally different.

In another study by Ward et al. [2017], it was found that trust and acceptability of AV technology varied greatly with the age of people and their knowledge. From the study, it was found that younger people have a higher knowledge of AV technology in comparison to older people which also positively correlated to the higher trust of young people on AV. However, when participants were provided more knowledge and insights about AV technology, their perceived benefits of AV technology increased and perceived risks of AV technology decreased leading to an overall improvement in their trust in AV technology.

2.4.3. Measuring driver's stress

The technology of automated vehicles is not fully developed yet and it is expected that there will be an element of distrust among drivers towards this evolving technology in the early stages of automation [Abraham et al., 2017]. Lack of complete information about AV technology can potentially lead to an increase in stress levels of drivers interacting with an AV. In a study by Lee and OH [2017], NASA-TLX survey showcased increase in workloads of drivers driving near the platooning environment.

There are multiple methods of measuring driver's stress. One common way of measuring the stress is using the Dundee Stress State Questionnaire (DSSQ) method where a user-friendly self-report questionnaire is used to ask perceived stress experienced by the driver [Matthews et al., 1999]. Another way of measuring the driver's stress is using the physiological Sensors which can measure the heart-rate, perspiration, respiration, skin conductors etc. [Healey and Picard, 2005]. From the research, it is known that physical as well as mental workload has a clear impact on heart rate variability [Mulder, 1986, 1988, 1992, Waard and Brookhuis, 1991]. It has been observed that the heart rate increases whereas the heart rate variability decrease with an increase in mental workload and stress [Mulder et al., 2005].

2.4.4. Appearance of the vehicle

Apart from the functionality of the vehicle, the appearance of the vehicle may also play an important role in the behavioural adaptation of road users. In a study by Dey et al. [2019], the road crossing intention of the pedestrians was studied with respect to the vehicle appearance, driving behaviour, and automation. The study concludes that the decision making of the pedestrians depends on the appearance and automation of the vehicle if the distance between the vehicle and pedestrian is short. However, if the distance between the pedestrian and vehicle is long, the driving behaviour of the vehicle is more crucial in decision making.

In a photo experiment by Hagenzieker et al. [2019] to study the interaction of cyclists with AV, it was found that there is no significant difference due to the type of appearance of vehicle (such as stickers or roof-top board saying that this is an Automated Vehicle) on people's recognisability of AV. Also, no significant interaction effect was observed due to the approach angle of the vehicle.

In another study by Velasco et al. [2019] regarding the pedestrian crossing behaviour, it was found that the pedestrians that were aware that the approaching vehicle is AV intended to cross less. It is probable that people adapt their behaviour depending upon their knowledge of automated vehicles and trust in these systems.

2.5. Summary

In this chapter, multiple research papers were reviewed with an aim to gain insights about the potential behavioural adaptation of human drivers due to their interaction with AVs. Also, the literature was reviewed in order to identify the various influencing factors that have an impact on driving behaviour.

A review of multiple papers related to behavioural adaptation indicated towards the existence of behavioural adaptation of human drivers due to their interaction with AVs. However, this research domain was found to be relatively unexplored. Most studies focus on behavioural adaptation due to platoons of AVs. However, very few studies were found which aim to study one to one interaction between AVs and HDVs. Most of the studies were focused on car-following and lane changing behaviour. However, only one study addressed the gap acceptance behaviour. In order to study different driving behaviour, several indicators were identified from the literature.

The literature review was also conducted to identify various influencing factors of behavioural adaptation. It was found that driver's stress, trust in AVs, driving style and appearance of AVs have an influence over the change in driving behaviour of HDV-drivers when they interact with AVs.

The literature review successfully identified the research gap in the domain of behavioural adaptation of HDV drivers due to their interaction with AVs which is discussed in the next chapter.

3

Research objective and research questions

This section aims to discuss the research gap based on literature review and define the objectives of this research. Further, a conceptual framework which was designed to study the behavioural adaptation of HDV-drivers interacting with AVs is discussed. Later, various research and sub-research questions of this study are discussed and hypothesis are formulated regarding the expected changes in driving behaviour.

3.1. Research gap

Automated driving is becoming a reality and with the introduction of fully automated vehicles, several consequences are expected to appear. It is expected that one potential consequence would be behavioural adaptation of HDV-drivers interacting with AVs. An extensive review of existing literature indicates towards such potential behavioural adaptation. However, this area of research is relatively unexplored and there is a lack of research which aims to understand the interaction between HDV-drivers and AVs on an operational and tactical level.

There are a few studies which try to understand the behavioural adaptation of HDV-drivers upon their interaction with AVs. However, most of these studies are based on certain assumptions whose validity can be questionable. First, some of the studies are based on the assumption that AVs will drive in a platoon and thus tries to study the impact of platoon on other road users. However, in the early phases of automation, when the penetration rate of AVs will be relatively lower, possibility of platooning will be rare and thus its benefits might not be realised. Second, most studies are based on the assumption that AVs behave in a different manner in comparison to HDVs and exhibits different driving dynamics. However, advancements in technology are bringing AVs closer to human-like driving and thus there is a requirement to consider the possibility that AVs might behave similar to a conventional HDV without any driver behind the wheel. Third, most of the studies are based on driving simulator experiment and makes an assumption that differences observed within driving simulator might also be valid in real life. Although driving simulator experiments might successfully indicate the difference between various scenarios, they might fail in providing the real magnitude of behavioural adaptation which would otherwise be observed in real-life driving. Apart from these assumptions, the effect of positive/negative information about AVs, learning effect over multiple interactions with AVs, stress during interaction with AVs and trust in AVs are crucial for early stages of automation but hasn't been studied yet.

Due to these limitations, existing studies have not covered the entire spectrum of behavioural adaptation and thus there is a requirement to perform more extensive research which aims to fill existing gaps regarding understanding of interaction between HDVs and AVs. In order to gain complete insights, it is crucial to understand behavioural adaptation with respect to different driving manoeuvres. Also, it would be interesting to investigate the effect of information, stress, trust and multiple interactions to gain more insights which are relevant for early phases of automation. An exploration of these uninvestigated research areas would fill the existing research gap.

3.2. Research objective

This research aims to fill the existing research gap and collect empirical evidence of potential behavioural adaptation in human drivers emerging due to AVs. The main objective of this research is to shed light on the effects of behavioural adaptation during early phases of automation when the penetration of AVs in road traffic is not enough to harvest the benefits of platooning. Thus, majorly one to one interaction between AVs and HDVs will take place. In the early phases, when HDV-drivers will be not used to having AVs on roads, it is interesting to see how shift in their driving behaviour will take place over time.

This research makes two assumptions. First, AVs look different and are recognisable by HDV-drivers. Second, AVs drives similar to HDVs. These assumptions are made to ensure that the differences in driving behaviour of HDV-drivers is not a result of difference in driving style of AVs but only due to recognizability of AVs. Thus any behavioural adaptation observed is entirely due to the fact that HDV-drivers can recognise that interacting vehicle is an AV.

This research aims to focus on mainly three different driving behaviour as follows:

- Gap acceptance at un-signalized intersections (critical gaps)
- Car following behaviour (longitudinal control)
- Overtaking behaviour (lateral control)

Another objective of this research is to study the effect of information about AVs on driving behaviour of HDV drivers. This research also aims to study the learning effect of drivers over multiple interactions with AVs which also involves a change in stress and trust in interacting vehicle over multiple interactions. In order to study the learning effect, it is important to study multiple similar interactions where driving behaviour along with the reported level of stress and trust over multiple interactions can be compared.

3.3. Conceptual framework

Figure 3.1 refers to the conceptual framework of this research. This conceptual framework refers to the decision process of a human driver who is driving a HDV (will be referred as HDV-driver) and interacts with other HDVs or AVs (will be referred as interacting vehicle). The driving decisions of a HDV-driver can be different for interaction with both HDVs and AVs. This conceptual framework is based on findings from literature and uses several important components of behavioural adaptation models proposed by Rudin-Brown and Noy [2002] and Wege et al. [2013].

While driving, when a HDV-driver encounters a situation where it must interact with a vehicle, the first steps involve identifying the characteristics of the interacting vehicle. A vehicle may be recognized by the driver as an HDV or an AV based on its physical appearance, brand, visibility of sensors, presence/absence of driver etc. Another important observation made is regarding the driving dynamics of interacting vehicle such as driving speed, acceleration or deceleration, possibility of overtaking etc. These observable characteristics of the interacting vehicle play an important role in framing out the driving decisions as well as have an impact on the stress and trust during interaction.

The driving decisions of the HDV-driver also depends upon various personal and external factors. Personal characteristics of the HDV-driver such as age, gender, driving experience, driving style, education, field of study and work, have an impact towards understanding the dynamics of interaction and thus forming a strategy to safely interact with any vehicle. These personal characteristics of a HDV-driver also affect their stress during interaction and trust in interacting vehicle. External factors such as presence of other road users, infrastructure, weather, visibility, type of vehicle of HDV-driver etc, also plays an important role in forming a strategy for interaction but also affects the HDV-driver's expectations towards the interacting vehicle. The HDV-driver's expectations may change with the changes in external environment. For example, slow driving is expected in heavy rainfall or snow due to reduced visibility or slippery road.

When a HDV-driver interacts with a vehicle, it has an expectation towards the driving behaviour of the interacting vehicle. Based on the expected driving manoeuvres of interacting vehicle, the HDV-driver makes

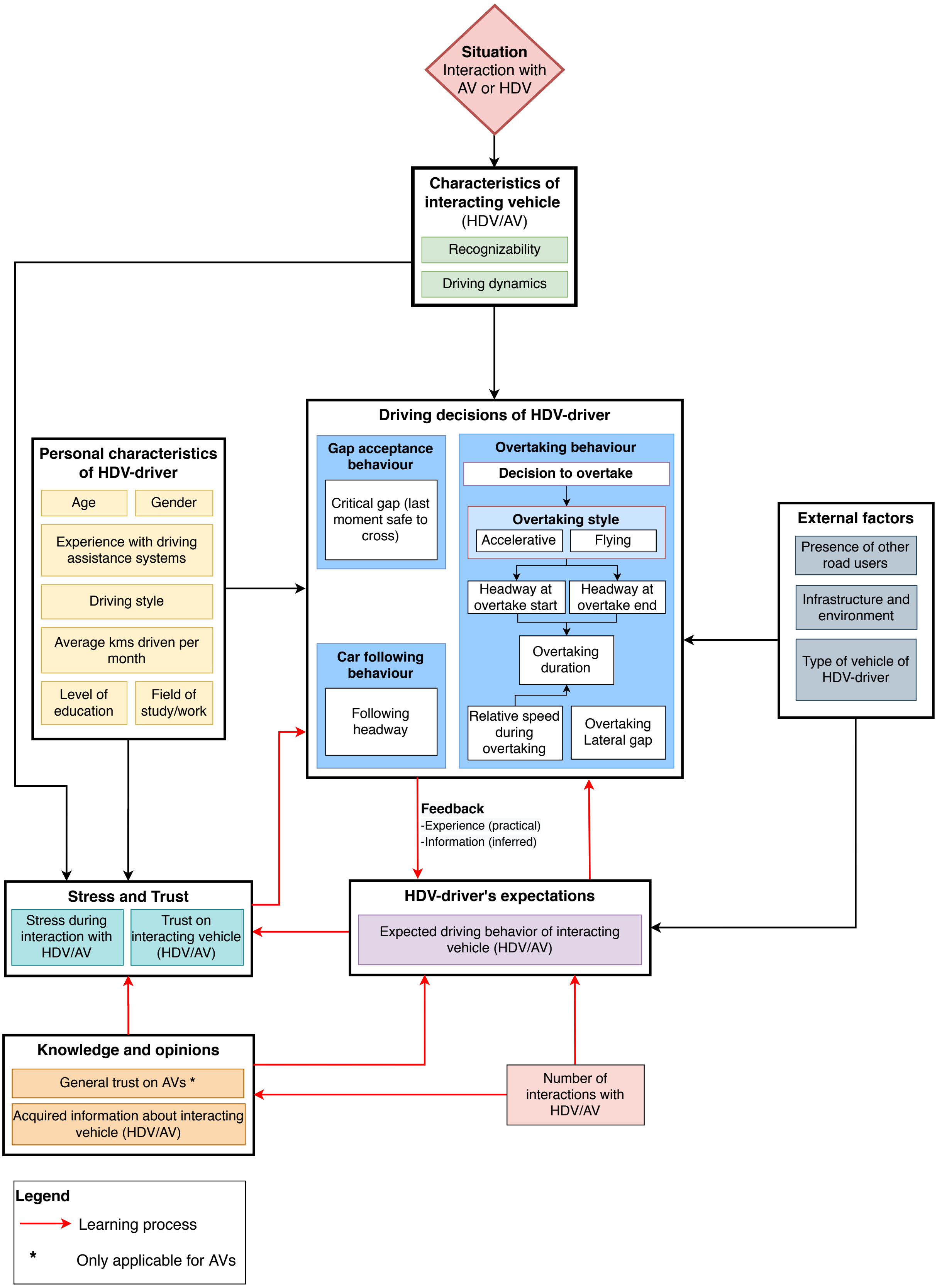


Figure 3.1: Conceptual framework for behavioural adaptation of HDV-drivers due to their interaction with AVs

corresponding driving decisions in terms of gap acceptance, car-following and overtaking manoeuvres on a tactical and operational level. However, the real driving manoeuvres of the interacting vehicle can possibly be different from what was expected by the HDV-driver leading to some practical experiences and information which promotes learning in form of reshaping expectations. The expected driving behaviour may keep changing with multiple interactions with similar type of vehicles. The expectations may also get influenced by any acquired positive or negative information from external sources. In case of interaction with AV, general trust in AVs also plays a role in framing out the expectations from interacting vehicle.

The knowledge of a HDV-driver builds up over time and over multiple interactions. Over multiple interactions, HDV-driver acquires more information on how AVs or HDVs drive in general and what are their capabilities. Information can also be acquired from external sources for example articles about AVs in the media and may have positive, negative or neutral nature. Over multiple interactions, trust in AVs can also be affected. These knowledge and opinions affect the HDV-driver's expectations as well as stress and trust during the interaction. Stress and trust during interaction in turn also play a role in driving decisions of a HDV-driver.

The driving decisions of a HDV-driver are complex and can depend upon multiple factors as discussed above. However, these factors may also have an influence on how a manoeuvre is performed. In case of overtaking, factors such as the presence of other road users, type and driving dynamics of the interacting vehicle, characteristics of vehicle of HDV-driver, overtaking opportunity, HDV-driver's personal characteristics etc., not only affects the decision to overtake but if HDV-driver decides to overtake, it also affects their overtaking style and thus various other indicators associated with it. Similarly, multiple factors may also influence car following and gap acceptance behaviour.

Since with multiple interactions, the factors such as HDV-driver's expectations, knowledge and opinions, stress and trust during interaction keeps on changing and affecting the driving decisions, the relationship between them forms a part of the learning process. Any driving decision made for interaction results into some learning for future giving rise to learning effect over multiple interactions.

Ultimately, in order to observe any difference in driving behaviour due to the behavioural adaptation, the driving decisions made during interaction with AVs and HDVs can be compared with each other.

3.4. Research question and sub-questions

As the objective of this research is to investigate any potential behavioural adaptation of HDV-drivers when they interact with AVs, the main research question in this research is

What are the potential behavioural adaptations of human drivers during their interaction with Automated Vehicles?

The following sub-research questions were formulated in order to answer the main research question:

1. What are the differences in gap acceptance, car following and overtaking behaviour of HDV-drivers interacting with AVs in comparison to interacting with HDVs?
2. What is the impact of positive and negative information regarding AVs on the driving behaviour of HDV-driver during interaction with AV?
3. What is the difference in experienced stress and trust of HDV-drivers interacting with AVs in comparison to interacting with HDVs ?
4. What is the effect of multiple interactions with AVs on driving decisions of HDV-driver while interacting with AVs?

Sub-question 1 aims to highlight the difference between three main driving behaviour upon interaction with AV and HDV. The three main driving behaviour that are being studied are gap acceptance at an un-signalized intersection, car-following and overtaking behaviour. Study of these three different driving behaviour will enable us to investigate and comment about the overall behavioural adaptation upon interaction with AV.

Sub-question 2 aims to understand the impact of positive and negative information about AVs on the driving decisions of HDV-drivers.

Sub-question 3 aims to study the experienced stress of drivers during interaction and their trust in the interacting vehicle, as both of these factors can have an influence over the way drivers interact differently with AV in comparison to HDV.

Sub-question 4 aims to investigate the learning effect of drivers over multiple interactions with AV. Over repeated interactions, as more information is acquired, the trust in the interacting vehicle and resulting stress might change over time which may have an impact on the behavioural adaptation towards AVs.

3.5. Hypothesis formulation

In order to find the answer to various sub-research questions discussed in the last section, several hypotheses were formulated which would be tested separately in order to gain insights into overall behavioural adaptation. The hypothesis were formulated in accordance with the findings from the literature. Various hypothesis for different driving behaviour related to different sub research questions are provided in Table 3.1.

The hypothesis table is structured as follows. On the top row of the horizontal axis, different categories of analysis (or main research areas) are listed which would help in answering sub research questions. These categories of analysis will be evaluated by comparing two scenarios. The main scenario is listed in 2nd top row ("Effect studied for") and comparison scenario is listed in 3rd top row ("In comparison with"). These categories of analysis are numbered from H1 to H6. On the vertical axis, different indicators of all three focused driving behaviour and stress/trust are provided. The Hypothesis H1 to H6 will be evaluated for these variables. These indicators are numbered from 1 to 9.

For each category and indicator, a hypothesis was formulated which relates to the expected effect of the main scenario ("Effect studied for") with comparison scenario ("In comparison with") . These hypotheses can be referred with the help of reference numbers separated by a dot(.) for example Hypothesis H1.1, H2.5 etc. An alternative hypothesis can be formulated easily with the combination of categories and indicators. For example, alternative hypothesis H1.1 can be stated as: Critical gap in case of an AV will be higher in comparison to that of HDV.

The different hypothesis categories (H1 to H6) will help in answering sub research questions as follows:

Ref no	Category	Explanation
H1	Effect of scenario	This category aims to investigate the effect of type of vehicle (HDV or AV) on driving behaviour, stress and trust. In order to achieve this objective, different indicators during AV scenarios are compared with indicators in HDV scenario. This category aims to answer Sub question 1 and 3. This hypothesis is addressed in section 7.3.1.
H2 & H3	Effect of information	This category aims to investigate the effect of positive or negative information about AVs on driving behaviour, stress and trust during interaction with AVs. In order to achieve this, a comparison between information and no information scenario is made. This category aims to answer Sub question 2. This hypothesis is addressed in section 7.3.2.
H4	Over multiple interactions (Learning effect)	This category aims to investigate the change in driving behaviour, stress and trust over multiple interactions with AVs. This category aims to answer Sub question 4. This hypothesis is addressed in section 7.3.3.
H5	Effect of trust over interacting AV	This category aims to investigate the effect of trust over interacting AV on different driving behaviour indicators. In order to achieve this, change in driving behaviour is observed with change in trust levels. This category aims to support various sub-questions. This hypothesis is addressed in section 7.4.1.
H6	Effect of stress during interaction with AV	This category aims to investigate the effect of stress during interaction with AV on different driving behaviour indicators. In order to achieve this, change in driving behaviour is observed with change in stress levels. This category aims to support various sub-questions. This hypothesis is addressed in section 7.4.2.

Table 3.1: Hypothesis table indicating expected differences within different driving behaviour

	Category		Effect of Scenario	Effect of provided information (AVs)		Over multiple interactions (Learning effect)	Effect of trust over interacting AV	Effect of stress during interaction with AV
	Effect studied for		AV	Positive information	Negative information	AV	Higher trust	Higher stress
	In comparison with		HDV	No information	No information	Number of interactions	Lower trust	Lower stress
		Ref no	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**
Gap acceptance behaviour	**Critical gap**	**1**	Higher	Lower	Higher	Decrease	Lower	Higher
Car following behaviour	**Following headway**	**2**	Higher	Lower	Higher	Decrease	Lower	Higher
Overtaking behaviour	**Overtaking duration**	**3**	Higher	Lower	Higher	Decrease	Lower	Higher
	Lateral gap while overtaking	**4**	Higher	Lower	Higher	Decrease	Lower	Higher
	Headway at start of overtaking	**5**	Higher	Lower	Higher	Decrease	Lower	Higher
	Headway at end of overtaking	**6**	Higher	Lower	Higher	Decrease	Lower	Higher
	Relative speed during overtaking	**7**	faster	Slower	Faster	Decrease	Slower	Faster
Stress and trust	**Trust over interacting vehicle**	**8**	Lower	Higher	Lower	Increase	-	-
	Stress during interaction	**9**	Higher	Lower	Higher	Decrease	-	-

3.6. Research methodology

Figure 3.2 shows the different steps involved in this research to achieve research objectives.

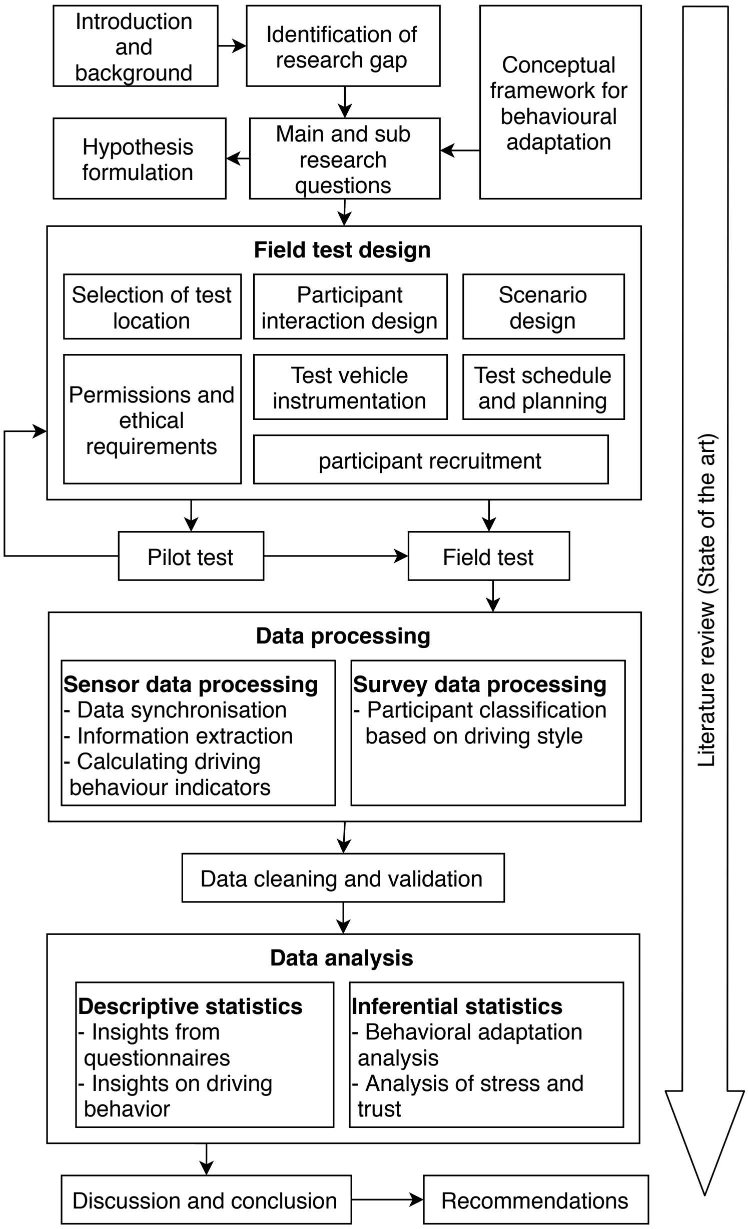


Figure 3.2: Research methodology

3.7. Summary

An extensive literature review indicated the existence of behavioural adaptation of human drivers interacting with AVs however this area of research was relatively unexplored. This chapter discussed the existing research gap in the study of interaction between HDVs and AVs and clearly formulated the objective of this research. Further, a conceptual framework was designed which aimed to establish a relationship between personal characteristics, external factors, stress and trust, HDV driver's expectations, knowledge and opinion and driving decisions of HDV-driver. This conceptual framework helps in identifying the influencing factors of behavioural adaptation. Later the main research question which aimed to achieve research objectives and fill research gaps was defined. Few sub-questions were formulated which would, in turn, answer the main research question. Furthermore, various hypothesis of this research were formulated based on findings from literature and expectations. Finally, an overview of the research methodology was provided.

4

Research design and field test setup

In order to answer the research questions discussed in the previous chapter, it is important to understand how a HDV-driver would interact with AV in comparison to an HDV. Thus, in order to understand that, a field test was designed in which HDV-drivers were made to interact with both HDVs and AVs. Since the HDV-drivers are study subject of this research, they were recruited for the field test and are referred to as "participants". The participants were asked to drive in their own vehicle which is termed as "Subject vehicle". During the field test, participants interacted with another vehicle that drove both as an HDV or an AV and collected data on driving behaviour of the subject vehicle. Since driving behaviour is evaluated with respect to this data collecting interacting vehicle, it is termed as "Test Vehicle (TV)".

This chapter aims to discuss the field test which was designed to collect data for the research and the processes involved to successfully conduct it. Section 4.1 aims to provide detailed information about the field test design planning. In this section, details about field test design objectives, test location, participant interaction plan, TV instrumentation, scenarios, permissions, recruitment and field test schedule are discussed. Later, a pilot test which was conducted to improve and confirm the field test plan is also discussed in section 4.2.

4.1. Field test design

In order to achieve the research objectives, a controlled field test was planned. The planning of the field test involved a lot of management and communication between different people/institutions. In the planning phase, an emphasis was provided to use available resources in the most efficient way, rectify any potential practical challenges, maximise the efficiency of data collection, and coordinate between different involved researchers. Within the design process, safety has always been the most important factor. This section aims to discuss field test design in detail.

4.1.1. Design objectives

As discussed in section 3.2, this research involves the study of mainly three different types of driving behaviour, namely gap acceptance, car following, and overtaking behaviour. It also involves the study of the learning effect over multiple interactions with AV. Since the quality of results depends on the data collected, it is important to carefully design an field test which can capture various intended driving behaviour efficiently. The following objectives were kept in mind during the design of the field test.

- Each run of the experiment should be able to capture all three driving behaviours: gap acceptance, car-following and overtaking upon interaction with HDV or AV.
- As multiple similar interactions are required to study the learning effect, the scenarios should be reproducible.

- Since multiple interactions are involved, an efficient time management strategy should be adopted.
- Experimental bias should be minimized.
- Additional safety measures should be implemented to facilitate social distancing due to COVID-19.
- In order to gain deeper insights about the participants and their decisions, there should be various questionnaires and interviews.

The experiment was designed in order to fulfill these design objectives.

4.1.2. Field test location

As the field test design mainly depends upon the road geometry and infrastructure facilities at the test location, the first step before making a detailed field test plan was to select a suitable test location and road section. Following criteria were considered while selecting test location:

- Minimal presence of other road users, required to facilitate a more controlled environment and less disturbance during the experiment.
- Two-lane bi-directional highway with straight road section to simplify experiment design.
- Sufficient parking lot facilities which can be used as start/end locations.

After considering multiple options, a 3 km long road section in Noordzeeweg near the town of Rozenburg was selected (figure 4.1). The test route starts near the EIC Mainport, Rotterdam, and ends near Maeslantkering in Noordzeeweg.

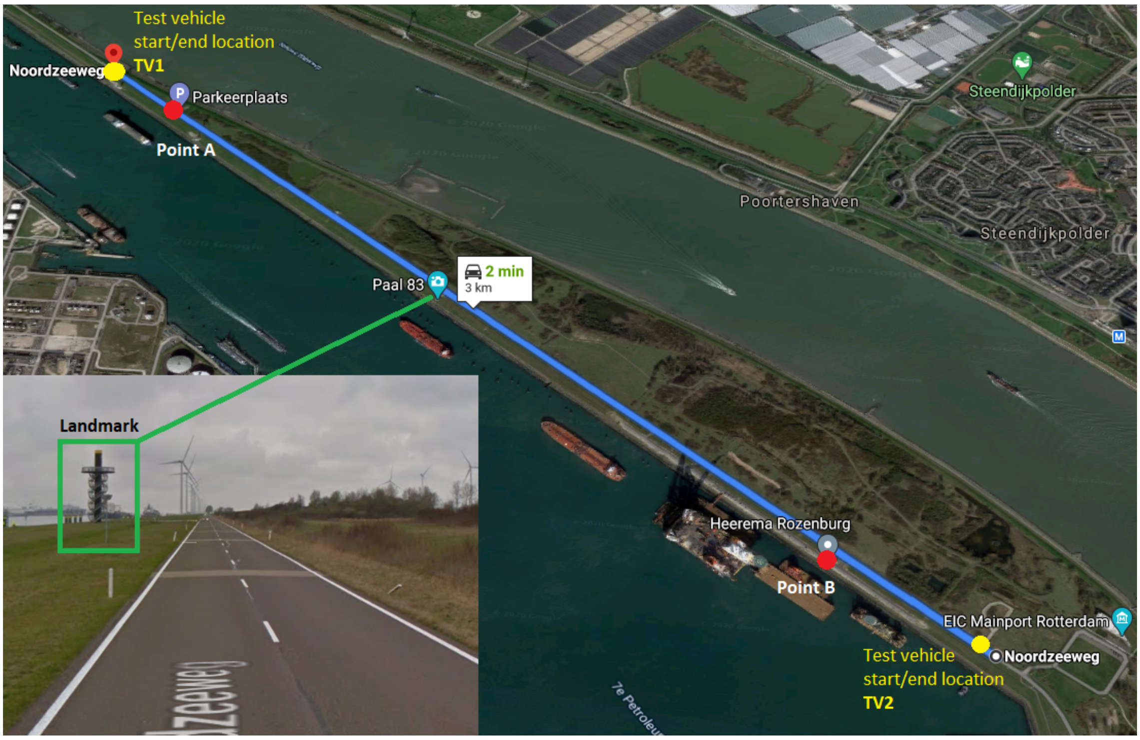


Figure 4.1: Selected road section for field test at Noordzeeweg - Source: Google maps

The selected location was ideal for conducting this field test as it provided two parking lots as a test start and end facilities on both sides of the road section. One major advantage of this road section is identical position of parking lots near the ends allowing to easily design reproducible scenarios from both ends of the road. The parking lots (referred as point A and B in figure 4.1) which were used as start/end location of subject vehicles are shown in figure 4.2.

Figure 4.2: Parking lot at point A (left) and Parking lot at point B (right)

Also, a landmark was present in the middle of the road section, which was used as a reference point. The selected road section was completely straight and traffic intensity was very low (around 30 vehicles per hour) . Table 4.1 provides the characteristics of the selected road section for field test.

Table 4.1: Characteristics of selected field test location

Attribute	**Value**
Traffic intensity	Very low
Type	Bi-directional
Speed limit	60 kmph
Number of lanes	2
Geometry	Straight
Total length	3 kms
Lane width	3.5 meters
Lane markings	Center - Interrupted / Broken Edges - Solid / Continuous
Overtaking	Allowed
Bicycle lanes	No

Additionally, the centre line lane marking had an interrupted/broken style where the length of white markings was 3 meters with 9 meters space between them.

4.1.3. Participant interaction design

After selecting the test location, a detailed participant interaction plan was prepared to collect data under the consideration of design objectives discussed in section 4.1.1. The interaction with participants was planned in three stages: before, during and after the field test where different interactions took place through questionnaires, real-life driving, and interviews after the field test.

The different stages of interaction with the participants are discussed in the following subsections:

a) Pre-experiment questionnaires

The first step for conducting the planned field test was to recruit participants, check their eligibility, and gain insight about the personal characteristics of interested candidates. Thus in order to achieve that, a recruitment questionnaire was prepared, which intended to collect insights about the personal characteristics of interested candidates. The recruitment questionnaire also intended to collect the general trust of potential participants towards AVs before the experiment. The recruitment questionnaire is provided in appendix B and participant recruitment procedure can be found in section 4.1.8.

The eligible and interested candidates were then provided with an information sheet which intended to give them a brief introduction to the field test and manage their expectations. Later, they were required to sign a consent form in order to play as a participant of the research test.

The selected participants were presented with a Multi dimensional style inventory (MDSI) driving style questionnaire which aims to gain insights about their self reported driving styles. The MDSI questionnaire can be found in appendix D.

b) Vehicle interaction plan

Considering the facilities present in test location and design objectives, a vehicle interaction plan was designed. Figure 4.3 illustrates the schematic diagram of the field test location. The inner parking lots (point A and B) were used as a start/end location of subject vehicles and the outer parking lots TV1 and TV2 were used as start/end location of the test vehicle.

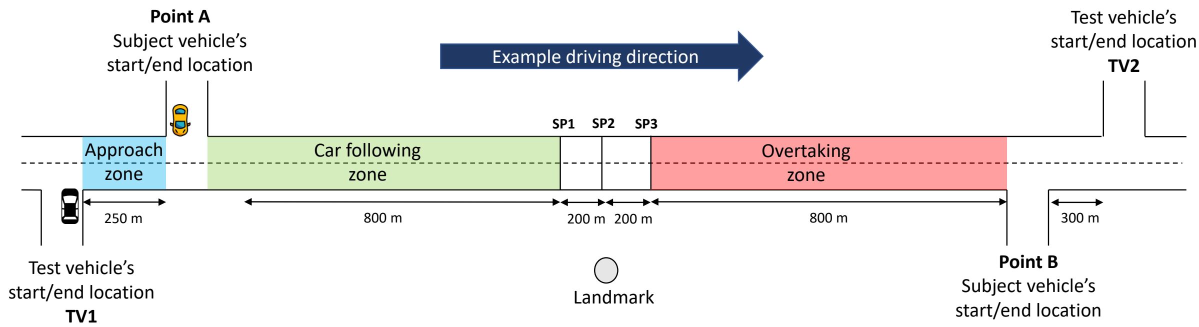


Figure 4.3: An illustration of field test plan

The experiment was designed in a way that the subject vehicle drives between points A and B and test vehicle drives between points TV1 and TV2. This ensured that the subject and test vehicles only interact during driving. In a single run of the field test, the subject vehicle either drives from point A to point B or vice versa whereas the test vehicle drives from TV1 to TV2 or vice versa respectively. The test vehicle always started from the parking lot near the start location of the subject vehicle. In each run of the field test, the subject vehicle interacted with the test vehicle within all three focused domains of interaction: Gap acceptance, car-following and overtaking. The aim of the subject vehicle was to reach its end location.

At the start of each run of the experiment, the subject vehicle and test vehicle aligned themselves in their respective starting location. In the given example, the test vehicle started from TV1 and the subject vehicle started from Point A. The aim of the subject vehicle was to reach point B and test vehicle to reach location TV2. The interaction between the subject vehicle and test vehicle took place in the following manner:

1. **Gap acceptance:** A run begins when the test vehicle started driving from its start location TV1 and approached participant (point A) at a speed of 40 kmph. This speed provided ample opportunity for the participant to observe the type of vehicle. From a subject vehicle's perspective, the test vehicle approached from its right-hand side in the opposite (farther) lane. When the vehicle was approaching towards the subject vehicle in approach zone, the participant was expected to indicate its critical gap i.e., last moment when a driver would decide to merge in front of an approaching vehicle. The critical gap was indicated by the participant with the help of a hand gesture. However, the subject vehicle was not expected to take any action at this point.

2. **Car following:** After the indication of critical gap, once the test vehicle had crossed the parking lot at point A and entered the car following zone, the subject vehicle was allowed to drive towards its end location (point B). When the subject vehicle started driving, the test vehicle was slowly accelerated

from a speed of 40 kmph to 60 kmph. As the test vehicle was driving at the speed limit of the road in this section, there was not enough incentive for the subject vehicle to overtake the test vehicle. Thus, the subject vehicle followed the test vehicle for approx 1 km distance (1 minute driving) at a speed of 60 kmph.

3. **Overtaking:** At the end of the car following zone (recognised by a landmark), the test vehicle was gradually slowed down from a speed of 60 kmph to 40 kmph encouraging the subject vehicle to overtake. The slowing down took place at one of the three randomly chosen slow down point SP1, SP2 and SP3 (scenarios can be found in appendix G). SP1 and SP3 were located 200 meters before and after the centre of landmark point. Within the overtaking zone, the subject vehicle was able to decide whether and when to overtake the test vehicle. The overtaking was possible within the next 800 meters before reaching the endpoint of the subject vehicle. After successful overtaking by subject vehicle, the test vehicle was accelerated again to drive behind the subject vehicle.

After a sequential interaction within these three manoeuvres, the subject vehicle stopped at its end point B and the test vehicle proceeded straight to its end point TV2. In the next run of the experiment, the subject vehicle drove from point B to point A. In this case, the approach zone was between TV2 and point B, followed by a car following zone and overtaking zone. The interaction at point B was similar to point A as the test vehicle approached from the right of the subject vehicle and drove on the opposite (farther) lane.

c) During experiment questionnaire

The sub-research question 3 aims to compare the stress during interaction and trust in the interacting vehicle between different scenarios. Thus at the end of each run, the participants were presented with a small questionnaire where they were asked to indicate their experienced level of stress and their trust in the interacting test vehicle on a scale of 1 to 10 where 1 indicates no stress or trust and 10 indicates very high stress or full trust. The during experiment questionnaire can be found in appendix F.

d) Post-experiment questionnaire and interview

Since it is required to fully understand the decisions made by participants during the field test, a post-experiment questionnaire (appendix H) was designed which intended to collect more details about the experiences of participants. In the post-experiment questionnaire, the participants were again asked about their general trust in AVs which can be compared to their self-reported trust before the experiment. This might help to capture if their general trust in AVs changed after the experiment.

In order to get deeper insights about the experiences of participants, a set of interview questions were formulated which is given in appendix H.

4.1.4. Scenario design

Once the participant interaction plan was designed, different scenarios were formulated which would help in making comparisons to identify the difference in driving behaviour. In order to observe the difference in driving behaviour of HDV-drivers upon their interaction with AVs, the interaction with test vehicle was carried out within two main scenarios. In one scenario, the test vehicle was driven as a HDV whereas, in another scenario, the test vehicle was driven as an AV. The scenarios are named as i-HDV and i-AV, where i refers to interaction with the test vehicle (Toyota pr**i**us) as an HDV and AV.

As learning effect over multiple interactions is being studied, each participant interacts with test vehicle over 10 runs. Each participant within 10 runs interact 4 times in i-HDV scenario and 6 times in i-AV scenario. The scenario during the first run was always i-HDV. However, for the rest of the 9 runs, the scenarios were randomly assigned.

In order to study the effect of information, in the last three runs of i-AV scenario, a piece of positive or negative information was provided to the participant. The type of information a participant would receive was randomly selected with aim to achieve an equal number of positive and negative information recipients.

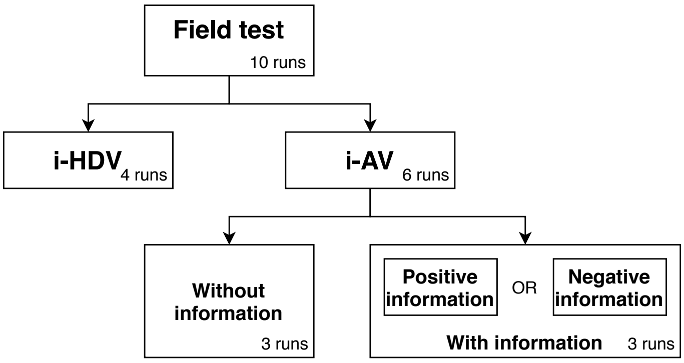


Figure 4.4: Scenario design

Also, as discussed in vehicle interaction plan, there were three different slow down points where the test vehicle would slow down to encourage overtaking. For each run, the slow down point was randomly selected. The change in slow down location can minimize any participant's expectation regarding the location of slowing down of test vehicle. The detailed scenarios for each participant are provided in appendix G.

4.1.5. Field test schedule

After designing the participant interaction plan and formulating different scenarios, the total time required to conduct a field test can be calculated. In order to efficiently conduct the experiment, the following factors were considered for scheduling different activities during field test:

- **Introduction and initial briefing time** - In order to brief participants on the process of the experiment, 5 minutes were required.
- **Driving time** - As the distance between test vehicle start and end location was 2.6 kms and the speed limit during the experiment was 60 kmph, a total driving time of 3 minutes per run was required.
- **Post experiment questionnaire and briefing** - A total time of 15 minutes was required to allow filling questionnaire, interview and de-briefing.
- **Buffer time** - A buffer time of 10 minutes was kept to allow unprecedented delays and breaks.

Thus, field test with one participant i.e., 10 runs, can be completed in 60 minutes. One hour was required to access/egress the test location and one hour was kept separate as lunchtime and buffer to fix unexpected problems. Given an 8 hour work day, a total of 6 hours was left to conduct experiment. With this schedule, the number of possible field test participants per day was 6.

4.1.6. Test Vehicle instrumentation

In order to collect data for this experiment, Toyota Prius from Smart vehicle laboratory (Faculty Of Civil Engineering and Geosciences) of Delft University of technology was used. This vehicle was instrumented with cameras, point LiDAR's and GPS module for data collection as shown in figure 4.5. The vehicle was also instrumented with a detachable fake LiDAR and Self-driving sticker to inform participants whether TV is driving in an AV or HDV scenario.

The point LiDAR's (Light detection and ranging) were installed on the left, right and rear of the vehicle with the intention to measure the distances of the nearby vehicles. The left and right LiDAR's were installed near the rear door's handles whereas the back LiDAR was installed on the rear bumper. The angle of the LiDAR's were adjusted such that its beam stays parallel to the road surface thus giving measurements only from the reflection by objects.

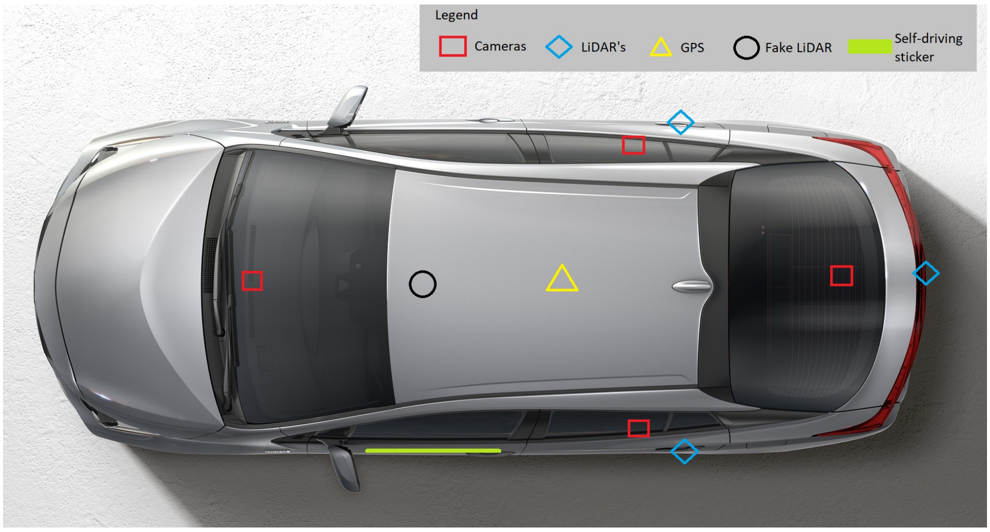


Figure 4.5: Location of various sensors instrumented in test vehicle

In order to capture the video footage of interacting participants and surrounding, four cameras were installed on the left, right, front and rear side of the vehicle. Additionally, the front camera has an inbuilt GPS module which provided the GPS coordinates, speed and current time in the form of subtitles in the video footage. Front camera used its own storage for recording. The other three cameras were connected to a central computer which recorded the footage and inscribed timestamp in videos.

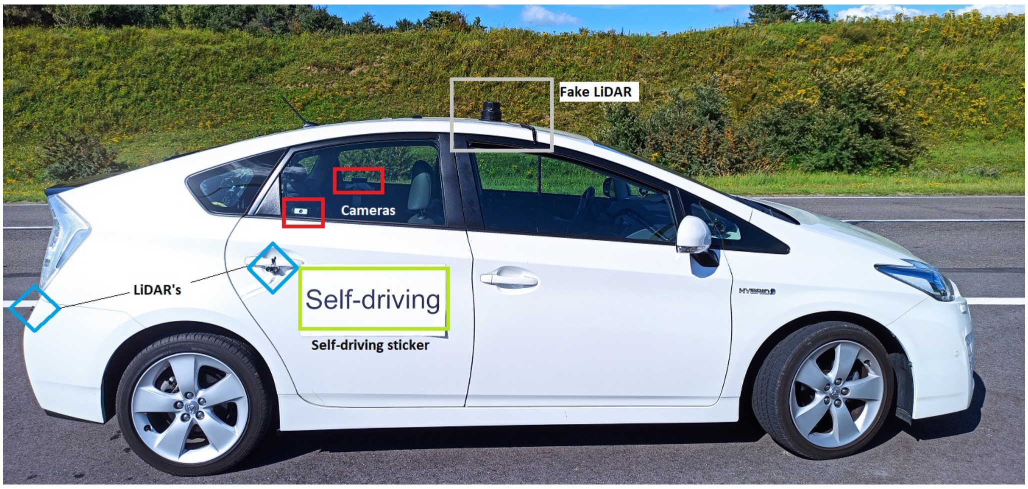


Figure 4.6: Sensors and instruments on the side of test vehicle

Also, the test vehicle had an inbuilt GPS module which recorded the GPS location and speed of the vehicle. The data from the GPS module and LiDAR's was recorded on another computer inside the vehicle in a CSV format. Table 4.2 gives the details about various data collection sensors instrumented in the vehicle.

In order to facilitate identification of test vehicle as an AV, the detachable magnet based fake LiDAR unit and a sticker with a note "Self driving" was present. These instruments can be easily instrumented or removed as per requirement. The various instruments in test vehicle are represented in figure 4.7 and 4.6.

Figure 4.7: LiDAR, GPS and data collection devices in test vehicle

Table 4.2: Specification of different sensors instrumented in test vehicle

Sensor	**Brand and model**	**Specifications**
Dash camera	Garmin dash cam	Field of view - 140 degrees Resolution - 1080p
Back, left and right camera	Logitech C930E	Field of view - 90 degrees Resolution - 1080p
Point LiDARs	Garmin Lidar Lite V3	Range - 5 cm to 40 m Accuracy - +/- 2.5 cm Frequency - 100 Hz
GPS module	G.top013	Update frequency - 5 Hz Accuracy - ~4 meters

4.1.7. Permission and ethical requirements

To conduct a controlled field test, several ethical and legal requirements were needed to be fulfilled. As the research involved the participation of human subjects, it is mandatory to get approval from the Human Research Ethics Committee (HREC) of TU Delft. Thus, the first step was to apply for approval from HREC. Securing approval involves a standard procedure of submitting ethics review application which involves providing a complete explanation of the research plan, informed consent form, potential risks and measures, copy of advertisement used to recruit participants, data management plan and briefing/debriefing text used to brief participants during the experiment. Within the application, the measures to tackle COVID-19 were also introduced. A field test can only be conducted once application is approved. The whole application procedure took around 3 weeks after which necessary practical arrangements for field tests were carried out.

As the field test was planned to be carried out on the public road, it was important to get an approval from the relevant road authority and address any underlying concerns. Thus, after receiving ethical approval, the second step was to contact the Municipality of Rotterdam and Port of Rotterdam as they are responsible for maintenance and operations in Noordzeeweg (field test location). The possibility to close the road during the experiment was also investigated. Given additional feedback and concerns towards safety, relevant changes in experiment design were made.

The third step was to obtain approval from the participants. Thus, interested candidates for research were provided with an information sheet and consent form before the experiment (appendix C). This form provided participants information about the purpose, experimental procedure, underlying risks and discomforts, data confidentiality and right to refuse and withdraw from the experiment. The candidates were only allowed to participate once they filled this form.

4.1.8. Participant recruitment

Once the field test design was approved and necessary permissions were obtained, participant recruitment was started for the main field test. The objective and design of the research require the interaction of participants with both HDV and AV. Although the experiment design ensures complete safety, it is possible that less experienced drivers may undergo higher workload and stress during interaction in i-AV scenario. Also, a more experienced driver, someone who drives frequently, may better understand how humans drive and interact in road and thus may behave consistently with HDV. Therefore a criterion was chosen to recruit participants who have a driving experience of more than 5 years.

With the outbreak of COVID-19 pandemic, it was important to ensure participant's safety by having minimal interactions. For which the- participants were requested to bring their personal vehicles to take part in the field test. Allowing participants to bring their personal vehicle provided several advantages. First, no familiarisation time with the vehicle was required making the test process faster. Second, driving in a personal vehicle reduces experimental bias as participants can drive their vehicle in their usual driving style. Third, participants can choose to stay inside their vehicle during the entire course of the experiment, facilitating social distancing.

The following criteria were proposed to recruit the participants for the research. If a driver satisfies these criteria, he/she was permitted to take part in the study.

- Driver has a driving experience of at least 5 years and possesses a driver's license valid in the Netherlands.
- Driver can reach the experiment location with a personal vehicle and be able to use it to participate in the experiment.

The participants for this research were recruited using the following methods:

- Through email advertisement to the employees of Royal HaskoningDHV and colleagues of Delft University of Technology.
- Through an advertisement on social media platforms such as Facebook and Linkedin
- Sending out advertisements to Delft church community and related groups.
- By words of mouth, personal contacts, friends and colleagues.

The advertisement included a link to a Google form which intended to collect the personal characteristics and contained a short recruitment survey related to participant's current level of trust in AV. The advertisement flyer and recruitment survey questionnaire can be found in the appendix. The selected participants were also provided with a compensation of €25 for their time and fuel expenses.

Given the experiment team's availability, a total of 4 days was dedicated to conduct the field tests. Out of 4 days, one day was required to conducting a pilot test to practice and checking of the experiment design. And the remaining three days were kept for conducting the main experiments. Since 6 participants can take part over one day, a total of 18 participants were expected to join the main field test.

After recruitment, a total of 20 confirmations were received, out of which 2 participants were selected for the pilot test and 18 participants were selected for the main field test.

4.2. Pilot test and lessons learned

Before the commencement of the actual field test, a pilot test was conducted on 14th July 2020. The main intention of conducting the pilot test was to find loopholes in the field test design and improve it. The most important factor of the pilot test was to practice the communication, interaction with participant and speed change manoeuvres of the test vehicle.

The main points which were checked during the pilot were suitability of test location, experiment design, recognizability of test vehicle in different scenarios, working of test and subject vehicle sensors, indication of critical gap by hand gesture, placement of field cameras, driving speed, team communication protocol, clarity of instructions, reference cone visibility, driving schedule and feasibility to use heart rate sensors for stress measurement.

All these inspection points were reviewed with the help of a checklist. In order to help in conduction of the field test, three other team members were present. One professional driver was responsible for driving the test vehicle as per scenario sheet. A technician was responsible for taking care of technical arrangements such as starting/stopping data collection, installing field cameras, fixing technical problems etc. Technician also worked as a safety officer and kept an eye on the ongoing activities to ensure that the field test was carried out safely. To assist participants at point B, a masters student who volunteered to help was present.

To conduct the pilot, 2 participants were selected from the list of registered participants. These participants were selected as they were not available on the dates of the main experiment. One participant was provided with negative information, while the other was provided with positive information on AV. The pilot started with an initial briefing and instrumentation of subject vehicle with GPS module. During each pilot, 10 runs with each participant were completed. One participant was asked to fill an online questionnaire at the end of each run while another participant was provided with a questionnaire sheet to indicate their stress and trust. At the end of each pilot, participants were asked to fill a post-experiment questionnaire and answer interview questions. Post debriefing, few additional questions were asked which was aimed towards identifying problems within the field test design.

The weather on the day of pilot was cloudy and rainy. The traffic intensity during the pilot was very low which allowed easy operations during the runs. No technical failures/difficulties were faced during the pilot. The following are the key takeaways from the pilot test which were further used to improve the field test design:

- The pilot participants reported that the test vehicle slowing down location becomes very predictable after a few runs of the field test. Thus it was required to randomise slowing down location in different scenarios.
- As the test route did not have much vehicle activity by other road users, the maximum speed restriction of 50 kmph in field test design was considered low. Since other road users were driving near the speed limit, it was safer to increase the maximum driving speed during the test equal to the speed limit of the road i.e., 60 kmph and approach/slowing down speeds to 40 kmph.
- It was noticed that more time was required to allow subject vehicle reorientation and filling out the questionnaires. However, it was possible to provide initial briefing to the next participant during the last few runs of the previous participant. Also, it was possible to interview previous participants once the next participant starts their tests. Thus, no changes in the test duration was necessary, but it was possible to gain more buffer time by overlapping start and end activities.
- The GPS module which was kept in the subject vehicle had a low frequency (1 observation every 5 seconds) and thus does not provide any useful data. Thus, a different GPS module was required to collect the subject vehicle's location information.
- It was noticed that lowering the hand to indicate critical gap was the most suitable hand gesture which can be clearly captured by field cameras.
- It was noticed that using heart rate sensors to capture objective stress was not feasible. One reason was that the wire of heart rate sensor interferes with the driving task making it unsafe. Another reason was technical difficulty due to limited battery capacity of data recording computer, as charging facility on the subject vehicle cannot be always used.
- It was noticed that bigger reference cones were required further from the camera as smaller cones were not visible through field cameras.
- It was noticed that it is important to clearly emphasise that the participant should drive near the speed limit and is allowed to make any driving decisions. Without clear instruction, the participants are less likely to overtake when the test vehicle slows down.

These insights led to small changes in field test design which helped in smooth operation during the field test. The main field test setup is discussed in chapter 5.

4.3. Summary

To gain insights about the change in driving behaviour of HDV-drivers due to their interaction with AVs, a field test was chosen as a medium of data collection. The field test was chosen to gain insights on real-life decisions made by the drivers. This section further discussed the design of the field test in detail and also provided information on the pilot test, which was conducted in order to validate the field test design in practice. The field test was designed to achieve a few design objectives and was planned to be conducted in Noordzeeweg near the town of Rozenburg in the Netherlands. During the field test, a complete interaction with participant consisted of completing pre-experiment questionnaires, driving and interacting with AVs, filling questionnaires during the experiment and completing a post-experiment questionnaire followed by an interview.

The driving plan consisted of interactions to gain insights about the gap acceptance, car-following and overtaking behaviour. Each participant interacted 10 times with test vehicle which was driven both as an HDV and an AV. For the interaction with AV, participants were also provided with either a positive or negative information for half of the runs in i-AV scenario. The data during the field test was collected with the help of sensors instrumented in both test and subject vehicles.

To conduct the field test, several ethical requirements were fulfilled and participants were recruited. Before the commencement of the main field test, a pilot test was conducted to check the experiment design and find loopholes in the data collection process. The insights from the pilot test were further used to improve the process of conducting the main field test.

5

Data collection and processing

In the previous chapter, field test design along with insights from the pilot test were discussed. Following the insights from the pilot test, the main field test design was improved and data was collected. This chapter aims to provide an overview of the processes involved during data collection and processing. This chapter is structured as follows. First, the final field test which was conducted for data collection along with collected raw data is discussed. Second, the systematic process of sensor and survey data processing is discussed which led to various driving behaviour indicators. Third, the process of cleaning and validating data is discussed. This chapter ends with a methodology to further analyse the data in order to gain insights regarding the driver's behavioural adaptation due to interaction with AVs.

5.1. Final field test and data collection

After successfully completing the pilot test, some important insights about required changes in field test design was obtained as discussed in section 4.2. Thus, small changes in the field test design were carried out to create a plan as discussed in section 4.1.

The final field test was carried out on 21st, 22nd, and 23rd July 2020. During these three days, the weather was consistent and sunny. Although traffic used to increase gradually from morning till afternoon, traffic intensity of the test route was still very low (approx 30 vehicles/hour) during the field test days. The test route had no obstructions during the test days. A total of 18 participants took part in the main field test out of which 6 participants took part on 1st day, 5 participants took part on 2nd day and 7 participants took part on 3rd day.

In order to help conduct field test, three other team members were present on each day. The test vehicle was always driven by the same professional driver in all three days to ensure that the driving style of the test vehicle remains consistent. Technical arrangements were ensured by a Technician from TU Delft. In order to assist participants in the parking lot at point B, three different masters students volunteered to help on each day of the experiment. These students were provided with clear instructions and training on their activities. The main job of the volunteers at parking lot B was to help participants align their vehicle and get them ready for the next run, communicate to the team when the participant is ready, remind the participant to fill the questionnaire after every run, remind the participant to perform hand gesture if they forget and provide information to the participant depending upon the scenario.

5.1.1. Field instrumentation and setup

Following the insights and practice from the pilot test, field test setup and instrumentation was carried out. The following preparations were carried out on the day of field tests before starting tests with participants.

Field instrumentation

For the data collection of hand gesture to indicate critical gap, a field camera was fixed on the side of parking lot A and B facing towards the parking lot (figure 5.1). Also, to estimate the approximate distance of the test vehicle at the time of critical gap indication, traffic cones for reference were placed in the approach zone. The traffic cones were placed up to 80 meters as cones further than that were not visible through field camera. For reference of further distance, road marking poles can be used.

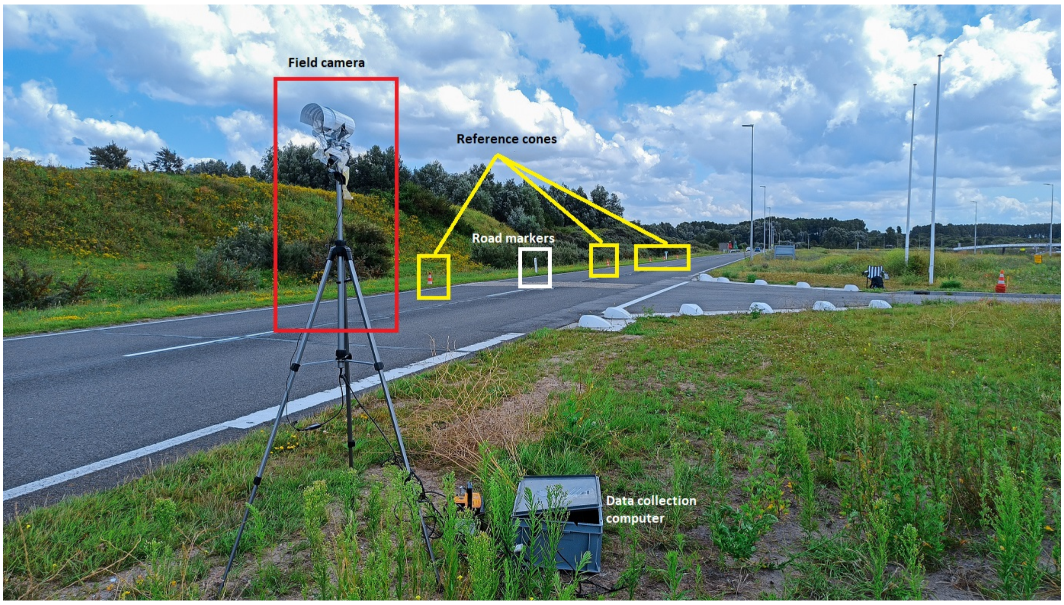


Figure 5.1: Field camera and reference cone setup near parking lot - point B

Subject vehicle

As the GPS module kept in subject vehicle during the pilot did not have sufficient frequency, another device was used to collect GPS data. The GPS data collection of the subject vehicle was carried out using an open-source "GPS logger" application on an android device. This application enabled GPS data collection with a frequency of 1 Hz and an accuracy of 4 meters.

Test vehicle

In order to identify the type of vehicle (HDV or AV), a visual distinction was made. In i-AV scenario, the test vehicle was instrumented with a self-driving sticker on the left side of the vehicle and a fake LiDAR on the top. In i-HDV scenario, the test vehicle had a normal appearance (figure 5.2). The participants were informed about this difference during the initial briefing (see appendix E).

Figure 5.2: Test vehicle in i-HDV scenario (left) and in i-AV scenario (right)

During the interview, the participants were also asked if they were able to recognize the type of test vehicle as HDV or AV from fake LiDAR and sticker. 16 participants indicated that they could easily see the LiDAR on the top of the test vehicle whereas 2 participants indicated that they were not paying much attention as they did not have to actually merge in front of the vehicle. All the participants were able to recognize AV due to the "Self-driving" sticker on the side of the test vehicle when it crossed in front of them.

5.1.2. Pre-experiment interactions

On the day of the experiment, when the participants arrived, an initial briefing sheet (appendix E) was provided to them which contained the clear instructions that they need to follow. It is important to note that before the day of the experiment, participants were not informed that they will be interacting with AVs in the experiment rather they were told that they need to drive their vehicle from one point to another interacting with different types of vehicles (Appendix C). Participants were informed about AVs only on the day of their experiment as a part of the initial briefing. This was done to ensure that participants do not have any expectations or do not do any preliminary research regarding AVs before the actual field test The participants who did not fill online consent form earlier were asked to fill a consent form(appendix C). Before starting their field test, they were also provided with a verbal briefing for the clarity of instructions.

Within verbal briefing, the following main points were emphasised:

1. The test vehicle is capable of running in a fully self-driving mode. However, a driver is always present to take over in case something goes wrong. When the test vehicle runs in self-driving mode, it has a sticker and a LiDAR on top of the vehicle.
2. Participants need to reach the parking lot at point B driving near the speed limit of 60 kmph.
3. Participants are free to make any driving decisions to ensure that they drive near the speed limit as much as possible.

After briefing, a GPS module and a phone with a GPS logger application was kept in the subject vehicle for its data collection. The participant was provided with a during experiment survey sheet (appendix F).

Before starting the experiment, few final checks were made as follows:

1. Checking whether the data collection in GPS logging device was started.
2. Checking for any enabled ADAS systems in the subject vehicle and ensuring that subject vehicle is driven completely manually by the participant.

5.1.3. Vehicular interactions

The vehicular interactions took place as described in section 4.1.3. However, this section aims to provide practical details about vehicular interactions.

The run of the field test started when the participant was ready. As a first step, the participant had to indicate the last moment when its safe to cross in front of the approaching test vehicle by using a hand gesture (putting the hand down when it's not safe to cross anymore). The test vehicle always approached the participant from its right and on its opposite lane (figure 5.3).

Once the test vehicle crossed the subject vehicle, the subject vehicle started driving and drove behind the test vehicle in car following zone (approx 1 km distance) at a speed around 60 kmph (figure 5.4). The test vehicle was accelerated from a speed of 40 kmph to 60 kmph when the participant started following.

At the end of the car following zone, at a certain slow down point as per scenario, the test vehicle was slowed down to a speed of 40 kmph encouraging the participant to overtake. The participant can decide to overtake within the overtaking zone (figure 5.5). Mainly two different overtaking styles were observed during the experiment: flying and accelerative. During flying overtaking, the subject vehicle did not follow the test vehicle before overtaking whereas during accelerative overtaking, subject vehicle followed the test vehicle before

Figure 5.3: Participant performing hand gesture to indicate critical gap for approaching test vehicle at point A

Figure 5.4: Subject vehicle starting to follow test vehicle from point A perspective

overtaking (see section 2.3.3). Flying overtaking was witnessed more frequently than the accelerative overtaking style. After a successful overtaking by the subject vehicle, the speed was restored to normal and the test vehicle was driven behind the subject vehicle. From safety considerations, if there were other high-speed road users present and slowing down was not safe, the driver of test vehicle can decide not to slow down and continue without providing overtaking opportunity to the subject vehicle.

At the end of the run, the subject vehicle drives to its end location where a team member would assist the participants in the realignment of subject vehicle for next run and reminding them to fill the during experiment questionnaire. The test vehicle drives to its end location where it was prepared for the next run of the test. It is to be noted that test vehicle's end location was at least 250 meters away from subject vehicle's end location and thus the preparations for next run (putting self-driving sticker and mounting fake LiDAR in case of AV scenario) cannot be clearly seen. At the end of each run, the participants were asked if they want to share something regarding the last run and any useful information was noted down. The next run of the test was again started once everyone is ready.

5.1.4. Scenario management

As discussed in section 5.1.1, the scenarios regarding the type of vehicle were managed by changing the appearance of the test vehicle. However, it is important to note that the test vehicle was always driven in a similar fashion by the same professional driver in all scenarios. The i-AV scenario depended upon participant believ-

Figure 5.5: Subject vehicle overtaking near the slow down point (TV's rear camera perspective)

ing that the vehicle is driven in self-driving mode and the driver is just there to take over. To support this, within the i-AV scenario, the driver of TV tried to keep his hands lower (figure 5.2) to make it look like he is not driving the vehicle and just present to take over. In i-HDV scenario, the driver of the test vehicle tried to hold steering wheel from the top, making his hands more visible from his window.

As per the scenario design discussed in section 4.1.4, the participants were provided with either positive or negative information regarding the test vehicle for the last 3 runs of i-AV scenario. The information was provided by a crew member at point A or B through written text to maintain consistency. The positive and negative information that were provided are as follows:

Positive information

"The self-driving vehicle you are interacting with tends to avoid risk by driving very safely. It can fully detect its environment and is able to accurately predict the behaviour of other road users, which ensures safe driving."

Negative information

“The self-driving vehicle you are interacting with cannot always fully detect its environment. This may cause it not to correctly predict changes in its environment, leading sometimes to unsafe situations.”

Among 18 participants, 9 participants received positive information whereas 8 participants received negative information. One participant did not receive any information as the experiment had to stop due to windshield damage of the subject vehicle.

5.1.5. Post-experiment interactions

At the end of the last run, the participants were asked to fill a short post-experiment questionnaire as discussed in section 4.1.3. While they completed the questionnaire, the data collection of the subject vehicle was stopped and the devices were collected from the subject vehicle. After that, the participants were interviewed from a standard set of questions mentioned in appendix H. Post-interview, the participants were provided with a debriefing text (appendix I) and a voucher for their participation.

5.1.6. Technical and practical difficulties

There were a couple of incidents during the field test where data collection was interrupted due to technical problems. These problems sometimes led to loss of data whereas sometimes resulted in a delay in the start of the experiment. The following problems occurred during the field test:

- On day 1, due to delay resulting from technical problems, one participant could not complete 10 runs of the experiment. Only 6 runs were completed for that participant.
- On day 1, the GPS and LiDAR of test vehicle stopped recording for an hour and thus mainly the LiDAR data for participant 6 was lost.
- On day 1, one participant accidentally hit a pole on the parking lot while aligning vehicle and broke its windshield. Thus, the experiment had to stop and only 7 runs were completed for that participant.
- On day 3, a technical error in field camera at point A parking lot caused the recording to be stopped for 30 minutes resulting into loss of 4 gap acceptance observations.

Luckily, due to the presence of backup GPS sources, it was possible to recover some GPS data using data fusion. Additionally, becoming aware of the occurring errors, frequent checks were performed to ensure that data recording is always turned on.

5.2. Description of collected raw data

As discussed in the previous chapter, the data was collected through multiple questionnaires as well as sensors instrumented in both test and subject vehicle. In the following subsections, the collected sensor and survey data are discussed.

5.2.1. Sensor data

During the experiment, the data was collected by the sensors mounted on the test vehicle and GPS modules placed on the subject vehicle. Additionally, extra GPS modules were placed on both vehicles as a backup. Also, data regarding critical gap indication was collected using the field cameras mounted in both points A and B parking lots.

The following data was collected through devices during the experiment:

- **Camera footage from test vehicle perspective** - The four cameras mounted on the test vehicle continuously captured the surrounding during the entire field test. Thus the video footage of the subject vehicle's interaction with data collection vehicle is captured.
- **GPS data of test vehicle** - GPS module instrumented on test vehicle continuously collected the GPS coordinates and speed of the vehicle. This GPS device had a data collection frequency of 0.2 seconds.
- **LiDAR data** - The three LiDAR's mounted on the left, rear and right side of the test vehicle continuously captured the distances of the objects within the 40-meter range of test vehicle. This device had a data collection frequency of 0.01 second.
- **GPS data of subject vehicle** - The GPS devices placed inside the subject vehicle continuously collected its location as well as speed during the experiment. This GPS device had a data collection frequency of 1 second and accuracy ranging from 2-4 meters.
- **Field camera footage** - The field cameras mounted on both parking lots captured the hand gesture of participants when they indicated critical gap.

5.2.2. Survey questionnaire and interview data

As already discussed in section 4.1.3 and 5.1, there were multiple questionnaires which were filled by the participants in different stages of research. The questionnaires which were presented at the time of recruitment, few days before the experiment, during experiment and after experiment followed by an interview, gathered a lot of insights regarding the participants and their decisions. The table 5.1 gives a list of different variables which were captured with the help of multiple questionnaires.

Table 5.1: A list of different variables captured through multiple questionnaires and interview

Pre-experiment		During experiment (after every run)
• Age • Gender • Education • Employment status • Work/study field • Taken part in driving experiment earlier • Kilometres driven per month	• Driving experience in years • Brand and model of subject vehicle • ADAS systems in subject vehicle • Driving experience with ADAS systems • trust in AV technology • MDSI driving style questionnaire	• Stress experienced during interaction with test vehicle • trust in test vehicle

Post experiment	Interview
• trust in AV technology • Experienced difference in driving style of AV • Self-reported change in driving behaviour due to AV • Self-reported change in trust in AV • More experienced stress during interaction with AV - Stress during indicating critical gap - Stress during car following - Stress during overtaking - Stress during being followed by AV	• Self-reported effect of provided information • Slowing down expectation for TV • Ease of identification of i-AV scenario by its appearance

5.3. Sensor data processing

As discussed in section 5.2.1 a lot of sensor data was collected from the devices installed in both test and subject vehicles. This section aims to discuss the data processing steps to extract various indicators from the raw data.

5.3.1. Data synchronisation

As the data was collected by multiple sensors and cameras over multiple computers, timestamps among different datasets were not synchronised. In order to perform an analysis, the data first needs to be synchronised properly. The data synchronisation was carried out as a two-step process. First, the videos were synchronised. Second, sensor data was synchronised with the video data.

Video synchronisation

The data synchronisation was first performed on recorded videos. Upon initial inspection, it was found that the timestamps in the videos were slightly out of sync due to difference in time among the recording computers. Also, as the video recordings were segmented over a period of time to prevent loss of data, the difference in processing speeds of computer resulted in loss of some frames between videos. However, during data collection, cameras were frequently presented with an external digital clock in a mobile phone which allowed corrections during video synchronisation (figure 5.6). Also, during video processing it was found that camera mounted on the right of test vehicle did not capture any useful information and thus the video footage from the right camera was not used.

Figure 5.6: Presentation of external digital clock to camera for synchronisation

All the videos were synchronised together using a free and open-source video editing application - Shotcut version 20.07.11. The synchronised videos were assigned a new timestamp which started from zero at the start of the video. A still from a synchronised video of day 3 is given in figure 5.7.

Figure 5.7: A still of combined video footage after video synchronisation

Sensor data synchronisation

As the LiDAR and GPS data of test vehicle was recorded using the same computer, they both were initially synchronised. As mentioned earlier in section 4.1.6 that front camera of test vehicle had an inbuilt GPS module which connects with the cellular network to obtain local time and inscribe in form of subtitles in its video footage. The GPS module used in subject vehicle and test vehicle also had cellular connectivity due to which the time was synchronised between these devices. Thus, using these common timestamps, the whole dataset was synchronised. The synchronisation was verified repeatedly during the data extraction process and minor corrections were applied whenever an observation appeared out of sync.

5.3.2. Information extraction from videos

The synchronised videos were processed manually to extract the information about gap acceptance, car-following and overtaking manoeuvres. The different extracted information as well its methodology is discussed in table 5.2.

Table 5.2: Extracted information from videos

Information	Extraction methodology
Run start/end timestamp	Run starts when the test vehicle starts moving from its starting location indicated by GPS and video footage Run ends when the test vehicle reaches its end location
Critical gap moment	Timestamp at which the participant performs hand gesture to indicate critical gap as observed from the video footage
Car following	Based on visual inspection of videos 0 - No car following took place (subject vehicle driving too far and not visible in camera / interruption by other road users) 1 - Subject vehicle apparently followed the test vehicle
Car following start/end timestamp	Timestamp when the subject vehicle apparently start/end following the test vehicle based on video inspection
Overtake	Based on video inspection 0 - No overtaking 1 - Subject vehicle overtook test vehicle
Overtake start timestamp	Timestamp at which the front left wheel of subject vehicle touches the center line lane marking at the start of overtaking (figure 5.8)
Overtake end timestamp	Timestamp at which the rear left wheel of subject vehicle touches the center line lane marking at the end of overtaking (figure 5.8)
Backpressure	Based on video inspection 0 - No road user behind the subject vehicle during overtaking 1 - Other road user overtook along with the subject vehicle
Overtaking order	Order of overtaking if other road users also overtake along with the subject vehicle
Double overtaking	Based on video inspection 0 - No double overtaking by the subject vehicle 1 - Subject vehicle overtook two vehicles at the same time
Overtaking style	Based on video and speed profile inspection (section 6.2.3) Accelerative if subject vehicle follows the test vehicle before initiating overtaking Flying if the subject vehicle does not follow the test vehicle before initiating overtaking
Camera based headways at the start/end of overtaking	Headways in meters based on the estimated distance of the subject vehicle from the test vehicle Distances were estimated using the known length and gap of center-line lane markings

The extracted information from the videos was used to filter raw sensor data and calculate different driving behaviour variables.

5.3.3. Calculation of driving behaviour indicators

Using the extracted information from the videos, further data processing was carried to filter out the unwanted data. The data processing was performed using calculation and filtration algorithms developed using Python programming language. The Python scripting and analysis was carried out with the help of open source development environment Spyder (Python version 3.8.3). The final dataset was processed to have a temporal granularity of 1 second.

Table 5.3: calculated driving behaviour indicators and calculation methodology

Driving behavior	**Variable name**	**Unit**	**Calculation methodology**
Gap acceptance behavior	Critical gap (distance)	Meters	Based on GPS, calculated as the distance between the centerline of the subject and the test vehicle at the moment critical gap is indicated
	Approach speed of TV	Kmph	Based on the average speed of TV (GPS based) over the last 5 seconds before indicating critical gap
	Critical gap (time)	Seconds	(Critical gap (distance) / Approach speed of TV) * 3.6
Car following behavior	Car following headway (distance) Mean, Median, Std, Max, and Min	Meters	GPS distance between subject and test vehicles during car following - every 1 second
	Car following speed (subject vehicle) Mean and Std	Kmph	GPS speed of subject vehicle during car following (every 1 second)
	Car following speed (TV) Mean and Std	Kmph	GPS speed of TV during car following (every 1 second)
	Car following headway (Time) Mean, Median, Std, Max Min	Seconds	Instantaneous time to collision (TTC) of the subject vehicle during car-following (every 1 second) (Car following headway(distance) / car following speed (P)) * 3.6
Overtaking behavior	Overtaking duration	Seconds	Derived from video – Time between the moment when the front-left wheel of subject vehicle touches centerline of the road at the start of overtaking and when the rear-left wheel of the subject vehicle touches centerline of road at end of overtaking (figure 5.9)
	Overtaking lateral gap Mean and Median	Meters	Lateral gap between subject and test vehicle during overtaking based on distances measured by left LiDAR of the TV (figure 5.9)
	Headway at start/end of overtaking - distance (GPS and camera-based)	Metres	Headway between the subject and test vehicle at the start and end of overtaking based on GPS and camera distances (figure 5.9)
	Overtaking start/end speed - subject vehicle (GPS based)	Kmph	Speed of subject vehicle at the moment overtaking starts / ends
	Overtaking start/end speed - TV	Kmph	Speed of TV at the moment overtaking starts / ends
	Headway at start/end of overtaking - time (GPS and camera-based)	Seconds	TTC of the subject vehicle at the start of overtaking and accepted time gap at the end of overtaking (Headway at start/end of overtaking (distance) / Speed of P or TV)*3.6
	Relative speed during overtaking	Kmph	Speed difference between the subject and test vehicle when both are driving next to each other during overtaking (based on GPS)
	Relative speed - Start /End of overtaking	Kmph	Speed difference between subject and test vehicle at start and end of overtaking (based on GPS)

Figure 5.8: Moment of start (left) and end (right) of overtaking manoeuvre

During the calculation of variables, it was found that the data captured by back LiDAR is not accurate and thus cannot be used for the calculation of car following headways. The inability to capture the distances using back LiDAR is due to the fact that the LiDARs used for data collection were point LiDAR. Since the front of the vehicle is usually curved, the light emitted by LiDAR does not reflect back to the sensor and thus the distance cannot be measured. Thus, the readings of back LiDAR were not used in the calculation of car following headway, instead, the GPS data was used to calculate headways. Since the GPS modules in both vehicles had an accuracy of +/- 4 meters, an overall error of +/- 8 meters in the headway estimation cannot be avoided. However, considering the median of observations can help to minimize the fluctuation due to driving dynamics.

As the study by Vogel [2002] suggests that headways above 6 seconds can be considered in a free flow state, the observations with a car following headways above 6 seconds were removed during processing.

In order to study the overtaking behaviour, various indicators were calculated. Figure 5.9 illustrates the various indicators of overtaking behaviour.

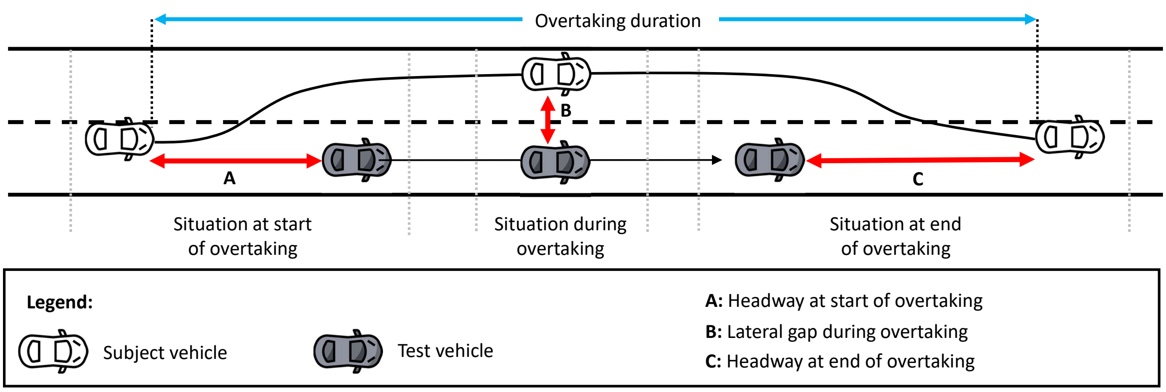


Figure 5.9: An illustration of various indicators calculated to capture overtaking behaviour

The headways at the start and end of overtaking are calculated at the moment overtaking starts/ends and can be calculated through GPS data. However, in GPS readings, the error was significant and thus headways were not reliable. Thus the headways at the start and end of overtaking were manually calculated from the video by estimating distance using the known length of lane markings. The headways after video processing have better accuracy of 3 meters (length of the solid line in centerline marking).

5.3.4. Filling gaps in data

Due to some recording errors, the data collected by different sensors wasn't complete and there were few instances when the observations were missing from the data collection vehicle's data. However, there were other sources of data such as subtitles inscribed in front camera's video footage, backup GPS modules placed in both participant and data collection vehicle and video footage from a different camera. Thus further processing was carried out to identify the missing data and whenever possible, the data was completed by fusing the data from other sources.

5.3.5. Description of processed dataset

Once the processing of sensor data was complete, it was combined with participant, scenario, and questionnaire data and saved in a comma-separated values (CSV) file. The final dataset contained 173 rows where each row corresponds to an individual run of the experiment. The data contained a total of 89 variables resulting from the questionnaires and calculated indicators. The missing fields in the data were left blank. Lastly, data was imported to IBM SPSS Statistics version 26 where Nominal and ordinal variables were further coded into numbers for easy operation.

5.4. Survey data processing

As discussed in section 5.2.2, a lot of data was collected through pre, during, and post-experiment questionnaires. This section aims to discuss the processing methodology of questionnaire and interview dataset. Furthermore, as there were interpersonal differences between the participants, the methodology of their classification into different groups is discussed.

5.4.1. Initial processing

The personal information of all the participants was removed from the main data set and an anonymous random id was given to them. The data from all the questionnaires were compiled together and stored in a comma-separated values (CSV) file format. As participants shared some useful information during the experiment, a separate dataset was created which contained any revealed information during different runs. The participants were also provided with an MDSI driving style questionnaire which can be used to classify them in different groups of different driving styles. This classification is discussed in the following subsection.

5.4.2. Participant classification based on driving style

As discussed earlier, once the participants were recruited, they were asked to complete a multidimensional driving style inventory (MDSI) questionnaire (Appendix D) to assess their self reported driving style. In this questionnaire, the participants were asked to answer 44 questions on a scale of 1 to 6. The questions were later divided into 4 main driving style categories and a score for each category was calculated based on answers and factor loading as given by Taubman Ben-Ari et al. [2004]. Figure 5.10 shows the box-whisker plot of self-reported scores of different driving styles for all 18 participants.

Figure 5.10 indicates that the scores of "Anxious" and "Patient and careful" driving styles has less variations with a few exceptions. However, in terms of "Angry" and "Reckless and careless" driving styles, more variation among participants can be observed. This difference indicates towards the interpersonal difference between participants. Thus it is interesting to classify participants into groups for further analysis.

Thus, in order to classify the participants based on their self reported scores recorded through MDSI driving style questionnaire, cluster analysis was carried out. The first step towards performing cluster analysis was to identify the optimal number of clusters. Two methods were used to identify the optimal number of clusters. First, a dendrogram plotted using ward's linkage highlighted three main cluster branches in which participants can be divided. Second, Elbow method was used to identify the optimal number of clusters using a distortion curve. This method also suggested an optimal number of three clusters.

As the three optimal clusters were suggested, K-means clustering for 3 clusters was performed. The results of K-means clustering for 3 clusters showcased highly significant differences between the three clusters in terms of "Reckless and careless" and "Angry" driving styles. However, within the divided clusters, one cluster contained only 2 participants. The number of participants within this group was not enough to obtain any significant results in statistical analysis. Thus it was not desirable to take this group into account. The details about clustering for 3 groups of participants can be found in appendix J.

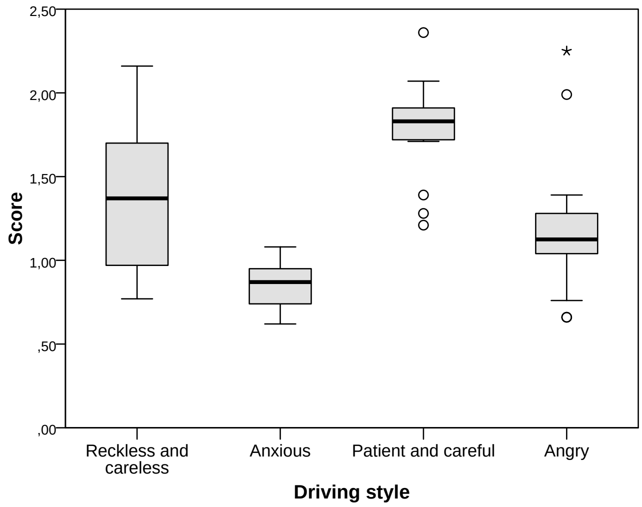


Figure 5.10: Box-whisker plot of self-reported scores falling in different driving style categories for 18 participants (18 data points in each category)

Therefore, K-means clustering was performed for 2 groups of participants. The results of K-mean clustering for 2 cluster of participants highlighted significant differences in terms of "Reckless and careless" and "Angry" driving styles between different clusters. However, no significant difference was found between factors in "Anxious" and "Patient and careful" driving styles. Table J.1 presents the ANOVA test results between different driving styles.

Table 5.4: ANOVA table for K mean clustering in 2 groups

ANOVA | K means | 2 clusters						
	Cluster		**Error**			
Driving style	**Mean Square**	**df**	**Mean Square**	**df**	**F**	**Sig.**
Reckless and careless *	1.474	1	0.075	16	19.730	**0.000**
Angry *	1.039	1	0.107	16	9.692	**0.007**
Anxious	0.006	1	0.018	16	0.344	0.566
Patient and careful	0.116	1	0.074	16	1.578	0.227
* Significant at p<0.05						

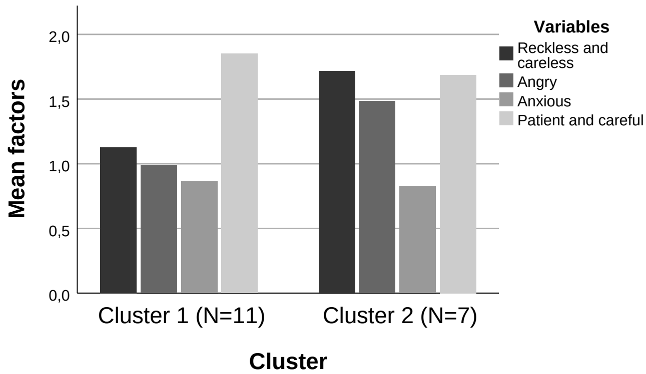


Figure 5.11: Mean MDSI-factors for different driving styles in different clusters

From Figure 5.11, it can be seen that cluster 1 and cluster 2 differs in their mean score of "Reckless and careless" and "Angry" driving styles. It can be observed that participants in cluster 2 have higher factor values for "Reckless and careless" and "Angry" driving styles tending towards more aggressive driving.

Since the number of participants in each cluster is sufficiently large, the participants were categorised in 2 groups. The cluster 1 participants can be abbreviated as less aggressive whereas cluster 2 participants can be abbreviated as more aggressive participants. Table 5.5 showcases the membership of participants in each cluster.

Table 5.5: Cluster membership of participants

Cluster no.	Abbreviation	No of participants	Participant membership
Cluster 1	Less aggressive	11	1,2,3,4,6,11,12,13,15,16,17
Cluster 2	More aggressive	7	5,7,8,9,10,14,18

5.5. Data cleaning and validation

In order to maintain the integrity of the dataset, all erroneous and invalid observations should be removed before doing analysis and making a conclusion. Inclusion of these erroneous data points might lead to incorrect results which are not desirable. This section aims to discuss the process of data cleaning and validation. First, the method to remove known erroneous observations is discussed.

5.5.1. Identification and removal of known erroneous observations

There were several moments during the experiment where the calculated data does not provide valid information. Also, sometimes the sensors do not give accurate information and thus such variable needs to be calculated in a different manner. Following are the instances when erroneous observations were identified and thus removed from the main data set.

- Due to double overtaking by the participant, several observations such as overtaking duration, headways at the end of overtaking, and relative speed at the end of the overtaking were not valid anymore and thus were removed from the main data set.
- In one specific run, the participant forgot to indicate the correct critical gap and informed about it. That observation was removed from the main data set.
- In one run of the experiment, there was a miscommunication regarding the moment to start the experiment and thus the experiment started early. Due to early start, the participant was not ready to indicate critical gap and thus ended up with wrong indication. That observation was removed from the main data set.
- During car following, there were few moments when other road user overtook the participant and interrupted in car following. The headways associated with those moments were removed from the dataset.
- As discussed earlier in section 5.3.3, the back LiDAR did not give accurate headways and thus readings associated with it were removed from the main data set.

5.5.2. Outlier management

In order to identify the outliers in the data, the box and whisker plots of various calculated variables were plotted. Some box and whisker plots of different variables are shown in appendix K, L, & M.

These outliers are verified manually for their validity by investigation of data and videos. However, all the extreme data points were valid cases and nothing strange was observed during the inspection. Thus, these data points were not removed from the main dataset. Table 5.6 shows the description of various outliers found in the dataset.

Table 5.6: Number of identified and valid outliers

Behaviour	Indicator	Number of outliers	Valid	Removed
Gap acceptance	Indicated critical gap [sec]	4	4	0
Car following	Car following headway [sec]	0	0	0
Overtaking	Overatking duration [sec]	3	3	0
	Overtaking lateral gap [m]	1	1	0
	Headway at start of overtaking [sec]	2	2	0
	Headway at end of overtaking [sec]	3	3	0
	Relative speed during overtaking [kmph]	1	1	0

5.5.3. Final dataset overview

After cleaning erroneous observations and removing outliers, the table 5.7 represents the total number of valid observations (scenarios) within each driving behaviour.

Table 5.7: Number of observations (scenarios) for different driving behavior in the final dataset

		Scenario		
Driving behaviour	**Indicator(s)**	**i-HDV**	**i-AV**	**Total**
Gap acceptance	Indicated critical gap [sec]	69	98	167
Car following	Car following headway [sec]	53	75	128
Overtaking	Overtaking duration [sec]	53	79	132
	Overtaking lateral gap [meters]	48	72	120
	Headway at start of overtaking [sec]	51	79	130
	Headway at end of overtaking [sec]	51	78	129
	Relative speed during overtaking [kmph]	52	79	131

5.6. Data analysis methodology

This section aims to discuss the analysis methodology of the processed data. In order to perform any analysis, the first thing to do is to select indicators which are reliable and can answer the research questions. Another important factor in carrying out analysis is to take different group and styles into consideration and perform analysis within separate groups. This section aims to provide a framework which will be followed for data analysis.

5.6.1. Selection of appropriate indicators

In order to perform further analysis, several appropriate indicators were selected to study different driving behaviour as discussed below.

- **Gap acceptance behaviour**: As the approach speed of the TV for critical gap indication varied within different runs (appendix K), the critical gaps in terms of distance was also affected. Thus the critical gaps are analyzed in terms of time as it also takes into account the speed of TV.
- **Car following behaviour:** In order to gain insights into the car following behaviour, car following headways were considered. During car following, factors such as reaction time can cause instances of high and low headways which may affect the mean. Thus, median of headways from a car following session were considered for analysis. As the speed during car following also varied during the experiment, time headways were calculated in order to take speed into account.
- **Overtaking behaviour:** Overtaking duration, lateral gap, relative speed and headways at the start/end of overtaking were selected for the analysis of overtaking behaviour. The headways at the start/end of overtaking were based on camera observations as the GPS observations were found to be erroneous during data validation. The time headways were calculated using the GPS speed and camera-based headway at the start/end of overtaking.

5.6.2. Sub-categorisation criteria

While performing the analysis, the data was also analysed within different subcategories as follows:

1. **Driving style:** As discussed in section 5.4.2, the participants in this research can be categorised into two different groups of different driving styles. As the participants with different driving style may behave in a different manner, analysis can be carried out separately for each group to gather more insights about the observations. Carrying out analysis separately is important because it is possible that both groups behave completely opposite to each other and the overall effect is not observed. Also, it is possible that one group has stronger effects than the other group.

2. **Overtaking style:** As discussed in section 5.1, there were mainly two types of overtaking styles observed during the field test. The overtaking styles were accelerative and flying. Since both styles differ in their mechanisms, it makes sense to analyze them separately while studying overtaking behaviour.

3. **Information groups:** As discussed in section 4.1.4, the participants were provided with either positive or negative information regarding the TV. Thus to study the effect of provided information, the analysis will be carried out as per groups of participants who received the same information.

5.7. Summary

This chapter discussed the process of data collection and provided insights about the field test setup. The field test was conducted where participants interacted with the test vehicle performing gap acceptance, car-following and overtaking manoeuvres. The participants were also provided with multiple questionnaires before, during and after the field test. The field test resulted in collection of a large amount of survey and sensor datasets which were further processed to calculate indicators in order to gain insights about the driving decisions made by the participants. Processing of survey data resulted in the categorisation of participants into two categories: Less aggressive drivers and more aggressive drivers. Processing of sensor data resulted in many indicators out of which few relevant and robust indicators were selected for further data analysis. The descriptive insights about collected data are discussed in the next chapter.

6
Data insights

From the field test, a lot of data was collected ranging from multiple questionnaires before, during and after the experiment, data from multiple sensors mounted on test and subject vehicle to the interviews as discussed in section 5.2. The collected data were processed to obtain information in form of several variables which can be used to perform further analysis in order to fully understand the driving behaviour. Before performing any statistical tests, it is important to understand the data and gain some initial insights regarding the potential relationships between different variables. These insights can help in aligning the focus areas of analysis.

This chapter aims to provide a descriptive overview of the collected data during the experiment. The chapter is structured as follows. First, an overview of data collected from multiple questionnaires is provided. This includes describing the participants of this study and the information they shared with the help of surveys and interviews. Second, this chapter aims to provide insights on driving behaviour with the help of driving behaviour indicators. Third, an overview of different scenario variables is provided. This chapter ends with a summary of interesting findings from the descriptive analysis.

6.1. Insights from questionnaires

The participants of field test were presented with multiple questionnaires before, during and after the experiment. This section aims to discuss various responses from these questionnaires.

6.1.1. Socio-demographics of participants

At the time of recruitment, the participants were presented with a questionnaire (appendix B) which intended to collect their personal characteristics and general trust in AV. A total of 18 male participants took part in the field test. 77.7% of the participants belong to the age group of 35-60 year where 22.3% of the participants were less than 35 years old. The participants were highly educated where 66.7% completed PhD, Masters or Post-doc, 22.2% completed bachelors and 10.1% completed Senior secondary education. 83.3% of the participants were employed full time and 66.7% of the participants belonged to science, technology and engineering field. Participants were experienced drivers with minimum experience of 7 years of driving and 83.3 % of the participants had an experience of more than 10 years. Several participants had driving experience with various ADAS where 50% had experience with ACC, 50% had experience with LKS, 33.3% had experience with FCW, 22.2% had experience with AEB. Only one participant had past experience with level 2 AV. Participants differ in their driving exposure (average km driven per month) as shown in figure 6.1.

The participants were also provided with a driving style questionnaire whose insights are discussed in section 5.4.2.

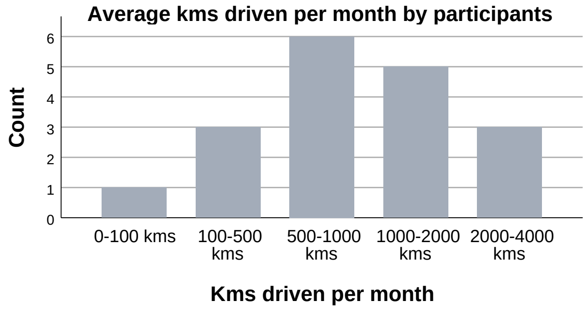


Figure 6.1: Histogram of average kilometers driven per month by the participants

6.1.2. Stress and trust

During the experiment, after every run, the participants were asked to indicate their experienced stress during interaction with TV and their trust in interacting TV on a scale of 1 to 10. As the road was empty, the stress during the field test was in general very low (mean=1.93, std=1.30). Figure 6.2 shows the histogram of indicated stress during interaction with TV during i-HDV and i-AV scenarios. From the histogram, it can be seen that some participants indicated higher stress (rated 5) in i-Av scenario. 8 participants indicated no stress during the whole experiment. The maximum stress indicated was 6. One participant indicated that higher stress was due to the presence of other road users.

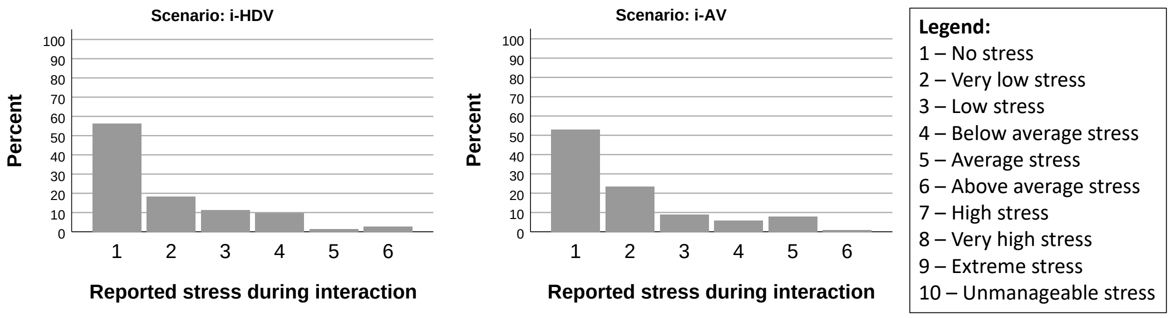


Figure 6.2: Histogram of reported stress during interaction with Test vehicle in i-HDV (left) and i-AV (right) scenarios

The reported level of trust had higher variations in the range of 2-10 (mean=8.14, std=1.95). Figure 6.3 shows the histograms of reported trust in TV during i-HDV and i-AV scenarios. From the histograms, it can be seen that reported trust in i-AV scenario is more skewed towards right indicating towards higher trust in AVs. However, some participants also indicated relatively lower trust in i-AV scenario. Some participants admitted that their trust in AV increased over multiple interactions.

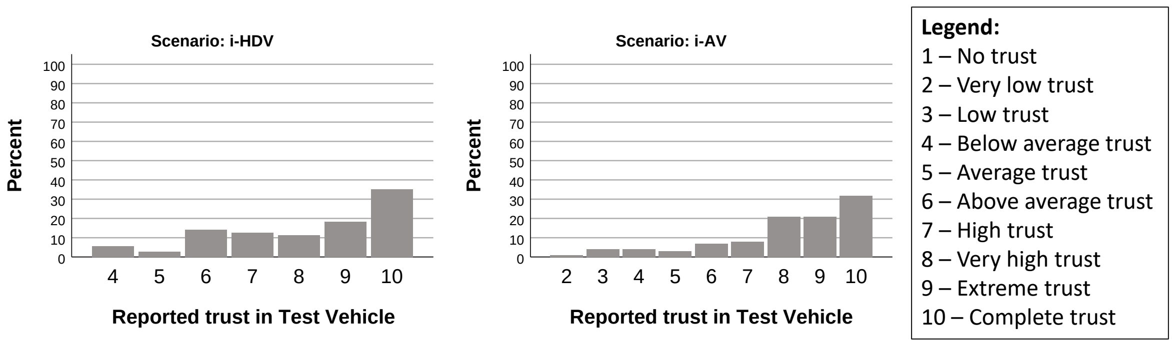


Figure 6.3: Histogram of reported trust in Test vehicle in i-HDV (left) and i-AV (right) scenarios

It was also observed that less aggressive people reported higher trust in TV in comparison to more aggressive people over different runs (figure 6.4).

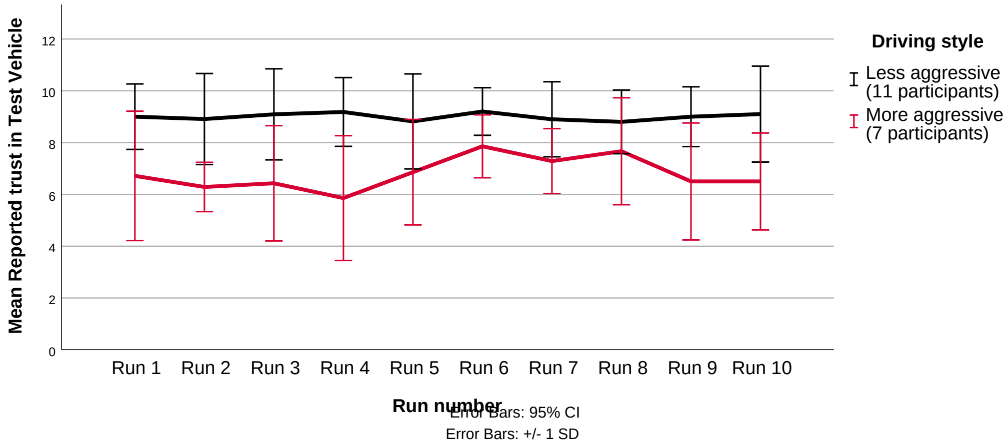


Figure 6.4: Mean reported trust over different run for less and more aggressive drivers

The reported stress and trust had a highly significant negative correlation (Pearson's $r = -0.564$, p-value = 0.0001, N=172) which was expected.

6.1.3. Insights from experiment

During the run, when the TV was slowed down, the participants were expected to overtake. However, participants did not overtake every time. The main reason behind not overtaking (when asked) was that the participants were thinking that overtaking is not allowed. The other reasons behind not overtaking were either lack of opportunity or the low overtaking tendency of the participant. The summary of other revelations by the participants is given in table 6.1.

Table 6.1: Self reported facts by participants

Self-reported facts	**Participant number**	**Percentage**
Participants admitting changing their driving behaviour on interaction with AV	3,6,7,13,14,16,17	38.9%
Participants thinking that driving style of i-AV was different than that of i-HDV	2,3,7,8,10,12,14,15,16	50.0%
Participants reporting that information influenced their behaviour	6,8,9,10,13,14,18	38.9%
Participants reporting increase in stress due to interaction with AV	6,10,12,13,17	27.8%
Participants expecting slowing down of TV after few runs	2,5,7,9,10,12,14,18	44.4%

It is interesting to note that many participants were keen to observe the driving behaviour of AV as a result of which half of the participants thought that the driving style of AV was different in comparison to HDV. Among these participants, most of them reported that AV was not able to maintain lane properly, was not driving smoothly, and was swaying near the edge of the road. This observation caused them to trust AV less. Some participants felt that AV was driving more smoothly and in a straight line. One participant felt that AV keeps little extra distance while driving from the parked vehicle at the side of the road.

The participants also self-reported any influence on their driving behaviour due to the provided information. Most of the participants who received negative information did not believe that there was any effect of information in their driving behaviour during interaction with AVs. Although they believed in the provided information, they were convinced from previous interactions that AV is behaving normally and there is nothing complex in the test route which vehicle might fail to detect. One participant reported a slight increase in stress due to negative information but also reported forgetting information after 1 run when it was provided.

Recipients of positive information reported higher trust in the i-AV scenarios. It was reassuring for the participants that AV is careful and safety systems are active to make it safer. After receiving positive information, one participant felt performance anxiety to be able to keep up with the driving manoeuvres of AV while following it.

The participants who felt more stressful while interacting with AVs were also asked about the manoeuvre in which they felt more stressful. Out of five participants, two participants reported overtaking more stressful, two participants reported car following more stressful and one participant reported indicating critical gap as more stressful manoeuvre among the other driving manoeuvres. None of the participants found driving in front of an AV stressful. In fact, participants expressed higher comfort and confidence when AV was driving behind them.

The participants were investigating the reason for slow-down of AV and many participants indicated that slowing down in case of i-AV scenario was unexpected as there was no reason to slow down. Some participants were trying to observe if AV is slowing down near intersections or due to interaction with the nearby vehicles. This erratic slowing down behaviour of AV made them think that technology is not working properly. After a few runs, they realized that its a part of the experiment. Some participants indicated that AV should communicate its intention to slow down.

6.1.4. General trust in AVs

At the time of recruitment, the participants were provided with a questionnaire (appendix B) where they were asked about their current level trust in AVs on a scale of 0 to 5. After completion of the experiment, the participants were again asked to indicate their current level of trust in AVs in the same scale. The participant's reported trust in AVs before and after the experiment is given in figure 6.5.

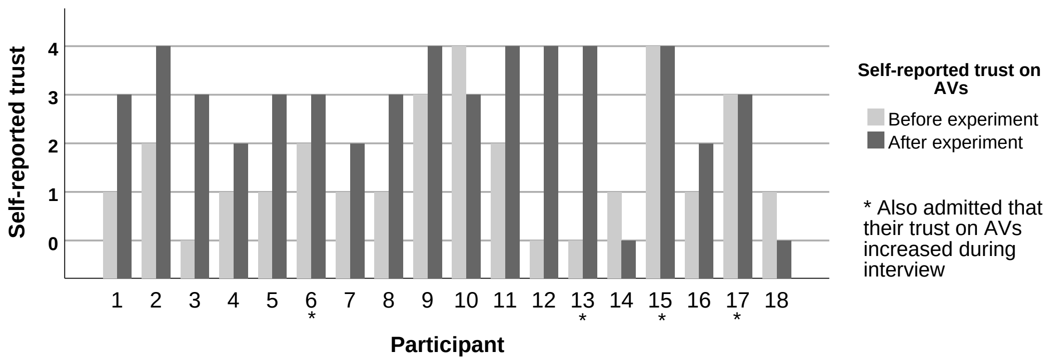


Figure 6.5: Change in self reported trust in AVs before and after the experiment

Also, the participants were asked subjectively if they think that there is any change in their trust towards AVs due to the field test. 4 participants reported an increase in their trust towards AV which is indicated as an asterisk (*) in figure 6.5

From figure 6.5, it can be seen that 13 participants indicated higher score of trust after the field test out of which 2 admitted increase in trust. 2 participants indicated the same score even after admitting increase in trust. 3 participants indicated a lower value of trust after the experiment but admitted no change in trust.

During the interview, some participants indicated that they trust AVs more in general as they are designed to be safer. Some participants attributed their higher trust due to test location conditions. Few reasons behind higher trust were simplicity of the road where the test was conducted, low traffic intensity at test location, limited interactions with other road users, fact that AV is approved to drive on road, presence of visible LiDAR, and presence of a driver to overtake in case something goes wrong. These factors were also the reason due to which participants did not consider negative information to make decisions. Participants indicated their skepticism towards the performance of AV in a more complex situation like mixed road users in a city centre and expressed their concern towards the failure of sensors/technology. However, after the experiment, few participants indicated that they gained trust in AVs after experiencing them in practice.

6.2. Insights on driving behaviour

This section aims to provide descriptive insights into the different driving behaviour that are studied in this research. First, the insights regarding gap acceptance behaviour are provided. Second, car-following behaviour is discussed. Lastly, overtaking behaviour is discussed.

6.2.1. Gap acceptance behaviour

The participants indicated their critical gap when the test vehicle approached towards them from the right direction in the opposite lane. However, the speed of the approaching test vehicle varied during different runs of the experiment as can be seen in appendix K. Thus, taking into account the speed of approaching TV, the critical gap is studied in terms of seconds.

Due to the differences in driving styles, a variation among the indicated critical gap can be seen between different participants. The Figure 6.6 represents the critical gap of different participants in i-HDV and i-AV scenarios. It can be observed that the critical gap indicated by different participants is distinct.

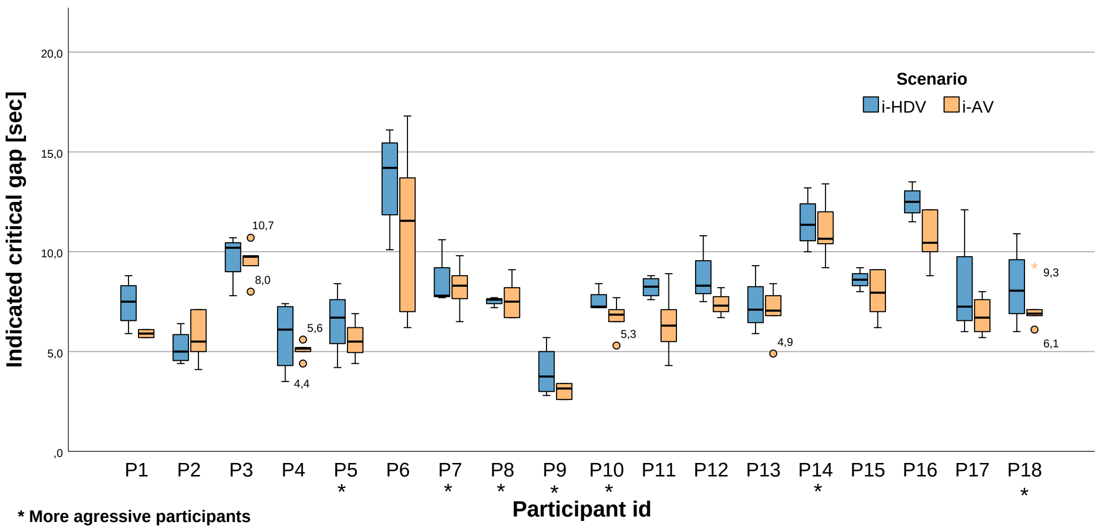


Figure 6.6: Difference between participants in gap acceptance behaviour

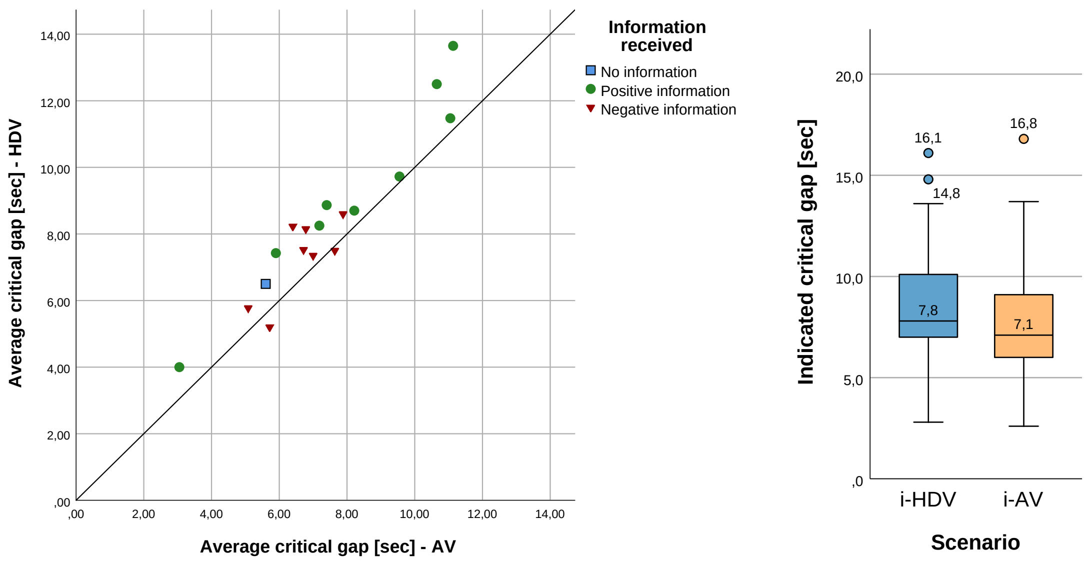


Figure 6.7: Scatter plot of average critical gaps per participant (left) and box plot (right) of average critical gaps indicated in i-HDV and i-AV scenarios

It can also be observed that mean indicated critical gap in i-AV scenario is generally lower than that of i-HDV scenario. This can be further clearly observed through scatter plot where most of the participants indicated lower critical gap in case of i-AV scenario in comparison to i-HDV scenario (figure 6.7). Box plot in figure 6.7 indicates an overall decrease in critical gap by 0.7 seconds in case of i-AV scenario, measuring collectively for all participants.

Investigating further into the critical gap among participants with different driving style, it can be seen that less aggressive drivers tend to choose higher critical gaps in comparison to more aggressive drivers (figure 6.8 (left)). However, decrease in critical gap due to AV is more in case of less aggressive driver (0.9 seconds in comparison to 0.6 seconds of more aggressive drivers) bringing mean indicated critical gap with AV nearly equal between both groups.

In the case of a group of participants who received negative information regarding interacting AV, no substantial difference from the scenario without information is observed. However, when the participant received positive information, critical gap decreased sharply by 1.9 seconds. This indicates towards an increase in trust when participants are provided with positive information. However, negative information does not seem to have any influence in the given field test setup.

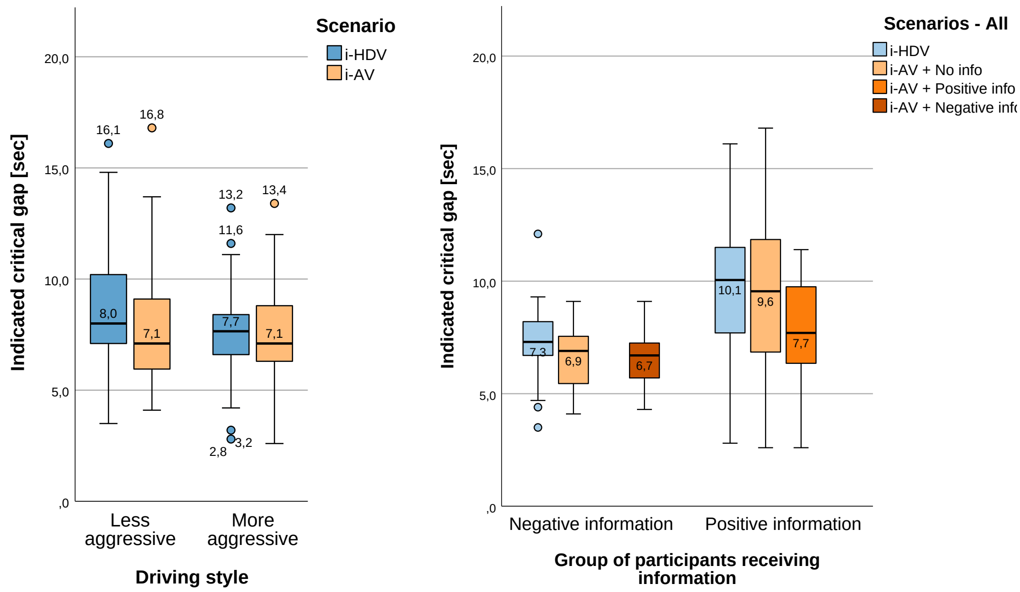


Figure 6.8: Indicated critical gap among participants with different driving style (left) and different information received (right) per scenario

6.2.2. Car following behaviour

In order to study the car following behaviour, analysis is carried out using the median time headways between subject and test vehicle during car following. Subject vehicle was considered to be following test vehicle when the time headway was less than 6 seconds [Vogel, 2002].

The car following headway varied between different participants indicating towards difference in driving styles (appendix L). However, no visible trend is observed regarding interaction in i-AV scenario in comparison to i-HDV scenario.

With further investigation, it was found that half of the participants kept smaller headways with AVs whereas half of the participants kept larger headways (figure 6.9 left) leading towards overall neutrality. Within i-HDV and i-AV scenarios, no notable difference in car following headways were observed (figure 6.9 right).

Taking groups of different driving styles into consideration, mean car following headways appeared to be a little smaller by 0.3 seconds in i-AV scenario (figure 6.10). No major difference was observed in participants with aggressive driving style.

Furthermore, in terms of information provided, no difference was observed among participants who received either positive or negative information (appendix L).

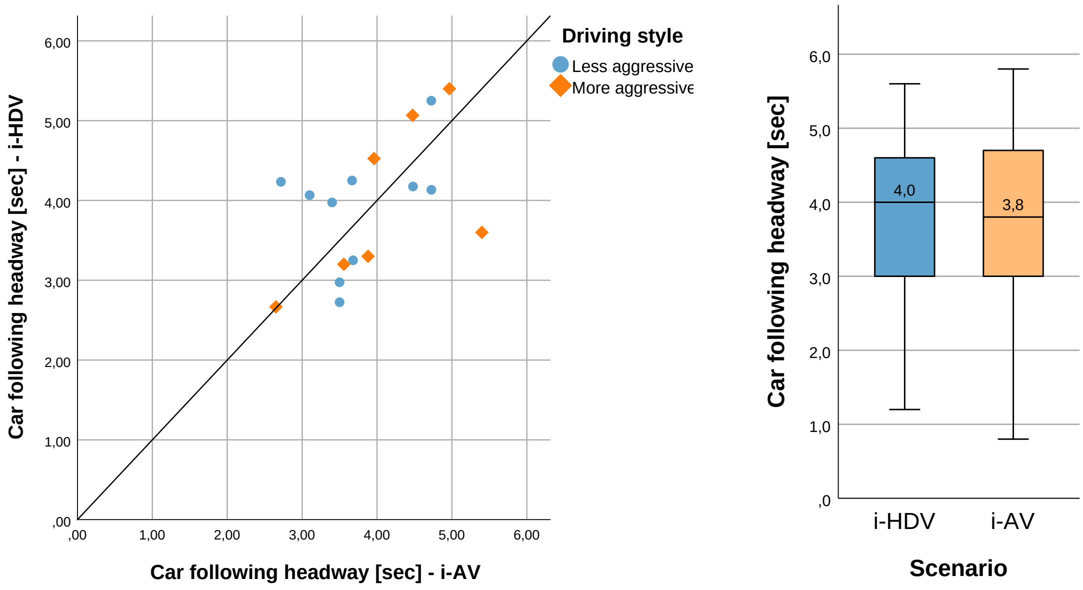


Figure 6.9: Scatter plot (left) and box plot (right) of mean car following headways in i-HDV and i-AV scenarios

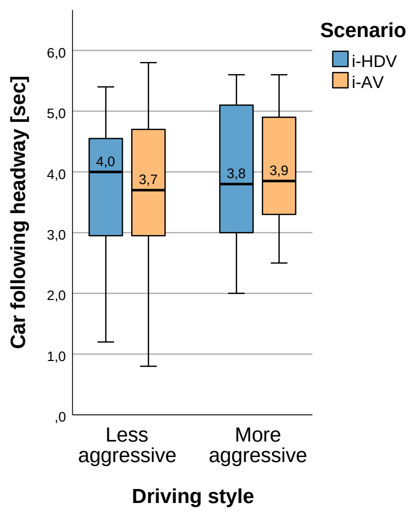


Figure 6.10: Car following headways among participants with different driving style

6.2.3. Overtaking behaviour

As overtaking is a fairly complex behaviour, multiple indicators are used to gain insights about the behavioural adaptation while overtaking. As discussed in section 5.6.1, overtaking behaviour is studies in terms of overtaking duration, overtaking lateral gap, relative speed during overtaking, headway at start of overtaking and headway at the end of overtaking. A schematic drawing of different measurement of these indicators is shown in figure 5.9.

During the experiment, there were mainly 2 types of overtaking style: Accelerative and flying. Figure 6.11 represents the speed profile of both subject and test vehicle in case of accelerative and flying overtaking styles. From this figure, the difference in the subject vehicle's trajectory can be clearly seen. In accelerative overtaking, the subject vehicle decelerates and follows the test vehicle for some time before accelerating again and overtaking whereas in flying overtaking, no deceleration can be seen. Since both types of overtaking differ in their driving mechanisms, overtaking behaviour is studied for each of the overtaking styles separately.

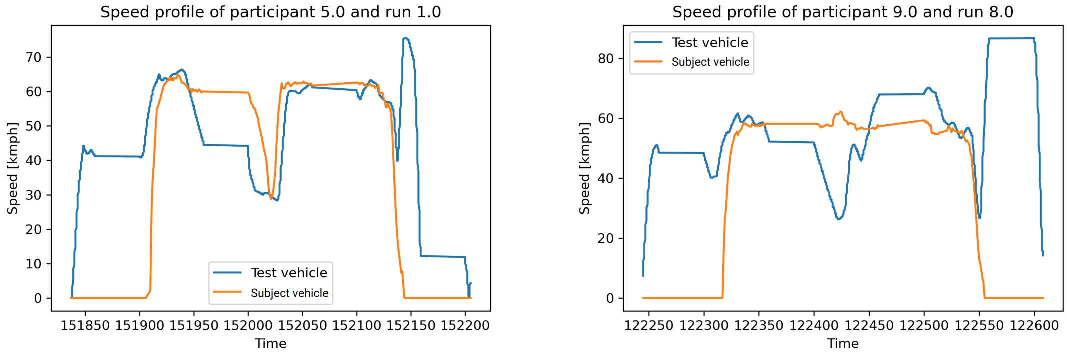


Figure 6.11: Speed profile in case of accelerative (left) and flying (right) overtaking

Overtaking duration:

In terms of overtaking duration, from a broad perspective, no notable difference was observed between i-HDV and i-AV scenarios (figure 6.12 (left)). However, upon separately looking within different overtaking styles, a difference in behaviour can be observed.

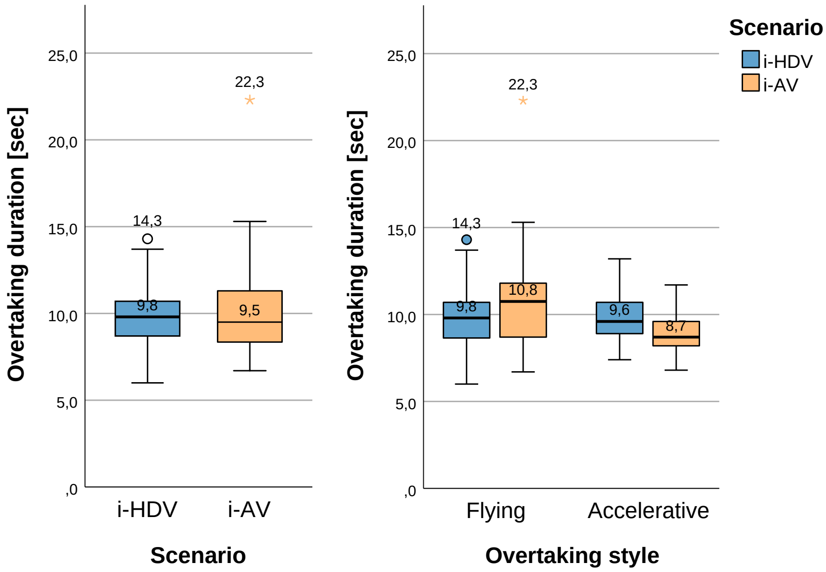


Figure 6.12: Overall overtaking behaviour (left) and overtaking behaviour within different overtaking styles (right)

It can be observed from figure 6.12 (right) that in case of flying overtaking style, the mean of overtaking duration increased by 1 second (excluding the extreme outlier). However, in contrast, overtaking duration in case of accelerative overtaking decreased by 0.9 seconds. One possible explanation is that participants were more careful while interacting with AV. Thus in case of flying overtaking opportunity, the overtaking is possibly initiated early (larger headway at start of overtaking) and completed keeping a distance (larger headway at end of overtaking). Due to this extra distance which needs to be covered, overtaking duration increased. However, in the case of accelerative overtaking opportunity, as the headway at the start of overtaking is lower, the participants probably want to drive faster to reduce exposure time with AV. This can lead to a reduction in overtaking duration in case of accelerative overtaking. However, to conclusively comment on reality, further investigations with the help of other indicators need to be carried out which will be discussed later in this chapter.

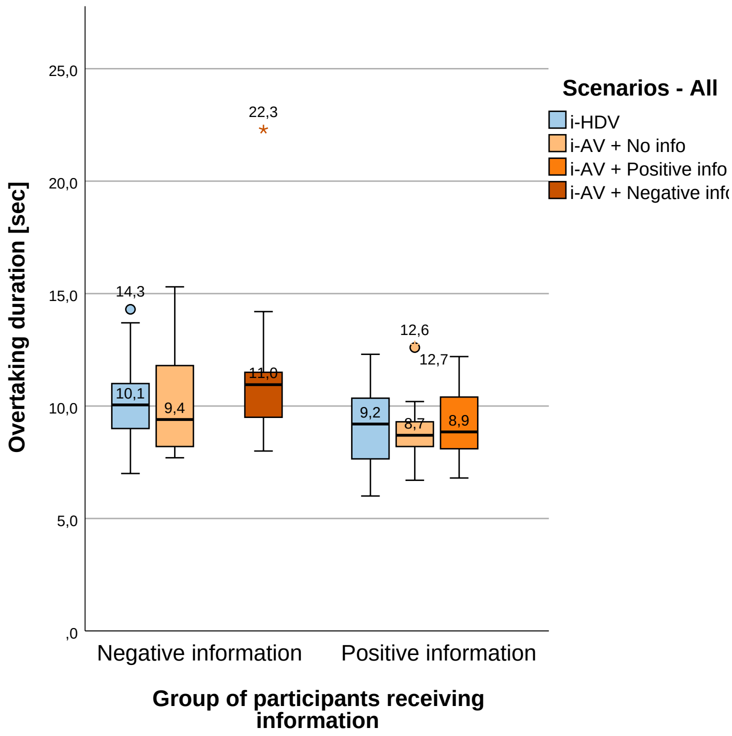


Figure 6.13: Overtaking duration as per information received by the participant and scenario

The effect of negative information also insinuates towards more careful driving as the overtaking duration increases by 1.6 seconds (figure 6.13). However, positive information does not seem to have any effect on overtaking duration.

Apart from these observations, no difference in behaviour was observed among participants with different driving styles. The other plots regarding overtaking duration can be found in appendix M.1.

Overtaking lateral gap:

In terms of overtaking lateral gap, no differences were observed between i-HDV and i-AV scenario and the mean lateral gap of 2.08 meters was the same in both scenarios. Further investigation into different driving styles, overtaking style and type of information also failed to point out any notable difference in lateral gap maintained during overtaking. The plots regarding overtaking lateral gap can be found in appendix M.2.

Relative speed during overtaking:

Upon investigating the relative speed during overtaking, no differences in relative speed due to i-AV scenario was found. Furthermore, relative speed was also investigated for participants with different driving style, overtaking style and information provided. Within these classifications, there is still no difference in driving behaviour due to AV. However, it might be interesting to note that more aggressive drivers tend to overtake faster by 4 kmph in comparison to less aggressive drivers. Also, the overtaking speed during flying overtaking is higher by 7kmph in comparison to accelerative overtaking. These insights will help in explaining the observed trends. The various descriptive plots of relative speed during overtaking can be found in appendix M.3.

Headway at start of overtaking

Upon investigating the headways, no noticeable differences in headway at start of overtaking due to AVs was observed. Furthermore, there is no notable difference in driving behaviour due to AV within the participants of different driving style, overtaking style and provided information group. However, it may be interesting to note that the headways at the start of overtaking in case of accelerative overtaking are smaller in comparison to flying overtaking.

Headway at end of overtaking

Within the overall scenario of i-AV and i-HDV, the headways at the end of overtaking are nearly the same. This also holds true for more aggressive as well as less aggressive participants. At the end of the overtaking, headways seem to be unaffected by overtaking style and are nearly equal between flying and accelerative overtaking.

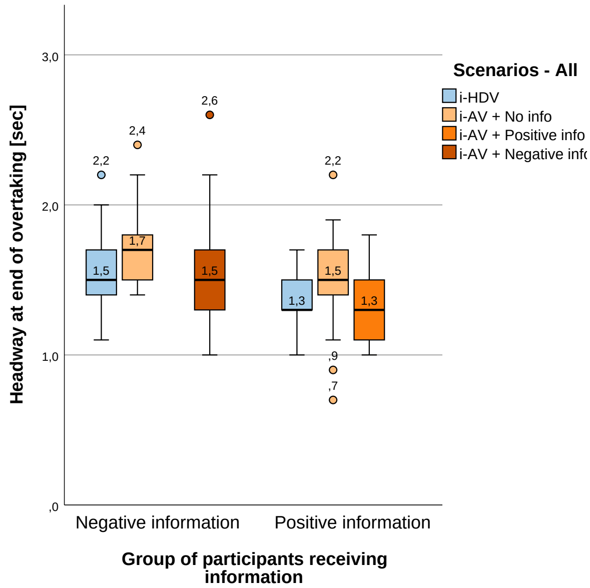


Figure 6.14: Headway at the end of overtaking as per information received

Considering the effect of provided information, no difference was observed in case of negative information. However, there seems to be a difference in headway at end of overtaking among the participants who received positive information (figure 6.14). The mean headway at the end of overtaking decreases by 0.2 seconds in case of positive information in comparison to interaction with AV without information. The decrease in headway at the end of overtaking in positive information scenario can be clearly observed just after receiving information i.e. 4th run (figure 6.15).

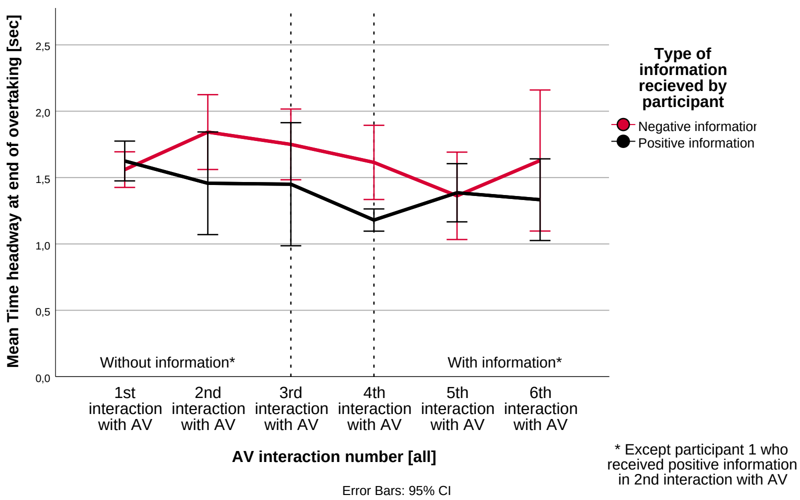


Figure 6.15: Headway at the end of overtaking over multiple interactions with AV (within information groups)

6.3. Scenario insights

As the scenarios were randomly assigned to different participants over different run, it is important to check whether there is any specific trend between different scenario variables, personal characteristics and driving decision. These insights will facilitate a better understanding of the observed trends.

6.3.1. Information received by participant vs driving style

As discussed earlier in section 5.1.4, 9 participants received positive information, 8 participants received negative information and 1 participant did not receive any information. Figure 6.16 represents the distribution of participants with different driving style falling within different information scenario. It can be observed that the negative information scenario is dominated by less aggressive participants. However, positive information scenario has nearly equal distribution of participants.

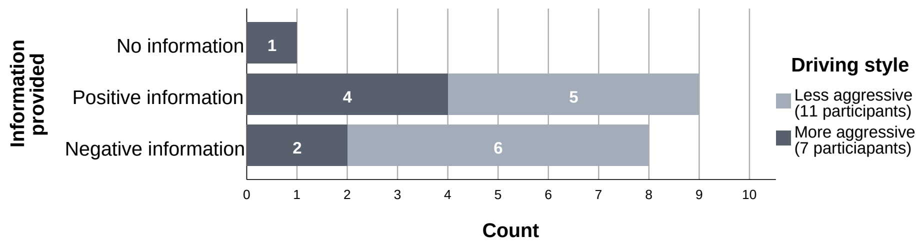


Figure 6.16: Participants with different driving style falling within different information scenarios

6.3.2. Driving style vs overtaking style

From figure 6.17, it can be seen that less aggressive participants performed more accelerative overtaking in comparison to more aggressive participants.

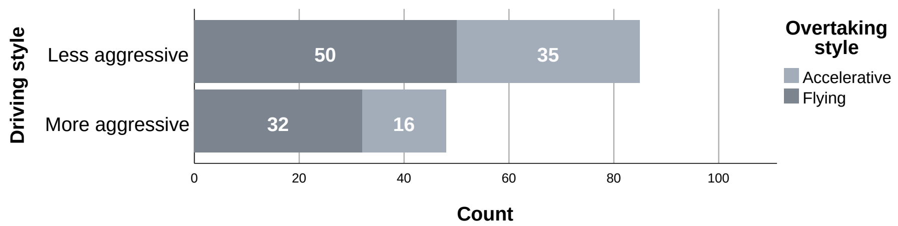


Figure 6.17: Type of overtaking by participants with different driving styles

6.3.3. Overtaking style vs scenario

From figure 6.18, it can be seen that the type of overtaking performed within different scenarios was nearly equi-proportional except negative information scenario where less accelerative overtaking were performed.

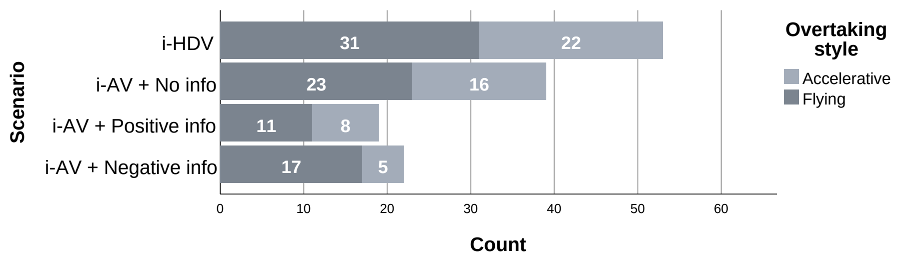


Figure 6.18: Type of overtaking performed in different scenarios

6.4. Summary and insights gained

As a lot of data was collected from the experiment and questionnaires, it is important to completely understand the data and identify relationships between different variables that can help in further analysis of the data. This chapter aimed to identify and gain insights about different relationships lying within the survey and sensor datasets. Within this chapter, first, the insights from multiple questionnaires and interviews were discussed. Later, further insights regarding the driving behaviour in terms of gap acceptance, car-following and overtaking behaviour were discussed. In the end, insights about various scenario variables were provided. The findings from this initial analysis can be summarized as follows:

Insights from questionnaires

- 18 male participants took part in this study where the majority were from science and engineering background.
- During the experiment, participants indicated their stress and trust during interaction with the TV. It was observed that participants reported higher trust in an i-AV scenario. Also, it was observed that less aggressive people indicated higher trust during all scenarios.
- Insights from interviews revealed the thought process of participants. Some of the participants indicated higher trust in AVs during the interview.
- The reported general trust of participants on AV increased after the field test.

Driving behaviour insights

1. Gap acceptance behaviour
    - Lower critical gap are indicated in i-AV scenario in comparison to i-HDV scenario.
    - Less aggressive drivers have higher critical gap in comparison to more aggressive drivers. However, decrease in critical gap is more for less aggressive drivers in i-AV scenario.
    - A decrease in critical gap was observed after providing positive information regarding AV.
2. Car following behaviour
    - No noticeable differences were observed within car following behaviour indicators due to scenario, driving style, and information.
3. Overtaking behaviour
    - In i-AV scenario, overtaking duration increased by 1 second during flying overtaking whereas decreased by 0.9 seconds in accelerative overtaking in comparison to i-HDV scenario.
    - With negative information regarding AV, the overtaking duration increased by 1.6 seconds in comparison to i-Av scenario without information.
    - No differences in overtaking lateral gap was observed within different scenarios.
    - No differences in relative speed during overtaking was observed within different scenarios.
    - No noticeable difference in headway at the start of overtaking was observed within different scenario.
    - Lower headways at the end of overtaking were observed when provided with positive information in i-AV scenario.
4. Scenario insights
    - Among negative information recipients, less aggressive participants were higher in number.
    - Less aggressive participants performed more accelerative overtaking in comparison to more aggressive participants.
    - In negative information scenario, less accelerative overtaking were performed.

7

Analysis results

In chapter 6, detailed investigation of the processed dataset was carried out and a lot of insights regarding potential behavioural adaptation was observed. The findings regarding the change in driving behaviour of participants towards AVs is summarised in section 6.4. However, in order to further consolidate the findings and confirm the significance of results, it is necessary to perform statistical testing to make sure whether observed effects are not by chance. In this chapter, the various hypothesis discussed in section 3.5 will be tested which would help in answering the main and sub research questions.

This chapter discusses the results of the statistical analysis that was performed to test various hypothesis. First, a systematic statistical testing procedure is discussed which was used to identify the analysis method and perform the statistical analysis. Second, the influence of driving and overtaking styles on driving behaviour was discussed. Later, the hypothesis testing was performed to gain insights into behavioural adaptation and its results are discussed. This chapter ends with a summary of various significant findings and an overview of various tests is provided.

7.1. Statistical analysis methods

Depending upon the types of variables and number of observations, the methods of analysis differ considerably. A lot of research has been conducted to identify and properly conduct statistical tests [Holmes, 1998, McCrum-Gardner, 2008, Siegel and Castellan, 1988]. The methods of analysis depend upon sample size as well as distribution followed by the data. There are basically two types of tests: Parametric and non-parametric whose characteristics are given in table 7.1.

Table 7.1: Parametric vs non parametric tests [Bhusari et al., 2018]

	Parametric	**Non-parametric**
Assumed distribution	Normal	No assumption
Assumed variance	Homogeneous	No assumption
Typical data	Ratio or interval	Ordinal or nominal
Observations	Independent	Any
Usual central measure	Mean	Median/mode
Benefits	More solid conclusions	More robust, unaffected by outliers

In order to gain insights regarding the driving behaviour, each participant was considered as one independent observation. Since each participant had multiple runs in the experiment, the data within the same scenarios were averaged together to conduct statistical testing. Since data from multiple runs are averaged, the random variations in observations due to unknown factors are expected to be less.

The parametric tests assume a normal distribution and thus should only be applied to the data which follows a normal distribution. Incorrect application of parametric test may result in Type-I error. In case data does not follow a normal distribution, non-parametric tests should be applied. Since the non-parametric tests are less sensitive, it is possible that smaller effects are unobserved leading to Type-II error.

Thus in order to identify the type of analysis to be conducted, data was first checked for normality. As the number of participants in this study is less, the observations do not follow a normal distribution. Thus, non-parametric statistical tests were used in the analysis. The analysis was carried out using IBM SPSS statistics following the systematic guidelines provided by Field [2013] and Garth [2008].

All the statistical tests were carried out with 95% confidence with α - value (threshold for statistical significance) as 0.05. Thus the proposed null hypothesis was rejected when the corresponding P-value resulting out of test were less than or equal to 0.05.

7.2. Driving behaviour within different overtaking/driving style

As discussed in section 5.6.2, the analysis can be performed within groups of different driving and overtaking styles, it is important to understand how driving behaviour within these categorization groups are different. Thus, statistical testing was performed to identify indicators which are significantly different within these groups.

7.2.1. Effect of overtaking style

As we know from section 6.2.3 that there were mainly two different types of overtaking styles that were observed during the field test: Accelerative and flying. As both of the overtaking styles differ in its driving mechanisms, they might lead to a difference in driving behaviour during overtaking. Thus in order to perform further analysis regarding behavioural adaptation and interpret its results, it is important to identify the driving behaviour indicators which has significant difference due to overtaking style. Separately studying driving behaviour within different overtaking style might unveil more insights which would rather not be observed without categorization. Thus, this categorization would lead to a better interpretation of behavioural adaptation in terms of overtaking behaviour.

In order to identify significant differences in driving behaviour due to change in overtaking style, Wilcoxon Signed Ranks test was performed to conduct a pairwise comparison of different overtaking indicators for each overtaking style. For the analysis, observations falling under the same overtaking style were combined together and means of different overtaking behaviour indicators within different overtaking styles were compared for each participant. Table 7.2 showcases the Wilcoxon signed ranks test results for different driving behaviour indicators within different overtaking styles.

Table 7.2: Wilcoxon signed ranks test results for the difference in overtaking behavior among different overtaking styles

Test Statistics (a)				
	Scenario 1	**Scenario 2**	**Z**	**Asymp. Sig. (2-tailed)**
Mean overtaking duration	Accelerative	Flying	-2.959 (b)	**0.003**
Mean overtaking lateral gap	Accelerative	Flying	-1.193 (b)	0.233
Mean relative speed during overtaking	Accelerative	Flying	-2.741 (b)	**0.006**
Mean headway at start of overtaking	Accelerative	Flying	-3.362 (b)	**0.001**
Mean headway at end of overtaking	Accelerative	Flying	-.052 (b)	0.959
a. Wilcoxon Signed Ranks Test				
b. Based on positive ranks.				

From the analysis, the following are the main findings.

1. Overtaking duration in accelerative overtaking style is significantly lower by 1 sec than flying overtaking style (Wilcoxon Signed Ranks Test, Z=-2.95, p=0.003)

2. Relative speed during overtaking in accelerative overtaking style is significantly lower by 5.3 kmph than flying overtaking style (Wilcoxon Signed Ranks Test, Z=-2.74, p=0.006)

3. Headway at start of overtaking in accelerative overtaking style is significantly lower by 0.6 sec than flying overtaking style (Wilcoxon Signed Ranks Test, Z=-3.36, p=0.001)

no significant difference was observed within other overtaking behaviour indicators. Thus for further analysis within overtaking duration, relative speed during overtaking and headway at start of overtaking indicators, it is important to also observe any underlying effect within groups of different overtaking styles.

7.2.2. Effect of driving style

We have seen in section 5.4.2 that participants in this study had different driver characteristics and can be divided into two groups of less and more aggressive drivers. As there is a difference in driving style within these groups, these participants may have a difference in driving behaviour which can be captured with the help of various driving behaviour indicators. If in case there is a significant difference in some driving behaviour between these groups, a separate analysis is required for those indicators to take into account any effect which is strong within one group of participants. Thus, for the further analysis regarding the behavioural adaptation during interaction with AVs, it is important to identify indicators which are significantly different within different groups of driver characteristics.

In order to identify the significant differences in driving behaviour between different group of participants based on driving style, Mann Whitney U test was performed. The statistics of the Mann Whitney U test are provided in table 7.3.

Table 7.3: Mann Whitney U test results for the difference in driving behavior among different driving style group

Mann-Whitney U test Statistics (a) - **Less aggressive vs More aggressive drivers**							
Driving behaviour	**Indicator**	**Mann-Whitney U**	**Wilcoxon W**	**Z**	**Asymp. Sig. (2-tailed)**	**Exact Sig. [2*(1-tailed Sig.)]**
Gap acceptance	**Critical gap [sec]**	34.000	62.000	-0.408	0.684	.724 (b)
Car following	**Car following headway [sec]**	26.000	81.000	-0.878	0.380	.417 (b)
Overtaking	**Overtaking duration [sec]**	27.000	55.000	-0.781	0.435	.475 (b)
	Overtaking lateral gap [m]	18.000	63.000	-1.429	0.153	.174 (b)
	Relative speed during overtaking [kmph]	12.000	67.000	-2.245	**0.025**	**.025 (b)**
	Headway at start of overtaking [sec]	17.500	72.500	-1.709	0.087	.088 (b)
	Headway at end of overtaking [sec]	25.500	53.500	-0.929	0.353	.364 (b)
a. Grouping Variable: Driving style						
b. Not corrected for ties.						

From the analysis, it was observed that less aggressive drivers have significantly lower relative speed during overtaking (Mann Whitney U test, U=12, p=0,025) in comparison to more aggressive drivers. From section 7.2.1, it is known that relative speed during overtaking was significantly lower in accelerative overtaking in comparison to the flying overtaking. It is possible that lower relative speed during overtaking within less aggressive participants is due to the higher proportion of less aggressive participants performing accelerative overtaking (refer section 6.3.2).

Another analysis was performed to evaluate the effect of driving style on reported stress during interaction with TV and trust in interacting TV. In order to perform analysis, the stress and trust reported by participants were aggregated over their runs. On the average stress and trust reported by participants, relationship with driving style was evaluated by performing the Mann-Whitney U test. From the analysis, it was found that there is no significant difference in the reported stress by participants of different driving styles (Mann Whitney U test, U=26.5, p=0.255). However, more aggressive participants reported significantly lower trust in TV in comparison to less aggressive participants (Mann Whitney U test, U=9, p=0.006). This can also be seen in figure 6.4.

No significant difference was found in other driving behaviour indicators. Thus, during the analysis of behavioural adaptations, it would be interesting to consider driving style while analyzing relative speed during overtaking.

7.3. Behavioural adaptation analysis

In order to further consolidate findings regarding the potential behavioural adaptation of drivers due to their interaction with AVs, several hypotheses formulated in section 3.5 needs to be tested. The hypothesis testing is carried out in each category of hypothesis table together for all three different driving behaviour. The following subsections aim to test each research category of hypothesis table with respect to all driving behaviour indicators.

7.3.1. Effect of scenario (H1)

In order to understand the effect of scenario on the driving behaviour, the observations of i-HDV scenario were compared with the observations of i-AV scenario. Over multiple runs, the observations were aggregated per scenario for each participant. From the last chapter, it is known that there was a notable difference in the critical gap between different scenarios. In order to verify, Wilcoxon signed ranks test (a non-parametric equivalent of paired-t test) was performed on all driving behaviour. The outcome of the test is given in table 7.4.

Table 7.4: Hypothesis H1: Effect of scenario - Wilcoxon Signed Ranks test statistics

Test Statistics (a)				
	Scenario 1	Scenario 2	Z	Asymp. Sig. (2-tailed)
Mean critical gap	**i-AV**	**i-HDV**	**-3.419** (b)	**0.001**
Mean car following headway	i-AV	i-HDV	-.355 (b)	0.722
Mean overtaking duration AV	i-AV	i-HDV	-.233 (c)	0.816
Mean overtaking lateral gap AV	i-AV	i-HDV	-.909 (b)	0.363
Mean relative speed during overtaking AV	i-AV	i-HDV	-.621 (c)	0.535
Mean headway at start of overtaking AV	i-AV	i-HDV	-.310 (c)	0.756
Mean headway at end of overtaking AV	i-AV	i-HDV	-.621 (c)	0.535
a. Wilcoxon Signed Ranks Test				
b. Based on positive ranks.				
c. Based on negative ranks.				

From the test statistics, it can be seen that the mean critical gap in AV scenario is significantly smaller than that of HDV scenario. The effect observed is highly significant (Wilcoxon Signed Ranks test, Z value = -3.419, p-value < 0.001). Thus it can be said that smaller gaps are accepted in case of interaction with AVs.

However, no significant difference was found in other driving behaviour indicators. A similar analysis was conducted within groups of participants with different driving styles and observations with different overtaking styles. No significant difference was found within different categorization groups (Appendix N).

Apart from driving behaviour indicators, the effect of the scenario on stress and trust of the participants was tested. As the stress and trust both are ordinal and categorical variables, Chi-square test was performed to find a relation. From chi-square test, it was found that there is no significant relationship between stress during interaction and scenario (X^2(df=5, N=173) = 5.904, p=0.316). Also, no significant relation was found between trust in interacting vehicle and scenario (X^2(df=8, N=172) = 9,412, p=0.309). Relation of stress and trust with scenario was also investigated within participants with different driving style, however, relation between them was still found to be insignificant from statistical viewpoint (appendix N).

In another analysis, the average reported stress and trust of participants within i-HDV and i-AV scenario was compared together and Wilcoxon Signed rank test was performed. Test result revealed no significant difference in stress (Wilcoxon Signed Ranks test, Z value = -0.102,p-value = 0.919) and trust (Wilcoxon Signed Ranks test, Z value = -0.028,p-value =0.977) between different scenarios. Other plots regarding stress and trust in interacting vehicle can be found in appendix N.

Thus, from the analysis, only null hypothesis H1.1 can be rejected and it can be said that lower critical gaps are accepted in case of interaction with AVs in comparison to interaction with HDVs. However, it was expected that higher critical gaps would be accepted in case of AVs. Null hypothesis H1.2-9 cannot be rejected and it can be said that there is no difference in these indicators due to the effect of scenario.

7.3.2. Effect of provided information regarding AVs (H2 & H3)

As the participants were provided with either positive (H2) or negative (H3) information, it is interesting to check whether the information affects their driving behaviour, stress during interaction or trust in interacting vehicle. For analysis, the participants are divided into two groups as per positive or negative information received by them and separate analysis is conducted for each group. The analysis is conducted within and between the positive and negative information groups.

In a within-group analysis, in order to notice the difference, the i-AV scenario with information is compared with i-AV scenario without information and i-HDV scenario. In a between-group analysis, the i-AV (negative information) scenario of negative information group is compared with i-AV (positive information) scenario of positive information group.

As multiple scenarios were being tested together, Independent-Samples Kruskal-Wallis Test (non-parametric equivalent of ANOVA) was performed for rank-based one-way analysis of variance. In Kruskal wallis test, the null hypothesis states that the distribution of different groups is the same. Thus the alternative hypothesis states that there is a significant difference between the distribution of within different groups. When the test statistics show any significant difference between groups, post-hoc test is required to identify the scenario pairs which are dominant and statistically significant.

Both of the analysis are discussed below:

a) Within information group analysis

The analysis was conducted within each information group of participants where observations of i-HDV scenario were compared with observations within i-AV (no information) and i-AV (positive or negative information) scenarios. An average of multiple runs within the same scenario was considered to perform analysis.

The statistics of Kruskal-Wallis test revealed no significant differences in variance between with and without information scenarios on any driving behaviour indicators. The summary of Kruskal Wallis test results for both positive and negative information recipients is given in appendix O. Since the difference in variance between scenarios within each group is not significant, post-hoc tests are not required.

Apart from checking variances, Wilcoxon Signed Ranks test was performed to identify differences between observations without information and with information within information groups. To perform the analysis, averages of all the runs were considered. A further analysis was performed between participants of different driving styles. From these analyses, no significant difference between with and without information scenarios was found. The results of tests can be found in Appendix O.

Following the insights from interview, some participants indicated that they forgot the provided information after 1 run. Thus it is possible that the effect of information lasted for only one run after information was provided and taking an average of all scenarios with information might mask the actual effect of information. Therefore, it is interesting to verify if there is any difference in driving behaviour just after providing information. Thus, within the group of participants with either positive or negative information, an analysis was

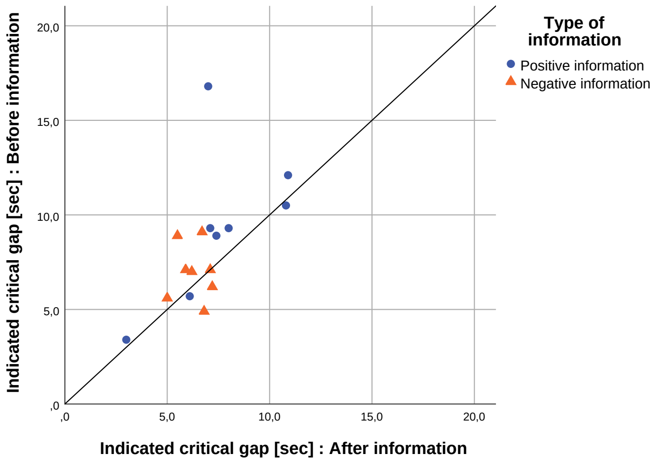


Figure 7.1: Scatter plot of indicated critical gap before and after providing information

carried out to investigate the driving behaviour just after providing information.

Table 7.5 presents the results of Wilcoxon signed ranks test to compare different driving behaviour indicators in i-AV scenario just before providing information (run 3 except participant 1) and just after providing information (run 4 except participant 1). From the analysis, it can be observed that indicated critical gap decreased significantly just after providing positive information (Wilcoxon Signed Ranks test, Z value = -2.033, p-value < 0.042) (also see figure P.1). No other significant relations were observed for other driving behaviour indicators.

Table 7.5: Wilcoxon Signed Ranks Test statistics for observations just before and after providing information within different information groups

	Test Statistics (a)						
				Type of information recieved by participant			
				Negative information		**Positive information**	
Driving behaviour	**Indicator**	**Scenario 1**	**Scenario 2**	**Z**	**Asymp. Sig. (2-tailed)**	**Z**	**Asymp. Sig. (2-tailed)**
Gap acceptance	**Critical gap [sec]**	AV 1st interaction with information	AV without information	-1.014 (b)	0.310	**-2.033 (b)**	**0.042**
Car following	**Car following headway [sec]**	AV 1st interaction with information	AV without information	-1.782 (c)	0.075	-1.826 (b)	0.068
Overtaking	**Overtaking duration [sec]**	AV 1st interaction with information	AV without information	-1.753 (c)	0.080	-.184 (c)	0.854
	Overtaking lateral gap [m]	AV 1st interaction with information	AV without information	-.944 (b)	0.345	-.730 (c)	0.465
	Relative speed during overtaking [kmph]	AV 1st interaction with information	AV without information	-.135 (c)	0.893	-1.095 (b)	0.273
	Headway at start of overtaking [sec]	AV 1st interaction with information	AV without information	-1.753 (c)	0.080	-.552 (b)	0.581
	Headway at end of overtaking [sec]	AV 1st interaction with information	AV without information	-1.890 (b)	0.059	-1.289 (b)	0.197
a. Wilcoxon Signed Ranks Test							
b. Based on positive ranks.							
c. Based on negative ranks.							

Figure 7.1 shows the scatter plot of critical gap observations just before and after information was provided. With positive information, smaller critical gaps were accepted just after receiving information. Observation from one participant showed high difference in critical gap before and after receiving information and was carefully investigated. However, observations from that participant were fairly consistent and much lower critical gaps were accepted by the participant after providing information in AV scenarios. The i-HDV scenario observations were still the same after providing information.

Thus from the analysis, the null hypothesis H2.1 can be rejected and it can be said that positive information on AVs significantly decreases the critical gap of drivers interacting with AVs.

In another analysis to compare the stress and trust within scenarios of different information (aggregated over different participants), it was found that reported trust was significantly higher in i-AV scenarios after providing positive information in comparison to no information scenarios (Table 7.6 and figure Q.1). Thus null hypothesis H2.8 can be rejected.

Table 7.6: Wilcoxon Signed Ranks Test results for difference in stress and trust over information and no information scenarios

Test Statistics (a)			
Type of information		**Stress (info) vs Stress (no info)**	**Trust (info) vs Trust (no info)**
Positive information	**Z**	-1.577 (b)	-2.117 (c)
	Asymp. Sig. (2-tailed)	0.115	**0.034**
Negative information	**Z**	-1.342 (c)	-.137 (c)
	Asymp. Sig. (2-tailed)	0.180	0.891
a. Wilcoxon Signed Ranks Test			
b. Based on positive ranks.			
c. Based on negative ranks.			

b) Between information group analysis

In a between information group analysis, the driving behaviour indicators were evaluated for all the participants to investigate if there is any difference in driving behaviour between the participants who received positive information in comparison to the negative information recipients. In order to compare different scenarios, Kruskal-Wallis test was performed in different scenarios within all participants. The summary of Kruskal-Wallis test results is provided in table 7.7

Table 7.7: Kruskal-Wallis Test Summary for the difference in driving behavior between information groups

Independent-Samples Kruskal-Wallis Test Summary				
	Total N	**Test Statistic**	**Degree Of Freedom**	**Asymp. Sig. (2-tailed)**
Mean critical gap	53	4.662 (a,b)	3	0.198
Mean car following headway	48	0.292 (a,b)	3	0.962
Mean overtaking duration	48	6.117 (a,b)	3	0.106
Mean overtaking lateral gap	44	0.905 (a,b)	3	0.824
Mean relative speed during overtaking	48	1.807 (a,b)	3	0.613
Mean headway at start of overtaking	48	0.053 (a,b)	3	0.997
Mean headway at end of overtaking	48	11.183 (a)	3	**0.011**
a. The test statistic is adjusted for ties.				
b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.				

Table 7.8: Dunn's pairwise test with Bonferroni correction for headway at end of overtaking

Pairwise Comparisons of Scenarios - All					
Sample 1 vs Sample 2	**Test Statistic**	**Std. Error**	**Std. Test Statistic**	**Sig.**	**Adj. Sig. (a)**
i-AV (Positive info) vs i-HDV	9.438	6.049	1.560	0.119	0.712
i-AV (Positive info) vs i-AV (Negative info)	-11.250	6.985	-1.611	0.107	0.644
i-AV (Positive info) vs i-AV (No info)	19.625	6.049	3.244	**0.001**	**0.007**
i-AV (Negative info) vs i-HDV	1.813	6.049	0.300	0.764	1.000
i-AV (No info) vs i-HDV	10.188	4.939	2.063	0.039	0.235
i-AV (Negative info) vs i-AV (No info)	8.375	6.049	1.384	0.166	0.997
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic significances (2-sided tests) are displayed. The significance level is 0.05.					
a. Significance values have been adjusted by the Bonferroni correction for multiple tests.					

The test results suggested that there is a significant difference in distribution between different groups for headway at the end of overtaking observations. Thus a posthoc Dunn's pairwise test with Bonferroni correction comparison was carried out to identify the scenario pairs which have significantly different distributions. Table 7.8 shows the test statistics of Dunn's pairwise comparison test. From pairwise comparison, it is found that headway at the end of overtaking has significantly different distributions between positive and no information scenarios with AVs. Thus significantly lower headways were accepted at the end of overtaking in case of positive information. This can also be observed in figure 6.15.

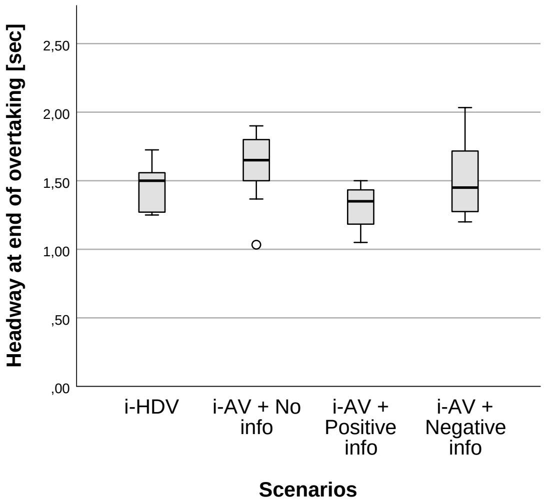


Figure 7.2: Headway at end of overtaking within different information scenarios between participants

Thus from the analysis between information groups, the null hypothesis H2.6 can be rejected and it can be said that significantly lower headways at the end of overtaking (mean = 1.3 sec) is accepted in case of positive information scenario in comparison to no information scenarios (mean = 1.7 sec) for AVs.

Another analysis was conducted to investigate the difference between reported stress and trust between participants who received positive and negative information. The reported trust for each participant was aggregated over different run and a comparison between different groups was made using the Mann-Whitney U test. Test results indicated no significant difference in reported stress (Mann Whitney U test, U=25, p=0.272) and trust (Mann Whitney U test, U=29, p=0.499) between information groups of participants.

7.3.3. Learning effect (H4)

Over multiple interactions with AVs, it is possible that driving behaviour changes as drivers gain more information regarding interacting AVs. The observed effect can be in the form of changes in driving manoeuvres or changes in stress and trust while interacting with an AV. In order to study the learning effect, correlations of various driving behaviour indicators with the number of interactions in i-AV scenario was evaluated. The correlations were also evaluated within sub-categorization groups of driving style, overtaking style and information provided.

From the analysis, no significant correlations were observed within different driving behaviour indicators with the number of interactions. To investigate within sub-categorization groups, an analysis was carried out within different driving style and provided information groups. No significant correlations were observed within these groups as well. The results of these correlation analyses along with plots are provided in appendix P.

Since there is a significant difference in indicators between different overtaking styles (section 7.2.1), an analysis was also carried out within different overtaking style observations whose summary is shown in table 7.9. Within accelerative overtaking style, it was observed that Headway at the end of overtaking significantly decreases with number of interactions. This can also be observed in figure 7.3.

Table 7.9: Correlations of overtaking behavior indicators with number of interactions with AV (as per overtaking style)

Correlations						
	AV interaction number					
	Flying			Accelerative		
	Pearson Correlation	Sig. (2-tailed)	N	Pearson Correlation	Sig. (2-tailed)	N
Overtaking duration [sec]	0.160	0.267	50	0.063	0.745	29
Overtaking lateral gap [meters]	-0.007	0.960	48	-0.101	0.639	24
Relative speed during overtaking [kmph]	-0.233	0.104	50	-0.114	0.556	29
Time headway at start of overtaking [sec]	-0.095	0.510	50	-0.139	0.472	29
Time headway at end of overtaking [sec]	-0.051	0.728	49	-.509**	**0.005**	29

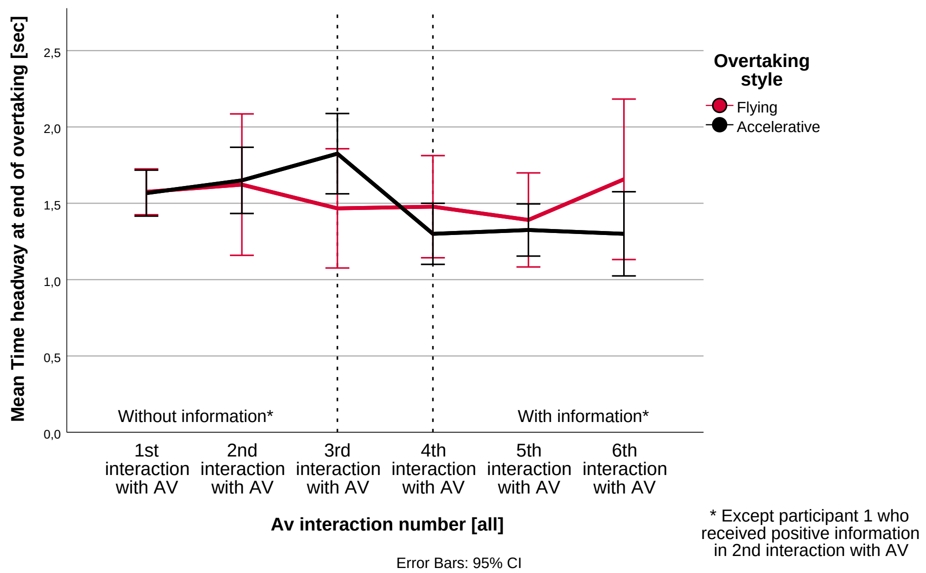


Figure 7.3: Headway at the end of overtaking over multiple observations (Within different overtaking styles)

Thus, Null hypothesis H4.6 can be rejected and it can be said that Headway at the end of overtaking decreases over multiple interactions with AV within accelerative overtaking style.

It is also interesting to note that headway at the end of overtaking during 4th interaction (when information is provided) is much lower for participants with positive information in comparison to participants with negative information (figure 6.15).

In order to study the change in stress and trust over multiple interactions with AV, correlation analysis was performed. The analysis was also performed within groups of different information and driving styles. However, no significant correlation was observed within any analysis. Thus learning effect was not observed within reported stress and trust. The results of correlation analyses can be found in appendix Q.

7.4. Analysis of stress and trust

The stress or trust in interacting vehicle can have an impact on driving behaviour. However, same level of trust (or stress) may have different influence on driving behaviour depending upon whether the interacting vehicle is an HDV or an AV. Thus, it is interesting to investigate how change in stress or trust on different type of vehicle affects the driving behaviour. As stress and trust may affect the driving decisions, investigating them can explain the observed behavioural adaptation effects.

7.4.1. Effect of trust in interacting AV (H5)

In order to investigate the effect of trust in different driving behaviour indicators, several analyses were carried out. First, the correlation between trust and different driving behaviour indicators in different scenarios were investigated. Table 7.10 shows the correlations between reported trust and different driving behaviour indicators.

Table 7.10: Correlation between different driving behaviour indicators and reported trust in Test vehicle within different scenarios

Correlations						
	Reported trust in Test Vehicle					
	i-HDV			**i-AV**		
Indicators	**Pearson Correlation**	**Sig. (2-tailed)**	**N**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**
Indicated critical gap [sec]	-0.155	0.204	69	**-.245***	**0.015**	97
Car following headway [sec]	-0.083	0.554	53	-0.139	0.235	75
Overtaking duration [sec]	0.259	0.062	53	0.097	0.397	79
Overtaking lateral gap [meters]	-0.171	0.246	48	-0.031	0.796	72
Relative speed during overtaking [kmph]	**-.329***	**0.017**	52	**-.300****	**0.007**	79
Time headway at start of overtaking [sec]	-0.050	0.726	51	-0.099	0.383	79
Time headway at end of overtaking [sec]	0.091	0.523	51	-0.086	0.452	78
**. Correlation is significant at the 0.05 level (2-tailed).*						
***. Correlation is significant at the 0.01 level (2-tailed).*						

From table 7.10, it can be seen that critical gaps are significantly lower with an increase in trust in case of an i-AV scenario whereas in contrast, no such significant effect was found in case of i-HDV scenario. Significant correlation of relative speed during overtaking with reported trust in TV is less interesting as the correlation is found for both i-HDV and i-AV scenario.

Investigating further into the critical gap between different driving styles, it is found that more aggressive participants are more likely to accept lower critical gaps with higher trust in AV (table 7.11). However, they would not necessarily do the same with HDVs. Thus from the analysis, hypothesis **H5.1** can be rejected and it can be said that significantly lower critical gaps are accepted by the more aggressive drivers during their interaction with AVs with their increase in trust over interacting AV.

Since there is a significant difference between few indicators within different overtaking styles (section 7.2.1), it is interesting to check if there is any significant effect within these groups. Table 7.12 shows the correlations of overtaking behaviour indicators with trust over different overtaking styles. From the analysis, it can be seen that headway at the start of overtaking decreases significantly with an increase in trust in case of accelerative overtaking within i-AV scenario. However, in contrast, no such effect is seen with other scenarios or

Table 7.11: Correlation of critical gap with reported trust in TV: between different scenario and driving style

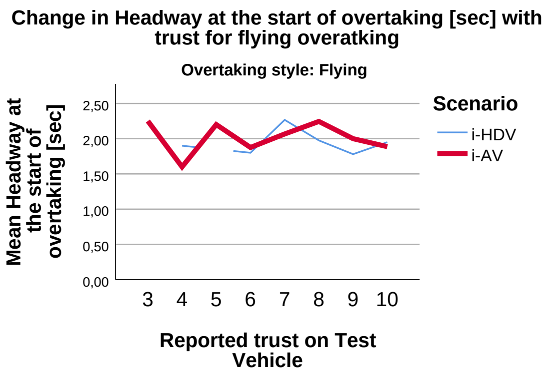
			Reported trust	
Indicator	**Scenario**		**Less aggressive**	**More aggressive**
Indicated critical gap [sec]	**i-HDV**	Pearson Correlation	-.316	-.326
		Sig. (2-tailed	**.039**	.104
		N	43	26
	i-AV	Pearson Correlation	-.372**	-.343*
		Sig. (2-tailed	**.004**	**.032**
		N	58	39

overtaking styles. This can also be seen in figure 7.4.

Thus from the analysis, hypothesis H5.5 can be rejected and it can be said that Headway at the start of overtaking decreases with an increase in trust in AV especially within the accelerative overtaking style.

Table 7.12: Correlation of overtaking behaviour indicators with reported trust in TV: Between overtaking style and scenarios

			Reported trust	
Sceanario	**Indicator**		**Flying**	**Accelerative**
i-HDV	**Overtaking duration [sec]**	**Pearson Correlation**	0.275	0.241
		Sig. (2-tailed	0.134	0.280
		N	31	22
	Time headway at start of overtaking [sec]	**Pearson Correlation**	-0.030	0.000
		Sig. (2-tailed	0.872	1.000
		N	31	20
i-AV	**Overtaking duration [sec]**	**Pearson Correlation**	0.078	-0.009
		Sig. (2-tailed	0.588	0.961
		N	50	29
	Time headway at start of overtaking [sec]	**Pearson Correlation**	-0.083	-.500**
		Sig. (2-tailed	0.569	**0.006**
		N	50	29



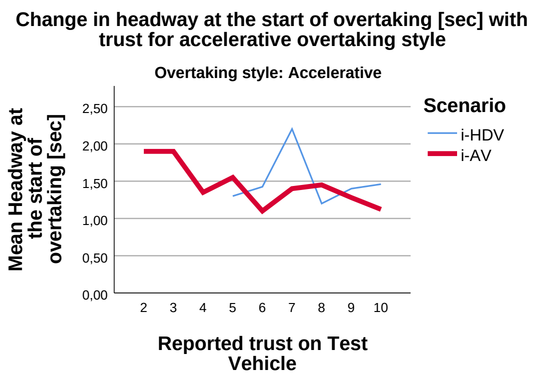


Figure 7.4: Change in headway at the end of overtaking with trust for flying (left) and accelerative (right) overtaking styles

7.4.2. Effect of stress during interaction with AV (H6)

A similar analysis was conducted to study the effect of stress on driving behaviour between i-HDV and i-AV scenarios. Table 7.13 shows the summary of correlation analysis within different scenarios.

From the analysis, it was found that relative speed during overtaking significantly increases with an increase in stress. However, this effect is observed for both i-HDV and i-AV scenarios. Thus it is not interesting to investigate further. However, no other significant differences between scenarios were observed within any driving behaviour indicators.

Table 7.13: Correlation between different driving behavior indicators and reported stress within different scenarios

Correlations						
	Reported stress during interaction					
	i-HDV			i-AV		
Indicators	**Pearson Correlation**	**Sig. (2-tailed)**	**N**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**
Overtaking duration [sec]	-0.255	0.066	53	0.001	0.993	79
Overtaking lateral gap [meters]	-0.055	0.708	48	-0.050	0.675	72
Relative speed during overtaking [kmph]	**.280***	**0.044**	52	**.279***	**0.013**	79
Time headway at start of overtaking [sec]	-0.049	0.731	51	0.165	0.145	79
Time headway at end of overtaking [sec]	-0.243	0.085	51	-0.046	0.690	78
Indicated critical gap [sec]	0.228	0.059	69	.233	0.061	98
Car following headway [sec]	0.194	0.165	53	0.008	0.943	75
**. Correlation is significant at the 0.05 level (2-tailed).*						

7.5. Summary

In this chapter, empirical analysis to understand the change in driving behaviour due to interaction with AVs was systematically conducted. The analysis was carried out with consideration of different influencing variables such as driving and overtaking styles. Table 7.14 presents various significant findings as a result of hypothesis testing. The hypothesis H1.1 revealed different behaviour than expected and thus carries a different colour. This section aims to summarise the findings from empirical analysis in terms of three studied driving behaviours. The significant findings from the empirical analysis along with a list of rejected hypothesis are as follows:

Effects in Gap acceptance behaviour

- **Hypothesis H1.1 :** Mean critical gap in i-AV scenario is significantly smaller than that of i-HDV scenario (Wilcoxon Signed Ranks test, Z value = -3.419, p-value = 0.001).
- **Hypothesis H2.1 :** Positive information on AVs significantly decreases the critical gap of drivers interacting with AVs (Wilcoxon Signed Ranks test, Z value = -2.033, p-value = 0.042).
- **Hypothesis H5.1 :** Significantly lower critical gaps are accepted by the more aggressive drivers during their interaction with AVs with their increase in trust over interacting AV (Pearson's r = -0.343, p-value = 0.032, N=39).

Effects in Overtaking behaviour

- **Hypothesis H2.6 :** Significantly lower headways at the end of overtaking (mean = 1.3 sec) is accepted in case of positive information scenario in comparison to no information scenarios (mean = 1.7 sec) for AVs (Dunn's pairwise test, Z = 19.625, p = 0.007).
- **Hypothesis H4.6 :** Headway at the end of overtaking decreases over multiple interactions with AV within the accelerative overtaking style (Pearson's r = -0.509, p-value = 0.005, N=29).
- **Hypothesis H5.5 :** Headway at the start of overtaking decreases with an increase in trust in AV especially within the accelerative overtaking style (Pearson's r = -0.500, p-value = 0.006, N=29).

Effect of trust in interacting vehicle

- **Hypothesis H2.8 :** Reported trust was significantly higher in i-AV scenarios after providing positive information in comparison to no information scenarios (Wilcoxon Signed Ranks test, Z value = -2.117,p-value = 0.034).

Table 7.14: A summary of observed effects within hypothesis table

	Category		Effect of Scenario	Effect of provided information (AVs)		Over multiple interactions (Learning effect)	Effect of trust on interacting AV	Effect of stress during interaction with AV
	Effect studied for		AV	Positive information	Negative information	AV	Higher trust on AV	Higher stress
	In comparison with		HDV	No information	No information	Number of interactions	Lower trust on AV	Lower stress
		Ref no	**H1**	**H2**	H3	**H4**	**H5**	H6
Gap acceptance behaviour	**Critical gap**	**1**	Lower	Lower (just after providing information)	-	-	Lower (More aggressive drivers)	-
Car following behaviour	Following headway	2	-	-	-	-	-	-
Overtaking behaviour	Overtaking duration	3	-	-	-	-	-	-
	Lateral gap while overtaking	4	-	-	-	-	-	-
	Headway at start of overtaking	**5**	-	-	-	-	Lower (Accelerative)	-
	Headway at end of overtaking	**6**	-	Lower	-	Decrease (Within accelerative overtaking style)	-	-
	Relative speed during overtaking	7	-	-	-	-	-	-
Stress and trust	**trust in interacting vehicle**	**8**	-	Higher	-	-	-	-
	Stress during interaction	9	-	-	-	-	-	-

8 Discussion and conclusion

This chapter aims to provide answers to research questions and conclude the results. Furthermore, this chapter aims to provide reflections on methodology and literature findings. The chapter ends with the contributions and limitations of this research.

8.1. Research overview

As automated driving technology is continuously developing, it is not so far in future when automated vehicles will be a part of normal day to day traffic with a significant penetration rate on our roads. The benefits of AVs are realised in terms of improvements in traffic flow and safety. However, in the early phases of automation, the penetration rate of AVs will be low leading towards limited benefits in traffic flow. Furthermore, it is not yet known whether the other HDV-drivers would interact with AVs in the same or a different manner. This raises a concern towards traffic safety and thus the behavioural adaptation of other HDV-drivers towards automated vehicles is required to be studied.

The scope of this research is to understand whether human drivers adapt their behaviour when interacting with AVs. The behavioural adaptation is being studied in terms of 3 different driving behaviour: Gap acceptance at the un-signalized intersection, car-following behaviour, and overtaking behaviour. Within these driving behaviour, the effect of multiple interactions with AVs was also studied to gain insights into learning effects. In order to study any change in driving behaviour due to AVs, a controlled field test was conducted for data collection. During the field test, the participants were made to interact with both HDVs and AVs. The data from both scenarios are compared with each other to gain insights regarding the change in driving behaviour.

A clear understanding of behavioural adaption of road users due to their interaction with AVs would help in better analysis of impacts of AVs on road traffic. With the help of this understanding of behavioural adaptation, current existing microscopic traffic flow models can be improved which may result into better predictions and estimations of the impact of AVs on traffic flow and safety. Furthermore, on the basis of understanding of the impact of this behavioural adaptation on the traffic flow and safety, recommendations can be made to the road authorities, transport consultants and vehicle manufacturers for better design and planning of road infrastructure, deployment policies, and AVs in future.

8.2. Answer to sub-research questions

The aim of this research is to understand the behavioural adaptation of human drivers interacting with AVs. In order to study this, the main research questions and corresponding sub research questions were formulated. In this section, the various research questions of this study are answered with the help of the results discussed in chapter 7.

Since the main research question can be answered with the help of sub-research questions, first various sub research questions are discussed sequentially.

Sub-question 1: *What are the differences in gap acceptance, car following and overtaking behaviour of HDV-drivers interacting with AVs in comparison to interacting with HDVs?*

In order to gain insights into the differences in driving behaviour, the analysis was carried out where the driving decisions during HDV scenario was compared with the driving decisions during AV scenario. In order to validate the findings, statistical analysis was carried out with 95% confidence level.

The analysis of gap acceptance behaviour revealed some significant differences in terms of the critical gap of drivers between HDV and AV scenarios. It was found that critical gap of drivers during interaction with AVs is significantly lower in comparison to interaction with HDVs (Wilcoxon Signed Ranks test, Z value = -3.419, p-value < 0.001).

However, no significant differences were found in car-following and overtaking behaviour due to their interaction with AVs in comparison to interaction with HDVs.

Sub-question 2: *What is the impact of positive and negative information regarding AVs on the driving behaviour of HDV-driver during interaction with AV?*

In order to study the impact of positive or negative information about AVs on driving behaviour, an analysis was made where information scenarios were compared with no information scenarios. Within the analysis, no differences in driving behaviour were observed due to negative information. However, the analysis with positive information revealed significant differences in terms of gap acceptance and overtaking behaviour.

With positive information about interacting AV, the critical gap during interaction with AV decreases significantly (Wilcoxon Signed Ranks test, Z value = -2.033, p-value = 0.042). Thus positive information has an influence on gap acceptance behaviour.

During overtaking, the headways at the end of overtaking during interaction with AVs significantly decreased when positive information was provided.

Sub-question 3: *What is the difference in experienced stress and trust of HDV-drivers interacting with AVs in comparison to interacting with HDVs ?*

As experienced stress and trust in the interacting vehicle has the potential to change driving behaviour, the stress and trust in different scenarios were investigated. From the analysis, no relationship was found between the effect of scenario (HDV or AV) on experienced stress or trust in AV.

However, some other observations regarding trust explain other adaptations in driving behaviour. It was found that trust in AV increases significantly when positive information was provided (Wilcoxon Signed Ranks test, Z value = -2.117, p-value = 0.034). This increase in trust in AVs due to positive information can explain the decrease in critical gap and headways at end of overtaking as discussed in sub-question 2.

Further analysis revealed that an increase in trust in AV significantly decreases the critical gap of more aggressive drivers (Pearson's r = -0.343, p-value = 0.032, N=39). Also, headways at the start of overtaking (with AVs) in case of accelerative overtaking style decreases with increase in trust in AVs (Pearson's r = -0.500, p-value = 0.006, N=29).

Sub-question 4: *What is the effect of multiple interactions with AVs on driving decisions of HDV-driver while interacting with AVs?*

From the analysis, it was found that headways at the end of accelerative overtaking with AV decrease significantly with an increase in number of interactions with AVs. However, no other learning effect was observed with other driving behaviour indicators.

8.3. Discussion

The main aim of this research is to understand the behavioural adaptation of human drivers during their interaction with AVs. Within the research, there were two main assumptions. First, it was assumed that HDV-drivers would clearly recognise the AVs during interaction based on its physical features i.e. they would be able to notice the fake LiDAR and sticker on side of the vehicle. Second, it was assumed that AVs drives exactly in the same manner as HDVs.

The key finding of this research is that drivers have higher trust in AVs in comparison to HDVs which leads towards closer interactions with AVs. During interaction with AVs, significantly shorter gaps were accepted in front of AV. This behavioural adaptation was strongly evident during the measurement of critical gap at an un-signalised intersection as well as during measurement of accepted gap at the end of overtaking. Both of these interactions are similar in a way that HDVs interact with AVs from its front. Due to the consistency of results between both measurements, the findings are further consolidated with more confidence towards observed behavioural adaptation.

In order to provide a clear scientific reflection on the nature of findings, it is important to evaluate the results critically. This section aims to provide a reflection on the findings from multiple perspectives. First, it aims to discuss the findings from the literature and relate them to the findings in this research. Second, it aims to discuss the methodology of this research and its implications on the results. Third, the interpretation of results is discussed.

8.3.1. Reflection on state of the art

Before the commencement of this research, an extensive review of the literature was carried out. The main aim of the literature review was not to just identify the research gap but also to identify the factors which might have an impact on the behavioural adaptation of HDV-drivers due to AVs. The literature review also aimed to identify the indicators which can be used to study different type of driving behaviour, stress and trust. From the literature review, it was found that a lot of studies tried to study the behavioural adaptation of drivers present inside the AV. However, there is a dearth of studies which aim to study the behavioural adaptation of human drivers who interact with AVs.

Among the few studies which aim towards understanding the behavioural adaptation of human drivers interacting with AVs, findings are based on the assumption that AVs drive in a different manner in comparison to HDVs. Usually, those studies aim towards studying behavioural adaptation near the platoons of AVs which is more applicable in high penetration rate scenarios of AVs. Also, most of the studies use a driving simulator for data collection which raises a question towards realism of observed effects. As in the early phases of automation, platooning of AVs are less likely to happen and most of the interactions would be one to one, it is imperative to study direct interaction of HDV-drivers with AVs.

In a study conducted by Rahmati et al. [2019] to study the car following behaviour of human drivers interacting with an AV during a field test, it was found that humans drive closer to their leader when the leader is an AV. This study found smoother speed profiles of human drivers when they follow an AV. However, in their study, there was no difference in the appearance of AV but rather AV followed a different speed profile. Similar findings were observed by Gouy (2013,2014) where drivers driving in a simulator next to a platoon of short time headways tend to drive closer and reduce their headways near to critical headway. In contrast, our study did not observe any difference in car-following behaviour between interaction with AV and HDV. One possible reason is that the AV in our study had the same driving style as that of an HDV. Another possibility is that significant effects were not observed due to the small sample size or error in GPS observations.

In a study conducted by Trende et al. [2019] to study the gap acceptance behaviour of drivers when they interact with HDV and AV in a driving simulator, it was found that more gaps were accepted when the approaching vehicle was AV. This result indicated towards potential exploitation of technological advantages of AV and its capability to perform safe manoeuvres by the human drivers. The gap acceptance results of our study are in line with the findings of their research. Significantly lower indicated critical gaps and lower gaps accepted at the end of overtaking in our research also indicate towards exploitation of technological advantages of AVs. Moreover, this finding is more concrete as it is observed via a controlled field test.

In other researches conducted to study the lane changing behaviour near platoons of AV, it was found that lane change duration increases with increase in the penetration rate of AVs [Lee and OH, 2017, Lee et al., 2018, Zhong et al., 2019]. In our research, since there were no platoons and penetration rate of AV was negligible, no significant impact in overtaking duration was observed due to AV.

8.3.2. Reflection on methodology

The methodology of this research involved data collection by conducting a field test, data processing and further performing statistical analysis to gain insights regarding the potential behavioural adaptations. As the process of conducting research has an influence over the findings and results, it is important to critically assess the possible implication due to the chosen methodology.

Reflection on field test

The data collection for the study was performed by conducting a field test which proved to be very useful in providing the necessary insights. However, the process of conducting a field test may have an influence on the driving behaviour of the participants. The data collection was performed in a controlled manner at a 2 lane bi-directional road with a lane width of 3.5 meters and a speed limit of 60 kmph. Given the shorter lane width, speed limit and presence of other road users in the opposite lane, this type of road infrastructure provides limited opportunities or freedom in terms of performing driving manoeuvres. It is expected that different driving behaviour might be observed in a different road environment.

During the field test, there were other road users present who interacted with subject and test vehicle from time to time. Although their presence added to the realism in the experiment probably leading towards a reduction in experimental bias, they might have a significant influence on the driving decisions of the participants. If the test location was closed for other road traffic during the experiment, the external influence of these other road users in the field test could have been avoided.

During the entire field test, the weather was clear and sunny with excellent visibility which allowed easy recognizability of test vehicle in different scenarios. In a different weather scenario such as rain, it is expected that driving behaviour would be different. Also, in lower visibility scenarios such as heavy rain or night, it would not be easy to differentiate between HDV and AV from a distance. Thus, it is possible that the critical gap would remain unaffected between different types of vehicles.

The participants were asked to subjectively indicate their critical gap with the help of a hand gesture. However, indicating the critical gap can be very different from the actual critical gap of the participants. If participants are asked to actually drive in front of approaching vehicle, more realistic observations can be obtained.

During the field test, a driver was always present in the test vehicle due to which participants might have felt more confident during their interaction in AV scenario. It is expected that absence of a driver in AV would lead to different driving decisions and probably HDV-driver would be more cautious while interacting with AV. A stronger learning effect can be observed in such a study setup.

Within AV scenario, a piece of positive or negative information regarding interacting AV was provided to the participants. The information was provided in a written text to maintain consistency during the experiment. However, the words used in the information also makes a difference. It is expected that different ways of conveying information such as newspaper article, video report or storytelling might have more influence on the driver's behaviour.

As the experiment design involved driving in a similar fashion over multiple runs, it is possible that participants may have already formed an expectation for the upcoming runs. A more dynamic experiment can lead to a reduction in expectations and thus different results might be obtained.

The stress measurement during the field test was based on the questionnaire where participants were asked to indicate their stress during run on a scale of 1 to 10. As the baseline stress can vary between the participants, the stress measurements are not consistent. A more robust way to measure stress through physiological measurements such as heart rate would provide better results and interpretation.

Reflection on data processing and analysis

As the GPS observations had lower accuracy, the headways during overtaking were calculated with the help of video. Due to time constraints, in order to calculate the headways at the start and end of overtaking, distances were estimated by visual inspection using the length of lane markings of road. Since the minimum length of lane marking was 3 meters, an error of 3 meters in the estimation of headways might be present. Although the accuracy is satisfactory, to improve the accuracy, distances could have been estimated with the help of video processing via computer algorithms. This would have resulted in even more reliable observations of headways.

As the sample size in this research is low (18 participants), non-parametric statistical tests were used for analysis. These tests are less sensitive to smaller differences and may lead to unobserved differences (Type-II error). If there were more participants in this research, parametric methods of statistical analysis could have been used which would have resulted in even more insights regarding driving behaviour.

8.3.3. Reflection on results

The key findings of this research insinuate towards closer interactions of HDV-drivers with AVs. From the statistical analysis, it was found that critical gap and headways at start of overtaking significantly decreases with an increase in trust in AVs. The outcome of the questionnaire and interviews suggests that participants of this study have higher trust in AVs in general. With positive information on AVs, the trust in interacting AV was found to be increasing significantly whereas critical gap, as well as headways at the end of overtaking, was found to be decreasing significantly.

All these findings indicate the intention of the HDV-drivers to closely interact with AV. The reason behind close interaction with AVs is higher trust in AV's technology. Providing positive information further consolidates this finding as indicated trust in interacting AV significantly increases whereas, as a result, critical gap and gap accepted at the end of overtaking decreases significantly. As AVs are designed to interact safely, these findings indicate towards potential exploitation of technological advantages of AVs. It is important to note that the participants in this study were from the background of science and technology and therefore were capable of better understanding the technology of AVs. In the case of a different group of participants from a non-technological background, totally different behaviour can be expected.

Some participants in this study were also provided with a piece of negative information regarding the interacting AV. However, no significant effect of negative information was observed in the driving behaviour, stress and trust. One possible reason behind not being influenced by negative information is the presence of a driver inside the test vehicle. The participants believed that the driver is always ready for takeover in case something goes wrong and thus were completely sure regarding the safety. In case of an absence of driver, the effect of negative information is expected to be significant. Another reason is the simplicity of the test environment, in which it is less likely for the AV to fail with its environment detection.

Within the analysis, no behavioural adaptation due to AV was observed in car-following behaviour. The reason behind not detecting any significant difference in car following could be due to inaccuracy of GPS data which was used to calculate car following headways as well as insufficient sample size to detect significant observations.

8.4. Conclusion

The insights obtained within the sub research questions are combined together to answer the main research question of this study. The main research question of this study is:

What are the potential behavioural adaptations of human drivers during their interaction with Automated Vehicles?

The behavioural adaptation was observed in terms of gap acceptance and overtaking behaviour.

Within gap acceptance behaviour, it was observed that the critical gap of drivers decreased significantly when they interact with AVs in comparison to HDVs. The critical gap seems to decrease further for interaction with

AV when positive information was provided to the drivers. The positive information also seems to significantly increase the trust of drivers in AV. In contrast, an increase of trust in AV seems to significantly decrease the critical gap of more aggressive drivers.

Within overtaking behaviour during interaction with AV, the headways at the end of overtaking significantly decrease when positive information regarding interacting AV was provided. Within accelerative overtaking style during interaction with AVs, the headways at the end of overtaking seems to decrease significantly over multiple interactions with AV. Also with increase in trust in AV, the headway at the start of overtaking seems to decrease especially in accelerative overtaking style.

These findings indicate that drivers, in general, have higher trust in AVs due to which they feel more comfortable to perform closer manoeuvres with AVs. Within all different driving manoeuvres, it can be seen that most significant differences can be observed within critical gap and headway at the end of overtaking. Both of these driving behaviours are similar in the respect that in both situations human driver interacts and accepts gap in front of AV. Thus, it becomes the responsibility of AV to maintain a safe headway from the human-driven vehicle. Positive information regarding the functionality of AV further confirms the driver that AV can detect its environment and interact safely. This leads to even closer interactions with AV. Relating it with insights from questionnaire and interviews, participants also indicated that they trust the driving behaviour of AVs more. For the participants who indicated higher stress during interaction with AV, driving in front of it was the least stressful. Many participants indicated higher comfort and confidence when AV was driving behind them.

Thus, from a behavioural adaptation perspective, it can be concluded that closer interactions at the front of AV can be expected in comparison to HDVs and thus smaller gaps in front of AV will be accepted. Positive information would further improve the confidence and trust in AV leading towards even closer interactions. Thus there is a potential of exploitation of AVs technology by HDV-drivers and more abrupt merging (cut-offs) can be expected with AVs. For interaction from the back and side of the AV, no difference in driving behaviour is expected.

8.5. Contributions: scientific and practical

This research provided following notable scientific and practical contributions.

8.5.1. Scientific contributions

Understanding of behavioural adaptation of HDV-drivers due to their interaction with AVs

There has been a lack of research which revolves around the behavioural adaptation of HDV-drivers when they interact with AVs. Most of the research has been done to understand the behavioural adaptation of drivers inside AVs who are expected to take over control. Some research also studies the effect of the interaction of drivers with AVs, however, most of them are based on driving simulators. There has been a lack of practical evidence and this research aims to fill that gap. This research provides a scientific and empirical understanding towards such change in driving behaviour.

Conceptual framework for behavioural adaptation studies

In this research, a conceptual framework was proposed based on the literature review. This framework is widely applicable and can be further used in behavioural adaptation studies which involve interaction between HDV-drivers and automated vehicles.

Dataset for future research

As a lot of data was collected during the field test, a part of it was used in this research to answer the main research questions. However, the data can be further used to gain more insights regarding behavioural adaptation.

The acceleration of both subject and the test vehicle were also collected with the help of an accelerometer. The acceleration of both vehicles can be analysed to gain insights regarding the braking response of participants due to slowing down of AV.

Since other road users were also present and interacted with test vehicle from time to time, their data can also be analysed to gain insights regarding the magnitude of experimental bias.

8.5.2. Practical contributions

Recommendations to various stakeholders responsible in the development of AVs

This research provides recommendations to different stakeholders who are involved in the development of automated driving technology. As the technology is continuously developing, its not far in future when these vehicles will be deployed in normal traffic. Thus it is imperative to study the impact of these vehicles in terms of traffic flow and safety. With an impact assessment, AV manufacturers can design better and safer automated vehicles. The road authorities could also improve infrastructure to accommodate the effect of behavioural adaptation and several policies can be implemented to define interaction rules for automated vehicles. The recommendations to various stakeholders are provided in the next chapter.

Insights for future field test

The practical insights gained from the field test would help in conducting better field tests in future.

8.6. Research limitations

Given the practical situation, analysis methods and various decisions that were made during the course of this research, there are a few limitations in this research. Some limitations are already discussed in section 8.3. Few other limitations are as follows:

Participants

- Since all the participants in this study were male, the sample is not representative of the entire population. Thus the findings of the research are limited to only male participants and different behaviour can be expected for other gender categories.
- Most of the participants in this study were highly educated and related to the science and technology field. These participants were experienced drivers with driving experience of more than 7 years. Thus it is expected that these participants had a quite clear understanding of how the technology works and may had clear expectations regarding AV. Thus the findings of this research are applicable to a similar group of people. For inexperienced drivers or drivers with low education, the behavioural adaptation could be different.

Data collection / Field test

- Since there was a professional driver present in the test vehicle during all scenarios and participants were told that driver can take over control in case something goes wrong, the scope of the research is limited to SAE level 3 automated driving. Absence of driver in the automated vehicle could have lead to completely different driving behaviour of HDV-drivers.
- This research did not investigate any effect due to external factors such as the presence of other road users (as other road users were present during the test), type of vehicle of HDV-driver (as different vehicles differ in driving controls), infrastructure (lane width, road markings, speed limit) and environment (weather conditions and visibility). These external factors may influence driving decisions of HDV-driver and thus different findings can be obtained.
- The critical gap was indicated for an approaching vehicle at speed around 40 kmph from the right side of the subject vehicle in the opposite lane. In case of different speed / direction of approaching vehicle, results could vary.

Data processing

- The data from the back LiDAR of the test vehicle was not useful as due to the curved front of subject vehicles, the reflection of light back to LiDAR was not perfect. Thus, car following headways were calculated with the help of GPS data. As the GPS data had an accuracy of 4 meters, an error of 8 meters in car following headways cannot be avoided.

Data analysis

- As the number of participants in this study is less, non-parametric methods of statistical testing were applied. Although the non-parametric tests are more robust, they are not capable of capturing small effects. Thus there is a possibility of type -II error due to which several significant effects are left unobserved.

9

Recommendations

In the development of AVs, various stakeholders are involved who contribute themselves towards the improvement, impact assessment, and implementation of the technology. This chapter aims to present the recommendations to various stakeholders who are involved in the development, assessment, and implementation of automated vehicle technology. Later, recommendations to improve field test and areas of further research are provided.

9.1. Recommendations for transportation consultants

The key findings of this research indicate that lower gaps will be accepted at the un-signalized intersections as well as at the end of the overtaking by the HDV-drivers when they would interact with AVs. This would result in either positive or negative implications in road traffic and it is expected that the capacity of un-signalized intersections, as well as road, might change. Thus, further analysis is required to identify the impacts of behavioural adaptations. Based on findings, calculations can be performed to identify the increase or decrease in capacity of intersections and roads. The assessment can be performed for different penetration rate scenarios of AVs.

Furthermore, the findings can be implemented in a microscopic simulation model to study the effect of this behavioural adaption on traffic flow and safety. With microscopic simulations, different traffic flow phenomena such as shock-waves can be studied in detail. With this analysis, it will become clear whether this behavioural adaptation is beneficial or detrimental to traffic flow and safety. Thus more accurate simulations for automated vehicles in mixed traffic can be carried out and accordingly better suggestions can be made within different projects related to AVs.

9.2. Recommendations for improvements in simulation packages

Current simulation packages do not have sophisticated algorithms to simulate AVs in mixed traffic. In most simulation packages, when AVs are programmed, they only differ from HDVs in their driving behaviour. Thus, the main differences in traffic flow and safety are measured due to the difference in the driving style of AVs. However, the behavioural adaptation of HDVs when they interact with AVs is not yet taken into account.

The behavioural adaptation identified in this research is based on the assumption that HDV-driver can recognise AV and thus behave in a different way. However, changing driving behaviour of HDV vehicles based on the type of interacting vehicle (either HDV or AV) is not yet available in simulation packages.

Thus, in order to take behavioural adaptation into account within simulation packages, it is important to include a feature to change the driving behaviour of HDV vehicles in simulation on the basis of the type of interacting vehicle.

9.3. Recommendations for AV manufacturers

There are two basic questions, answer to which are not yet known. First, should the AV manufacturing industry aim towards making AVs clearly recognisable in traffic? Second, would there be any additional benefits if AVs drives like an HDVs?

The answer to these questions lies in our understanding of the effects of behavioural adaptation on traffic flow and safety. Due to the change in driving behaviour of HDVs towards AVs, there can be either positive or negative impacts on traffic flow and safety. To reduce any potential negative effects of such behavioural adaptation, the driving dynamics of AVs can be modified to counterbalance any such effect. With positive effects, AVs can further be designed in a way that they are very clearly recognisable in traffic leading to maximisation of potential benefits.

Thus, it is recommended for the AV manufacturers to invest in research regarding the impacts of behavioural adaptation on traffic flow and safety. These findings would help in the better development of such vehicles.

9.4. Recommendations to road authority

With a better understanding of behavioural adaptation, road authority can improve road and intersection design to accommodate such behavioural adaptation. To facilitate safe interactions between HDVs and AVs, advanced traffic controllers can be designed which can communicate between AVs and HDVs and adjust traffic signals appropriately.

9.5. Recommendations to driving license authority

As the findings of this research indicate towards potential exploitation of technological advantages of AV, the driving license authority can introduce courses to promote safer interactions with AVs. Interaction with AVs should be a part of the testing process where the main focus should be towards minimising any potential exploitation of AV's capabilities.

9.6. Recommendations for future field tests

Several learning from the field test which would help in improving the field tests in the future are as follows.

- As single point LiDARs cannot always manage to receive reflected light due to curved surfaces in vehicles, multi-point or 3D LiDARs should be used for data collection.
- It is recommended to check the data collection status from time to time in order to ensure that errors do not disrupt data collection.
- The time required to prepare and set up the instruments before the field test should be identified within the pilot to avoid any delays on main field test days.
- For the synchronisation of videos, it is recommended to present a clock in all the cameras at the start of data recording. Alternatively, if the video records sound, a loud sound source can be used to synchronise the videos.

9.7. Recommendations for further research

As this research has multiple limitations, further research needs to be conducted to gain clarity regarding other aspects of behavioural adaptation. The outcomes of this research as well as the collected dataset provide tremendous opportunities to conduct further research and better understand the interaction of road users with AVs.

Since this research provided some insights regarding the behavioural adaptation in terms of critical gap accepted at un-signalized intersection and headway at the end of overtaking, one immediate implementation of this research is to investigate the effect of this behavioural adaptation into traffic flow and safety. This study can be carried out by implementing the results in a microscopic simulation model and performing simulations under different penetration rates of AVs in mixed traffic.

Another area of future research is to investigate the effect of other influencing factors such as HDV-driver's characteristics, subject vehicle characteristics, and external factors on the change in driving behaviour. This can be carried out by developing mixed regression models and analyzing the weightage of different variables that affects driving decisions. The outcomes of this analysis can be used to predict the driving behaviour in a different situation as well as to improve the existing gap acceptance, car-following, and overtaking models.

Furthermore, more data needs to be collected to take into account different driving behaviours, drivers of different characteristics, absence of the driver, different road type and speed limits, different recognizability of automated vehicle, and different environmental conditions such as weather, time of day, visibility, etc. to cover the entire spectrum of behavioural adaptation with AVs. Thus more field test and simulator studies need to be conducted.

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A

Recruitment advertisement

The following advertisement was posted in order to recruit participants for the study.

Do you live in the Netherlands and are you interested to participate in research to understand driving behaviour? Then this might be an interesting opportunity for you!

An experiment is planned at Noordzeeweg (near Maeslantkering) in first half of July to study driving behaviour while interaction with different types of vehicles, wanting your participation.

During the experiment, you will be asked to drive your own private vehicle from point A to B while interacting with other vehicles on road. As a gesture of gratitude for helping us by taking part in this experiment, you will receive a gift voucher of 25 Euros after completing the experiment.

All collected (personal) data will be treated confidentially and anonymized so it cannot be traced back to individual persons. Strict approved measures will be followed considering the COVID-19 situation to ensure the safety of participants.

This study is conducted as a part of an MSc thesis in collaboration with TU Delft and Royal HaskoningDHV.

In case of any questions/comments, please contact: Shubham Soni

B

Recruitment questionnaire

B.1. Introduction

Thank you for your interest to participate in this experiment. Before you decide whether to participate, it is important to understand the context of this research. Please read carefully the information provided below.

This research is a part of a master thesis project co-hosted and funded by the Delft University of Technology (TU Delft) and Royal HaskoningDHV. This experiment has been approved by the Human Research Ethics Committee (HREC) of TU Delft.

The purpose of this study is to understand the driving behavior by studying the interaction between different road users. With your valuable participation, you will help us understand the driving behavior in a better way and will contribute towards making mobility safe and efficient. Participation in this research is voluntary and you are free to withdraw from the study at any point in time.

During the experiment, you will be asked to drive your **own private vehicl**e from point A to B while interacting with other vehicles on the road. After the experiment, you will be requested to fill in a short online questionnaire.

This experiment is planned to be conducted at Noordzeeweg (near Maeslantkering) on 21st, 22nd, and 23rd July 2020 between 09:00 and 17:00. We will ask for your preference of date and time as per your availability. You will receive more detailed information about the experiment in your email id once you submit this form.

As a gesture of gratitude for helping us by taking part in this experiment, you will receive a bol.com gift voucher of 25 Euros after completing the experiment.

In order to take part in this experiment, please make sure that you satisfy these **eligibility criteria**:

1. You own a private vehicle and will be able to arrive with it at the experiment location and use it to take part in this study.
2. You hold a driving license valid in the Netherlands and have a driving experience of at least 5 years.

If you satisfy these eligibility criteria, please proceed with the form below.

This form intends to collect some information about your background, contact details, and the type of vehicle you will drive during the experiment.

It should take no longer than 5 minutes to fill this form and you are free to withdraw at any time.

Confidentiality:- All the data collected in this survey will be kept confidential. All the personal details about you will be anonymized to ensure that you are not personally identifiable in any document or dataset resulting from this study. Your personal details will only be used by the researchers involved in this study to contact you if needed for the requirement of this study.

Safety: Strict approved measures will be followed considering the COVID-19 situation to ensure the safety of participants.A minimum distance of 2 meters will be maintained during the entire process of the experiment. All the equipment used in the study will be sanitized properly using alcohol wipes. You will be advised to stay inside your private vehicle during the experiment. All communication during the experiment will be carried out using a mobile phone. Hand sanitizers will be made available at the experiment location.

Contact: In case you want further information related to the research or if you have any questions/problems, please feel free to contact us. The researchers listed below will respond to your queries.

Shubham Soni	Haneen Farah	Anastasia Tsapi
MSc Student, TU Delft / RHDHV	Assistant Professor, TU Delft	Consultant Sustainable Mobility, RHDHV
s.soni@student.tudelft.nl	h.farah@tudelft.nl	anastasia.tsapi@rhdhv.com

Your interest and participation in this experiment is very much appreciated!

B.2. Questionnaire

1. What is your gender?
   - ☐ Male
   - ☐ Female
   - ☐ Prefer not to say
2. What is your age?
   - ☐ 18 - 24 years
   - ☐ 24 - 35 years
   - ☐ 35 - 45 years
   - ☐ 45 - 60 years
   - ☐ > 60 years
3. What is the highest education that you have completed? (including ongoing education)
   - ☐ No or Primary education
   - ☐ LBO / VMBO (senior or professional) / MBO 1 / VBO
   - ☐ MAVO / HAVO or VWO (first three years) / VMBO (theoretical or mixed) / (M) ULO (Secondary education)
   - ☐ MBO 2, 3, 4 or MBO before 1998 (Senior Secondary education)
   - ☐ HAVO or VWO (4th, 5th or 6th class) / HBS / MMS
   - ☐ HBO (except HBO master) / WO candidates or WO bachelor (Bachelors)
   - ☐ WO doctoral / WO master / HBO master / postgraduate education (PhD, Masters, PostDoc)
   - ☐ Other:
4. What is your employment status?

Employed full-time	Employed part-time
Entrepreneur	Self Employed
Unemployed / Job seeker / Social service	Retired
Full time student (MBO / HBO / WO)	Other:

5. Which of the following best describes the field in which you are currently working?

Science, Technology, and Engineering	Healthcare / medicine	Human Services
Business Management and Administration	Arts and communication	Manufacturing
Agriculture and Natural resources	Education and Training	Information Technology
Law, Public Safety, and Security	Hospitality and tourism	Finance
Marketing, Sales, and Services	Transportation and Distribution	Not working
Government and Public Administration	Architecture and Construction	Other

6. Did you take part in any driving field experiment(s) earlier?

   - ☐ Yes
   - ☐ No

7. As you indicated that you took part in some driving experiment earlier, please give some more details about the experiment(s) you took part in.

8. How many kilometers do you drive approximately per month?

   - ☐ 0-100 kms
   - ☐ 100-500 kms
   - ☐ 500-1000 kms
   - ☐ 1000-2000 kms
   - ☐ 2000-4000 kms
   - ☐ 4000-8000 kms
   - ☐ > 8000 kms

9. How long have you been driving?

5-6 years	8-9 years
6-7 years	9-10 years
7-8 years	10 years

10. Please write the brand and model of the vehicle you will (most probably) use in the field experiment.

11. Is the vehicle that you will use in the experiment equipped with the following systems/technologies?

    - ☐ Forward collision warning (FCW)
    - ☐ Automated Emergency Braking (AEB)
    - ☐ Adaptive Cruise Control (ACC)
    - ☐ Lane keeping assistance (LKA) or Lane departure warning
    - ☐ Self driving technology
    - ☐ None of these

12. Which of the following systems/technologies do you already have driving experience with?

    - ☐ Forward collision warning (FCW)
    - ☐ Automated Emergency Braking (AEB)
    - ☐ Adaptive Cruise Control (ACC)
    - ☐ Lane keeping assistance (LKA) or Lane departure warning
    - ☐ Self driving technology
    - ☐ None of these

13. To which extent do you currently trust these systems/technologies?

Forward collision warning (FCW)	0	1	2	3	4	5
Automated Emergency Braking (AEB)	0	1	2	3	4	5
Adaptive Cruise Control (ACC)	0	1	2	3	4	5
Lane keeping assistance (LKA)	0	1	2	3	4	5
Self driving technology	0	1	2	3	4	5

C

Information sheet and consent form

C.1. Information sheet

Information Sheet

Research title:
A study to understand the driving behaviour during interaction with other road users.

Researchers:
Shubham Soni – MSc Student, TU Delft
Email – s.soni@student.tudelft.nl
Phone - +31 (0) 64 56 14 083

Dr. Ir. Haneen Farah – Assistant Professor, TU Delft
Email – h.farah@tudelft.nl

Ir. Anastasia Tsapi – Consultant Sustainable Mobility, Royal HaskoningDHV
Email – Anastasia.tsapi@rhdhv.com

Introduction:

This information sheet describes the purpose, procedure, potential risks and rewards of this study. If you decide to participate, your consent will be required. Please read this information sheet carefully before signing the consent form. If you desire a hard copy of this information sheet and consent form, you may request one during experiment.

Purpose of study:

The purpose of this study is to understand how drivers interact with other road users. The aim is to understand the change in vehicle control dynamics while interacting with different types of vehicles on the road. You will be asked to drive your own car in our test location Noordzeeweg (near Rozenburg) where you will be asked to drive from point A to B possibly interacting with other vehicles on the road. Any difference in driving behaviour will be assessed based on data collected by the sensors mounted on other vehicles driving on the road. In addition, speed and location of your vehicle will be collected during the experiment. You will be asked to complete a post experiment survey.

Experimental procedure and instructions:

In this experiment, you will be asked to drive your own vehicle in our test location Noordzeewg (near Rozenburg) during daytime where you will interact with different types of vehicles.
This experiment will take 60 minutes of your time (excluding the time required to reach and come back from our test location). Within 60 minutes, you will be asked to drive effectively around 30 minutes in 10 different sessions of 3 minutes each. The remaining time will be used to briefly explain the experiment, take small breaks between different sessions of driving and filling in a post-driving online survey. Driving will take place at Noordzeeweg near Rozenburg. Figure 1 depicts the experiment route with places where the test will start and end.
Exact meeting point is provided in the email with a google map link.

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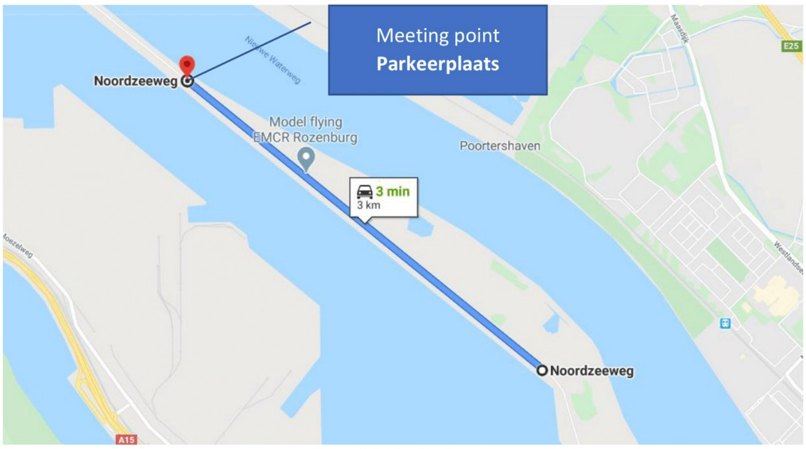


Figure 1: Test route location

Before the start of Experiment

You will be asked to fill in an online survey regarding your driving style before the experiment. The link to this survey questionnaire is included in the enclosed e-mail.

On the day of the experiment, you will be briefed shortly about the experiment where driving rules and other instructions will be made clear to you. You will have chance to clarify any doubts regarding the experiment. You will be provided with a device which can capture the GPS location, speed and acceleration of your vehicle and it will be kept in your car for capturing observations. The experimenter will provide you with the destination till where you need to drive.

As a measure to contain the spread of Coronavirus COVID-19, the experimenters will always keep a minimal distance of 2 meters during the entire process of experiment. Also, the device to collect data will be sanitized properly using alcohol wipes before the start of experiment.

During the Experiment

At the start of experiment, you can expect an approaching vehicle and you will be asked to indicate the last moment when you think it is safe to cross the road. After this, you will receive an indication from the experimenter to start driving. You are expected to drive till the given destination. During the driving, you will be totally free to make your driving decisions. Your main objective during the driving would be to reach your given destination following all traffic rules.

Once you will reach your destination, you will be asked a couple of questions regarding your experience while driving and the experimenter will prepare you for the next session of driving. Similar task will be provided to you in all the sessions of driving.

After the experiment

After 10 sessions of driving and a short rest, you will be provided with a 2 minutes long online questionnaire related to your observations and experiences during the driving. You will have the opportunity to share your experiences to the researcher.

Rewards

As a gesture of gratitude for helping us, you will receive a bol.com gift voucher worth 25 Euros after completing the experiment.

Risks and Discomforts

This experiment constitutes daily risk of driving. As a driver, you are ultimately responsible for the safe operation of your vehicle and your safety.

In case of any discomfort, you always have the freedom to abort the test at any point in time. You can always reach out the experimenter (Shubham Soni) in case of any doubts/clarifications.

Confidentiality

All the data collected in this experiment will be kept confidential. All the personal details about you will be anonymized to ensure that you are not personally identifiable in any document or dataset resulting out of this study. All the data collected during the experiment will be kept secured in the data archives of Royal HaskoningDHV and TU Delft. The data will only be made accessible to the researchers involved in this study. The data will only be used for scientific analysis during the researcher's master's thesis and possible future extensions of the research. The findings from this experiment may be published in scientific journals, research papers or maybe presented in conferences related to traffic safety, traffic flow or driving behaviour. The findings from this research may be used in other studies related to traffic flow, safety or driving behaviour.

Right to refuse and withdraw

Your participation in this study is entirely voluntary. You have the right to refuse or withdraw from this experiment at any time. By agreeing to participate in this study you do not surrender your rights and do not free the researchers, sponsors or institutions involved from legal and professional obligations.
We also emphasise that as the responsible driver, you have the right to take any driving decisions at every point in the experiment.

Questions and Contact

You can contact **Shubham Soni** (see top for contact details) in case of any questions / doubts / clarifications regarding the study or your rights as a research participant.

Dated: 17 July 2020

C.2. Consent form

Royal HaskoningDHV Enhancing Society Together

TU Delft

Consent Form for research on interaction between vehicles

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated 17 July 2020, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves 1. Driving a car on designated test location. 2. Filling out online surveys before and after the experiment that will include some personal information along with questions related to driving style and experiences during the experiment.	○	○
Risks associated with participating in the study		
I understand that taking part in the study involves the general risks of daily driving.	○	○
Use of the information in the study		
I understand that information I provide will be used in reports, scientific publications or may be presented in conferences on Traffic Safety.	○	○
I understand that personal information collected about me that can identify me, such as my name, address or contact details, will not be shared to anyone beyond the study team.	○	○
I agree that my answers in survey questionnaire can be quoted in research outputs with anonymity.	○	○
Future use and reuse of the information by others		
I give permission that all the data collected during the experiment and survey questionnaires filled by me can be archived anonymously in the repository of Royal HaskoningDHV and TU Delft so it can be used for future research and learning.	○	○

Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Shubham Soni ______________________ ________

Researcher Signature Date

In case of any doubts/clarifications, please contact:

Shubham Soni, *+31 645614083, s.soni@student.tudelft.nl*

D

MDSI driving style questionnaire

Dear Participant,

We would be grateful if you can spare a few minutes of your time to answer this short questionnaire seriously and honestly. The questionnaire is anonymous, and your answers will be used for research purposes only.

As this study is related to driving behavior, the following is a list of statements concerning how people drive and it will help us to gain some insights about your driving style. **Please read each statement carefully and indicate, on the following 6-point scale, to what extent the statement describes you.**

Rate your answers by the following scale:

1- not at all, 2 - very little, 3 - little, 4 - moderate, 5 - much, 6- very much							
1.	I often do relaxing activities while driving	1	2	3	4	5	6
2.	I often purposely tailgate other drivers	1	2	3	4	5	6
3.	I often blow my horn or 'flash' the car in front as a way of expressing my frustration.	1	2	3	4	5	6
4.	I feel I have control over driving	1	2	3	4	5	6
5.	I often drive through traffic lights that have just turned red.	1	2	3	4	5	6
6.	I usually enjoy driving on the edge	1	2	3	4	5	6
7.	On a clear freeway, I usually drive at or a little below the speed limit	1	2	3	4	5	6
8.	While driving I try to relax myself	1	2	3	4	5	6
9.	When I am in a traffic jam and the lane next to mine starts to move, I try to move into that lane as soon as possible	1	2	3	4	5	6
10.	Driving usually makes me feel frustrated	1	2	3	4	5	6
11.	I often daydream to pass the time while driving	1	2	3	4	5	6
12.	I often swear at other drivers	1	2	3	4	5	6
13.	When a traffic light turns green and the car in front of me doesn't get going, I just wait for a while until it moves	1	2	3	4	5	6
14.	I drive cautiously	1	2	3	4	5	6
15.	Sometimes lost in thought or distracted, I fail to notice someone waiting at a zebra crossing/pedestrian	1	2	3	4	5	6
16.	In a traffic jam, I think about ways to get through the traffic faster	1	2	3	4	5	6
17.	When a traffic light turns green and the car in front of me doesn't get going immediately, I try to urge the driver to move on	1	2	3	4	5	6
18.	At an intersection where I have to give right-of-way to oncoming traffic, I simply wait patiently for cross-traffic to pass	1	2	3	4	5	6
19.	When someone tries to skirt in front of me on the road I drive in an assertive way in order to prevent it	1	2	3	4	5	6

20.	I often fix my hair and/or makeup while driving	1	2	3	4	5	6
21.	I am often distracted or preoccupied, and suddenly realize that the vehicle ahead has slowed down, and I have to slam on the brakes to avoid a collision	1	2	3	4	5	6
22.	I like to take risks while driving	1	2	3	4	5	6
23.	I base my behavior on the motto "better safe than sorry"	1	2	3	4	5	6
24.	I like the thrill of flirting with death and disaster	1	2	3	4	5	6
25.	It worries me when driving in bad weather	1	2	3	4	5	6
26.	I often meditate while driving	1	2	3	4	5	6
27.	Lost in thoughts I often forget that my lights are on full beam until flashed by another motorist	1	2	3	4	5	6
28.	When someone does something on the road that annoys me, I flash them with the high beams	1	2	3	4	5	6
29.	I get a thrill out of breaking the law	1	2	3	4	5	6
30.	I often misjudge the speed of an oncoming vehicle when passing	1	2	3	4	5	6
31.	I feel nervous while driving	1	2	3	4	5	6
32.	I get impatient during rush hour	1	2	3	4	5	6
33.	I feel distressed while driving	1	2	3	4	5	6
34.	I often intend to switch on the windscreen wipers, but switch on the lights instead, or vice versa	1	2	3	4	5	6
35.	I often attempt to drive away from traffic lights in third gear (or on the neutral mode in automatic car)	1	2	3	4	5	6
36.	I often plan my route badly, so that I hit traffic that I could have avoided	1	2	3	4	5	6
37.	I often use muscle relaxation techniques while driving	1	2	3	4	5	6
38.	I plan long journeys in advance	1	2	3	4	5	6
39.	I often nearly (or actually) hit something due to Misjudging my gap in a parking lot	1	2	3	4	5	6
40.	I feel comfortable while driving	1	2	3	4	5	6
41.	I am always ready to react to unexpected maneuvers by other drivers	1	2	3	4	5	6
42.	I tend to drive cautiously	1	2	3	4	5	6
43.	I often honk my horn at others	1	2	3	4	5	6
44.	I usually enjoy the excitement of dangerous driving	1	2	3	4	5	6

E

Pre experiment briefing

E.1. General information

Dear participant,

Thank you being here and taking part in this experiment.

With your participation, you are helping the scientific community to make mobility safer and more efficient. This text intends to brief you about the experiment and will inform you about your first steps. So, please read this document carefully.

About Experiment

You are taking part in a study whose aim is to understand the driving behaviour during interaction with other road users. This means that you can expect to drive in different scenarios and interact with different type of vehicles during the experiment.

Time required

This experiment will take 60 minutes to complete. There will be a total of 10 iterations where you will be asked to drive from a point A to point B which is around 2 km apart from each other (see attached map E.2). Each run of the experiment will take 3 minutes and thus overall driving time would be 30 minutes. Rest of time will be utilised in taking short breaks and filling out questionnaire.

Preparations for the test

Once you finish reading this document, our team member will help you with preparations required for this test.

GPS module: Researcher will place a GPS module in your car to collect speed and location of your car.

Phone: You can request a speaker phone in your car. This phone will be connected with the researcher during driving. You can use this phone to communicate with researchers at any point during the experiment. Also, you are asked to communicate anything you feel or observe while driving during the experiment. However, the call will not be recorded.

You can also use your mobile phone if it's convenient.

Risks

This experiment constitutes daily risk of driving. As a driver, you are ultimately responsible for the safe operation of your vehicle and your safety. Please keep a eye on other traffic and drive responsibly.

Safety

For your safety, we have already sanitized the equipment. However, you can also use the alcohol wipes to clean it and sanitizers to clean your hand. You can find these items with the team members.

What you need to do?

Once these preparations are done, you are ready to start the experiment.

Please do not use any systems in the car. Drive manually.

E.2. Experiment steps

For the experiment, imagine a situation

"You are returning back from your friend's place. You made a stop at supermarket to pick some groceries. Now you are starting from the parking lot of supermarket and will drive to parking lot near your home which is 2 km away. There is an approaching vehicle in the main road. You will let the vehicle cross (as main road has priority) and then start driving towards your home."

Our team member will indicate the moment when experiment begins by showing a hand gesture (thumbs up). After indication by researcher, you will notice an approaching white vehicle.

This vehicle will either be driven manually or will be driven in a self-driving mode. Vehicle driving in self driving mode can be identified by black LiDAR on top and sticker on the left side of the vehicle as shown in picture E.1.

Figure E.1: Vehicle driven manually (left) and vehicle driving in self-driving mode (right)

When you see an approaching vehicle, please start your engine and raise your left hand up.

When you see this approaching vehicle, observe the vehicle carefully and perform these two tasks.

1. Observe the approaching vehicle and indicate the last moment when you feel safe to cross by lowering your hand. Do not drive before vehicle crosses the junction.
2. Once the vehicle has crossed, you can start driving towards your end point (see map).

The speed limit of the road is 60 kmph. Please try to drive near the speed limit as much as possible. You are free to make any driving decisions during the experiment.

Your ultimate aim is to reach your destination driving near speed limit.

Please keep a eye on other traffic and drive responsibly.

Once you reach point B, you will be asked to fill a questionnaire regarding last run and prepare for similar next run. Similar driving will be repeated 10 times.

End of Experiment

At the end of experiment, you will return the instruments. After that you will be provided with a small post-experiment questionnaire and a researcher will ask you a couple of questions regarding the experiment.

At this point, you have successfully completed the experiment.

You will receive a bol.com gift voucher of 25 Euros after completing experiment.

E.3. Location map

Figure E.2: Location of point A and point B

F

During experiment questionnaire

During experiment questionnaire

Full name: ____

On a scale of 1-10, How stressful was your driving experience in this run?

1 = No stress **10 = Very high stress**

Run 1	1	2	3	4	5	6	7	8	9	10
Run 2	1	2	3	4	5	6	7	8	9	10
Run 3	1	2	3	4	5	6	7	8	9	10
Run 4	1	2	3	4	5	6	7	8	9	10
Run 5	1	2	3	4	5	6	7	8	9	10
Run 6	1	2	3	4	5	6	7	8	9	10
Run 7	1	2	3	4	5	6	7	8	9	10
Run 8	1	2	3	4	5	6	7	8	9	10
Run 9	1	2	3	4	5	6	7	8	9	10
Run 10	1	2	3	4	5	6	7	8	9	10

On a scale of 1-10, What was your level of trust with the interacting vehicle in this run?

1 = No trust **10 = Full trust**

Run 1	1	2	3	4	5	6	7	8	9	10
Run 2	1	2	3	4	5	6	7	8	9	10
Run 3	1	2	3	4	5	6	7	8	9	10
Run 4	1	2	3	4	5	6	7	8	9	10
Run 5	1	2	3	4	5	6	7	8	9	10
Run 6	1	2	3	4	5	6	7	8	9	10
Run 7	1	2	3	4	5	6	7	8	9	10
Run 8	1	2	3	4	5	6	7	8	9	10
Run 9	1	2	3	4	5	6	7	8	9	10
Run 10	1	2	3	4	5	6	7	8	9	10

G

Field test scenarios

G.1. Type of interacting vehicle

Table G.1: Different interacting vehicle scenarios during the field test

Run -> participant	**Run 1**	**Run 2**	**Run 3**	**Run 4**	**Run 5**	**Run 6**	**Run 7**	**Run 8**	**Run 9**	**Run 10**
1	HDV	AV	HDV	AV (P)	HDV	HDV				
2	HDV	AV	AV	HDV	AV	AV (N)	HDV	AV (N)	HDV	AV (N)
3	HDV	HDV	AV	AV	HDV	AV	AV (P)	HDV	AV (P)	AV (P)
4	HDV	AV	HDV	AV	HDV	AV	AV (N)	AV (N)	AV (N)	HDV
5	HDV	AV	HDV	AV	HDV	AV	HDV			
6	HDV	AV	AV	HDV	AV	AV (P)	AV (P)	HDV	HDV	AV (P)
7	HDV	AV	AV	HDV	AV	AV	HDV	AV (P)	AV (P)	AV (P)
8	HDV	AV	HDV	AV	HDV	HDV	AV	AV (N)	AV (N)	AV (N)
9	HDV	AV	HDV	AV	HDV	AV	AV (P)	AV (P)	AV (P)	HDV
10	HDV	HDV	AV	AV	HDV	AV	AV (N)	HDV	AV (N)	AV (N)
11	HDV	AV	HDV	AV	AV	AV (N)	HDV	AV (N)	HDV	AV (N)
12	HDV	AV	AV	HDV	AV	AV (P)	AV (P)	HDV	HDV	AV (P)
13	HDV	AV	HDV	AV	HDV	AV	AV (N)	AV (N)	AV (N)	HDV
14	HDV	HDV	AV	AV	HDV	AV	AV (P)	HDV	AV (P)	AV (P)
15	HDV	AV	AV	HDV	AV	AV (N)	HDV	AV (N)	HDV	AV (N)
16	HDV	AV	HDV	AV	AV	AV (P)	HDV	AV (P)	HDV	AV (P)
17	HDV	AV	HDV	AV	HDV	AV	HDV	AV (N)	AV (N)	AV (N)
18	HDV	AV	HDV	AV	HDV	HDV	AV	AV (P)	AV (P)	AV (P)

Legend:	
HDV	Human driven vehicle scenario
AV	Automated vehicle scenario - Without information
AV (P)	Automated vehicle scenario - With positive information
AV (N)	Automated vehicle scenario - With negative information

G.2. Slow down points for test vehicle

During each run of the experiment, test vehicle was slowed down to encourage overtaking at a certain slow down point as illustrated in figure 4.3.

Table G.2: Slow-down point scenarios for the test vehicle

Run -> participant	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
1	SP1	SP1	SP2	SP1	SP1	SP1				
2	SP1	SP2	SP3	SP3	SP3	SP2	SP2	SP1	SP1	SP2
3	SP1	SP2	SP1	SP1	SP1	SP2	SP3	SP2	SP3	SP3
4	SP1	SP1	SP2	SP2	SP1	SP1	SP2	SP1	SP1	SP1
5	SP1	SP1	SP2	SP3	SP2	SP3	SP1			
6	SP1	SP2	SP3	SP1	SP2	SP2	SP1	SP1	SP2	SP3
7	SP1	SP2	SP3	SP3	SP3	SP2	SP2	SP1	SP1	SP2
8	SP1	SP1	SP2	SP1	SP1	SP1	SP2	SP3	SP2	SP1
9	SP1	SP1	SP2	SP2	SP1	SP1	SP2	SP1	SP1	SP1
10	SP1	SP2	SP1	SP1	SP1	SP2	SP3	SP2	SP3	SP3
11	SP1	SP2	SP1	SP1	SP2	SP3	SP3	SP2	SP3	SP2
12	SP1	SP2	SP3	SP1	SP2	SP2	SP1	SP1	SP2	SP3
13	SP1	SP1	SP2	SP2	SP1	SP1	SP2	SP1	SP1	SP1
14	SP1	SP2	SP1	SP1	SP1	SP2	SP3	SP2	SP3	SP3
15	SP1	SP2	SP3	SP3	SP3	SP2	SP2	SP1	SP1	SP2
16	SP1	SP2	SP1	SP1	SP2	SP3	SP3	SP2	SP3	SP2
17	SP1	SP1	SP2	SP3	SP2	SP3	SP1	SP2	SP3	SP1
18	SP1	SP1	SP2	SP1	SP1	SP1	SP2	SP3	SP2	SP1

H

Post experiment survey

H.1. Post-experiment questionnaire

Dear participant,

Thanks for taking part in this experiment. You have now successfully completed this experiment. Please answer a few last questions.

1. What is your current level of trust regarding these systems/technologies?

Technology / rating	**0**	**1**	**2**	**3**	**4**	**5**
Forward collision warning (FCW)						
Automated Emergency Braking (AEB)						
Adaptive Cruise Control (ACC)						
Lane keeping assistance (LKA) or Lane departure warning						
Self-driving technology						

2. Did you find interacting with self-driving vehicle more stressful in comparison to a normal vehicle?

   ☐ Yes

   ☐ No

3. If your answer to question 2 is Yes, please rate your level of stress during following manoeuvres while interacting with self-driving vehicle on a scale of 1-10.

   1 - Least stressful, 10 - Most stressful

Indicating last moment safe to cross.	1	2	3	4	5	6	7	8	9	10
Following self-driving vehicle.	1	2	3	4	5	6	7	8	9	10
Overtaking self-driving vehicle.	1	2	3	4	5	6	7	8	9	10
Driving in front of self-driving vehicle.	1	2	3	4	5	6	7	8	9	10

4. Do you think that your driving behaviour was different when you interacted with a self-driving vehicle in comparison to interaction with a normal vehicle?

   ☐ Yes

   ☐ No

5. Do you think that there was a difference in driving style of the vehicle - normal vs self-driving?

- ☐ Yes
- ☐ No

6. Do you think there is a change in your trust / opinion regarding self-driving vehicles after this experiment?
   - ☐ I trust self-driving technology more now
   - ☐ I trust self-driving technology less now
   - ☐ No change in opinion or trust

H.2. Interview questions

1. Why do you think that you did (did not) change your driving behaviour when you interacted with self-driving vehicle?
2. Did you notice or feel anything strange during the entire experiment?
3. What made you change (or not change) your opinion/trust towards self-driving vehicles?
4. Do you think if information affected your driving behaviour?
5. Were you expecting the test vehicle to slow down after few runs?
6. Was it easy to differentiate between human driven and automated vehicle?
7. Did you observe any difference in driving style of AV in comparison to HDV?
8. What was your overall experience during the experiment?

I

Post experiment debriefing

Thanks for taking part in this experiment. Before the experiment, you have been provided with information regarding the purpose and nature of the study along with some information regarding the experiment. However, some information was kept away from you in order to minimise any change in your driving behaviour.

First, it might be interesting for you to know that the automated vehicle you were interacting with was not a self-driving vehicle, but it was driven manually and safely by a professional driver. This ensured that there is no difference in driving style between human driven and self-driving vehicle.

Second, the real purpose of this study is to understand the behavioural adaptation of the human drivers when they interact with automated (self-driving) vehicles. We are focussing on car following, overtaking and crossing at intersection manoeuvres. The reason behind not providing this information earlier are as follows:

- **To make experiment more realistic**. In real world traffic, appearance of automated vehicle will not be expected in advance, but they will appear suddenly in road and thus all the driving decisions will have to be taken instantly while driving.
- **Trust and opinion management**. If it was informed in advance that this experiment involves interaction with an automated vehicle, some of the participants might have done some research before experiment to get more information regarding self-driving cars and thus might have formed an opinion about them. This change in opinion might alter trust and thus may lead to a different driving behaviour while interacting with automated vehicle.
- **To study learning effect**. In this experiment, we want to study how drivers adapt their driving behaviour upon multiple interactions with automated vehicles. This can be done by observing how you interact with a self-driving vehicle in first interaction and compare it with your interactions in different run. Thus, it was important that all participants are on same page and do not form any opinion regarding automated vehicles in advance.

We would like to give our heartful thanks for your cooperation and taking part in this study. Your contribution will help the scientific community in understanding human driving behaviour in a better way and thus will contribute towards making the future mobility safe and efficient.

In case you have any questions, please contact

Shubham Soni – MSc Student, TU Delft

Email – s.soni@student.tudelft.nl

Have a nice day and stay safe.

J

K-means clustering for 3 clusters

J.1. Identification of number of clusters

In order to identify the number of clusters of participants with significant differences in their driving style, two methods were used.

First, a dendrogram was plotted which gave insights about the main branches in hierarchy of participants based on their driving style. The plotted dendrogram indicated presence of 3 cluster of participants with major differences in driving style (dotted lines intersects major groups in figure J.1). Second, elbow method was used to identify the number of optimal clusters. The elbow method calculated the distortion (or loss) in measurements with respect to number of cluster. Figure J.2 shows the plot of distortion with number of clusters. It can be seen that change in distortion decreases when number of clusters goes higher than 3.

Both dendrogram and elbow method indicated that the participants can be divided into three groups with significantly different driving styles. Thus, K-means clustering was performed to identify the real differences in driving style between three groups of participants.

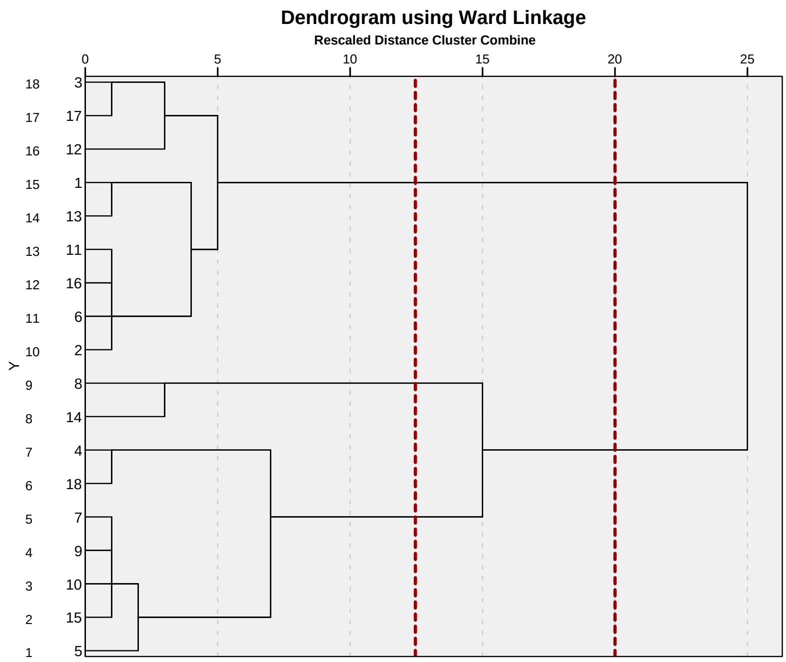


Figure J.1: A dendrogram plot using ward's linkage

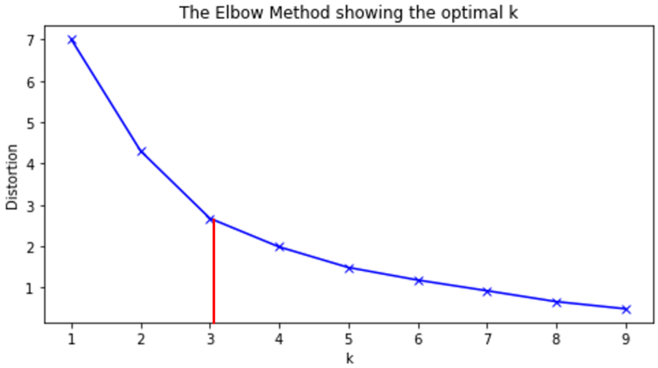


Figure J.2: Determination of optimal number of clusters using elbow method

J.2. K-means clustering for 3 clusters of participants

As the optimal number of cluster was found to be three, K-means clustering was performed to divide participants into 3 groups. Figure J.3 shows the bar plot of mean MDSI factors of different driving styles within each cluster of participants. From the plot, it can be seen that cluster 1 participants more tends towards "Reckless and careless" driving style, cluster 2 participants tends towards "Angry" driving style whereas cluster 3 participants tends towards "Patient and careful" driving style.

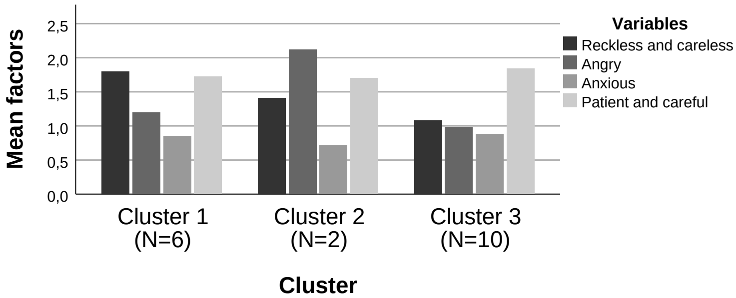


Figure J.3: Mean MDSI-factors for different driving styles in different clusters

Table J.1 presents the ANOVA test results between different driving styles. It can be seen that MDSI factors of "Reckless and careless" and "Angry" have significant differences between different clusters. However, no significant difference was found between factors in "Anxious" and "Patient and careful" driving styles.

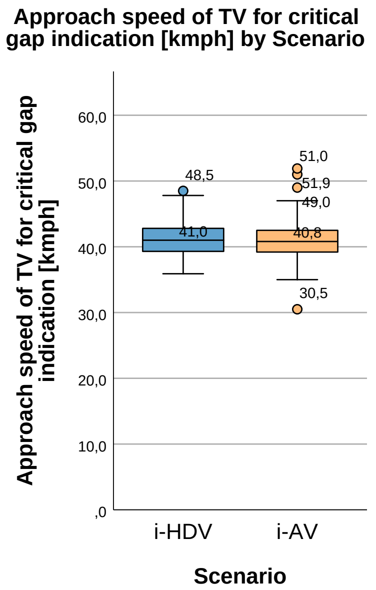
Table J.1: ANOVA table for K mean clustering in 3 groups

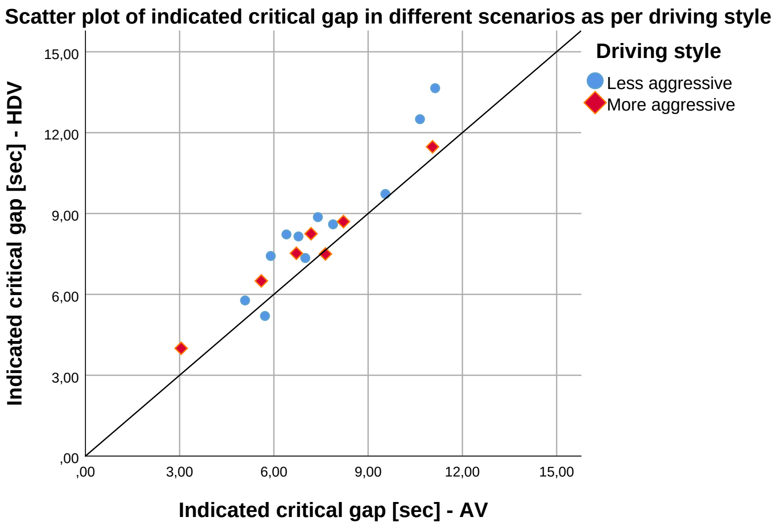
ANOVA | K means | 3 clusters						
	Cluster		**Error**			
Driving style	**Mean Square**	**df**	**Mean Square**	**df**	**F**	**Sig.**
Reckless and careless *	0.959	2	0.050	15	19.157	**0.000**
Angry *	1.077	2	0.040	15	26.866	**0.000**
Anxious	0.023	2	0.016	15	1.392	0.279
Patient and careful	0.033	2	0.082	15	0.409	0.672
* Significant (p<0.05)						

Since cluster 2 contains only two participants, lack of sample size will not lead to any significant results. Also, it can be seen that cluster 1 and cluster 2 have similar mean factor for "Reckless and careless" driving style, indicating similarity between these two groups. Due to these reasons, clustering in three groups is not desirable.

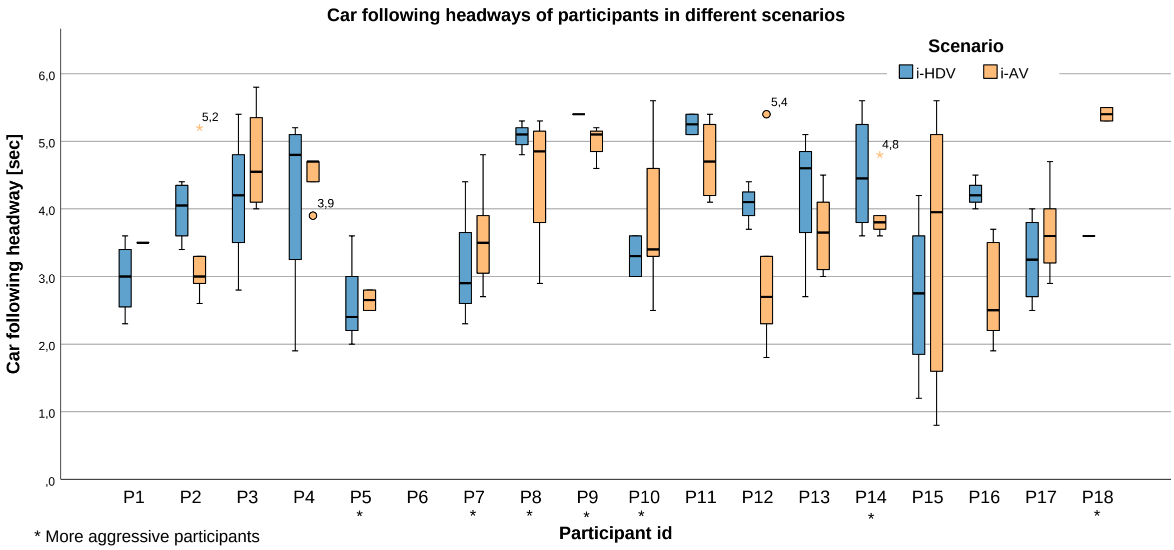
K

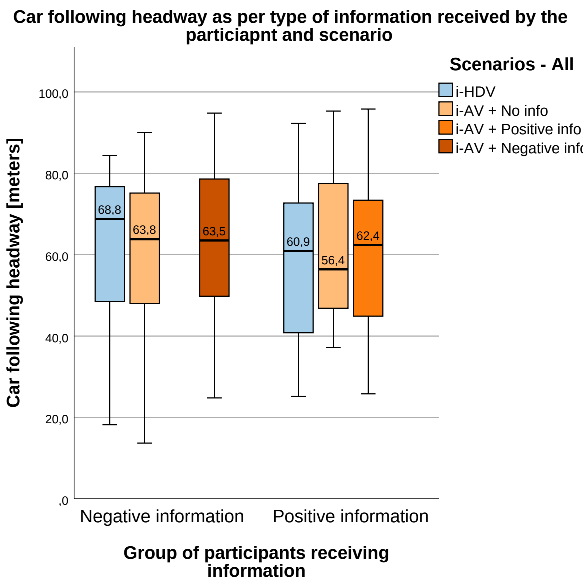
Gap acceptance descriptives





L
Car following descriptives

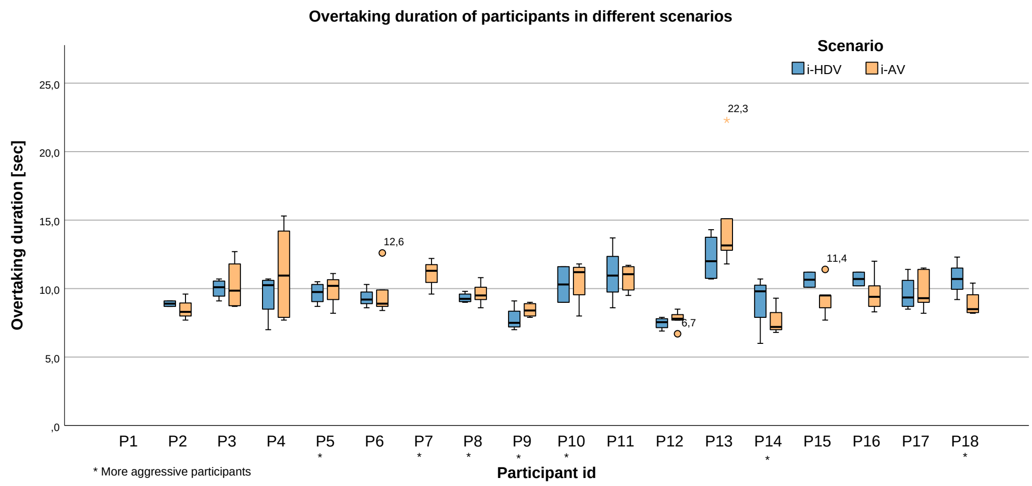


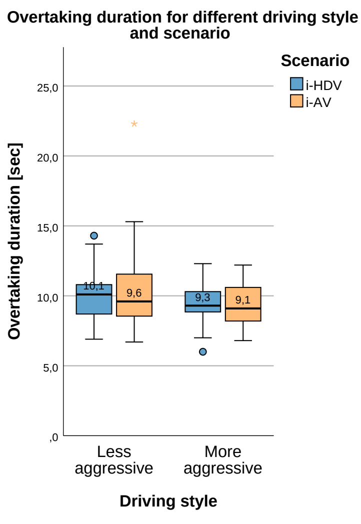


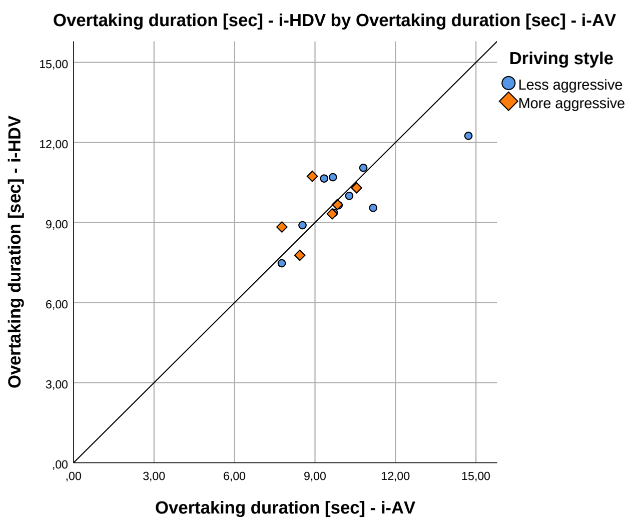
M

Overtaking descriptives

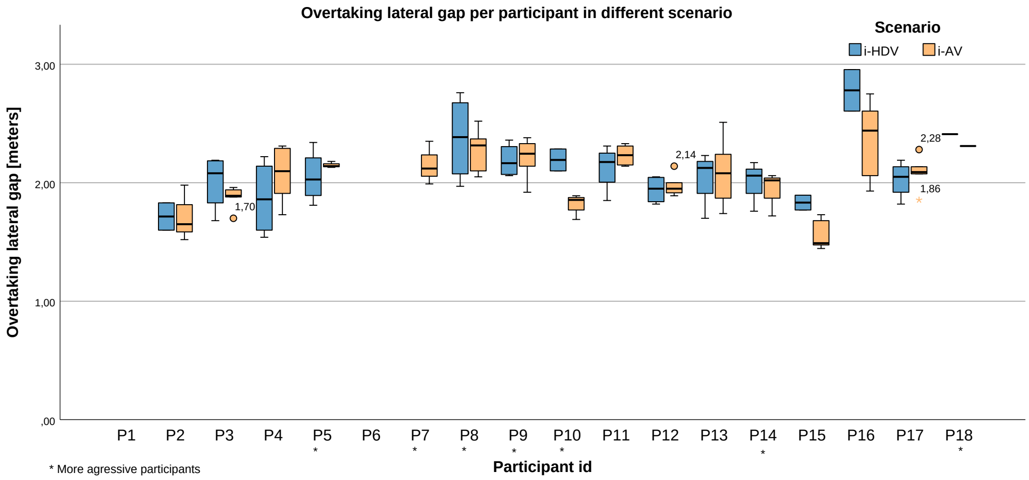
M.1. Overtaking duration

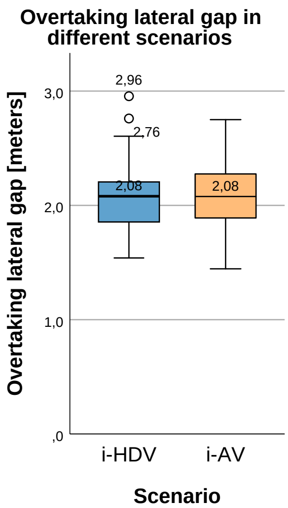


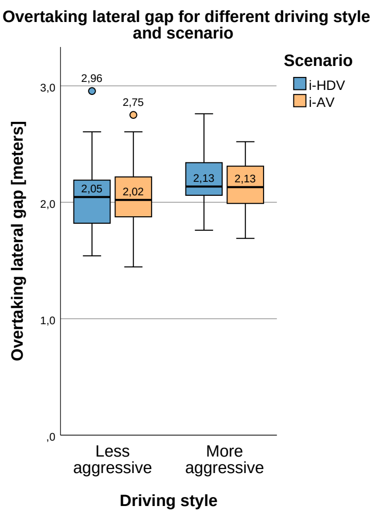


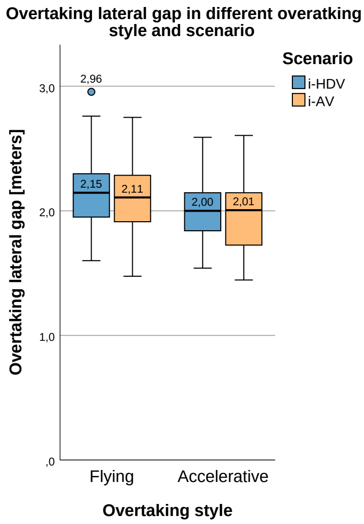


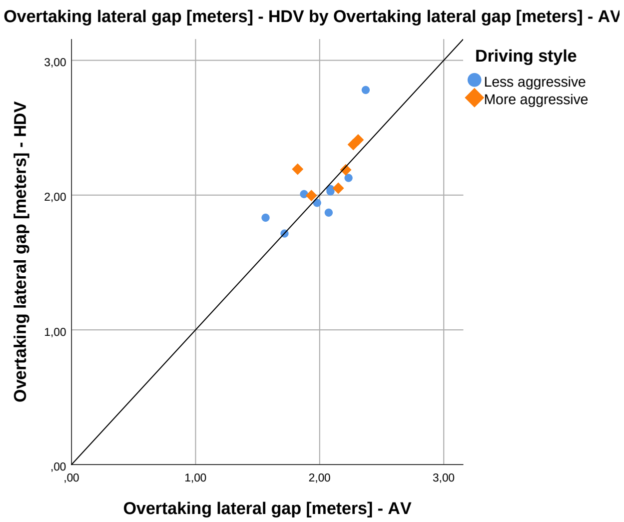
M.2. Overtaking lateral gap

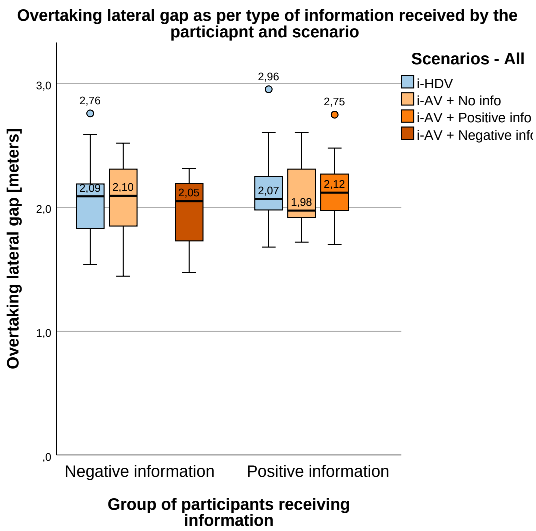




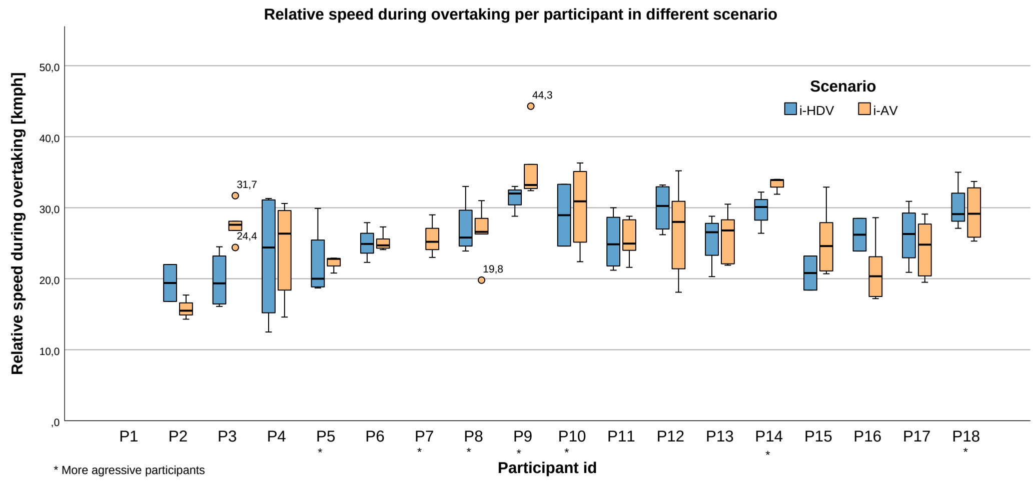


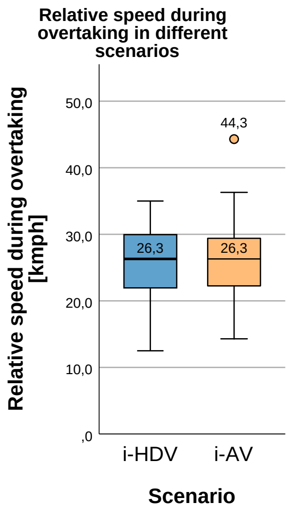


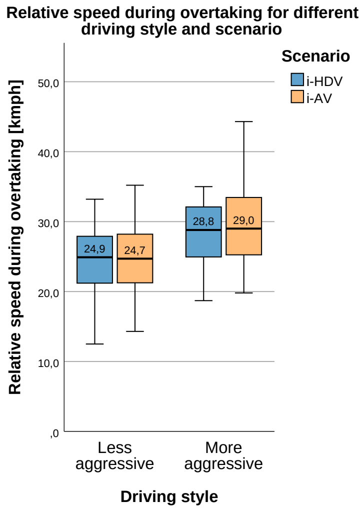


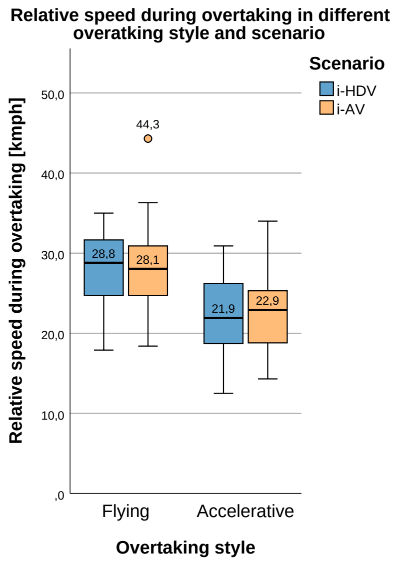


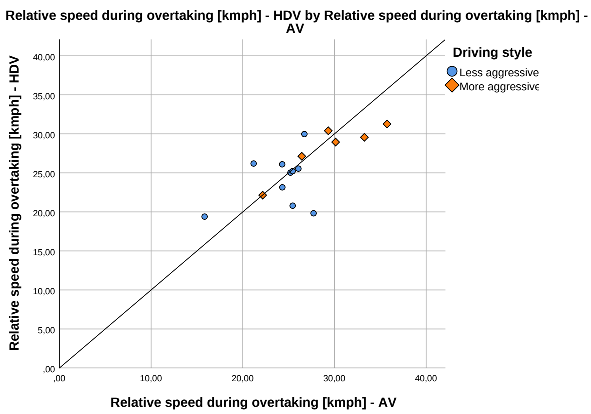
M.3. Relative speed during overtaking

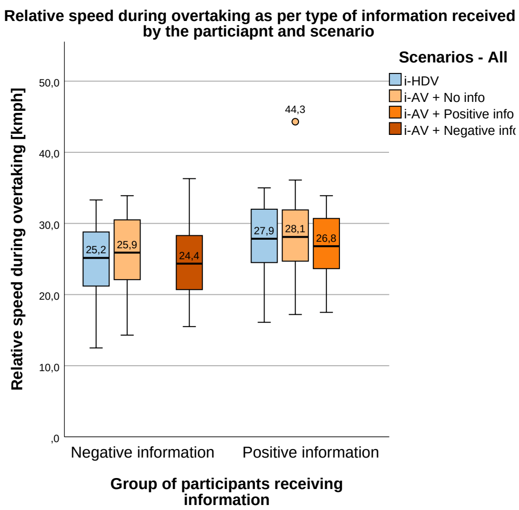




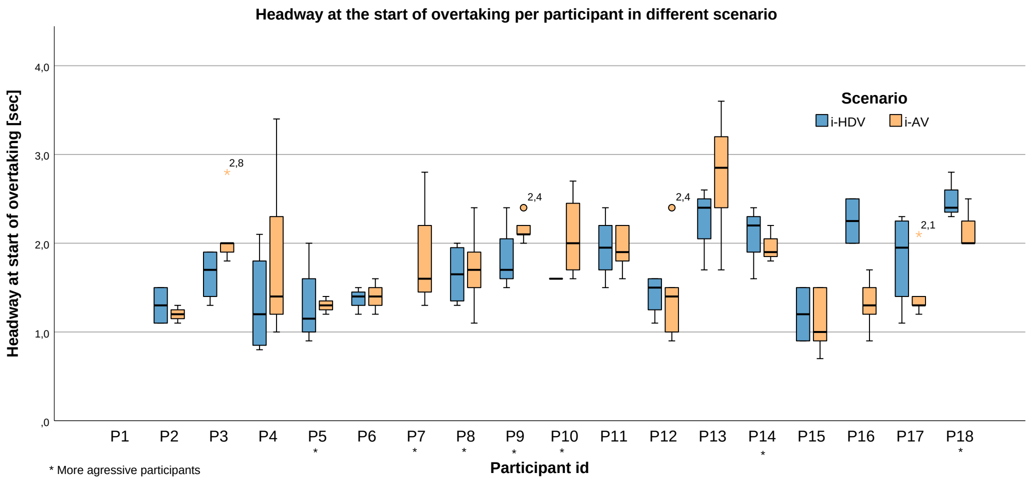


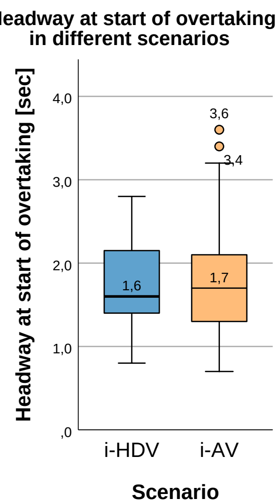


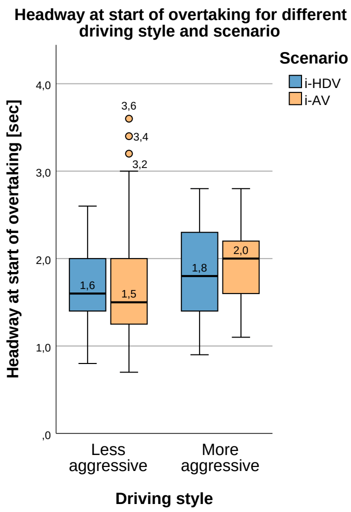


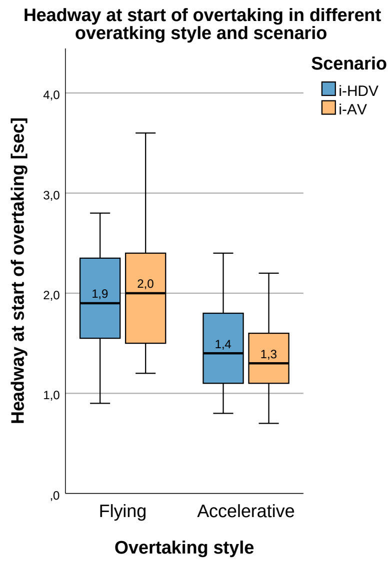


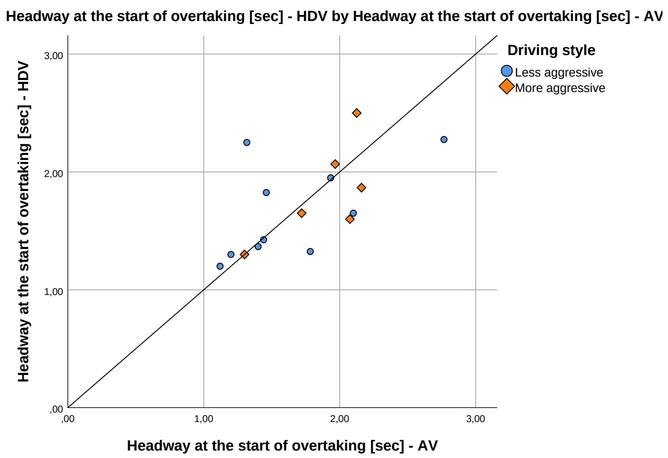
M.4. Headway at start of overtaking

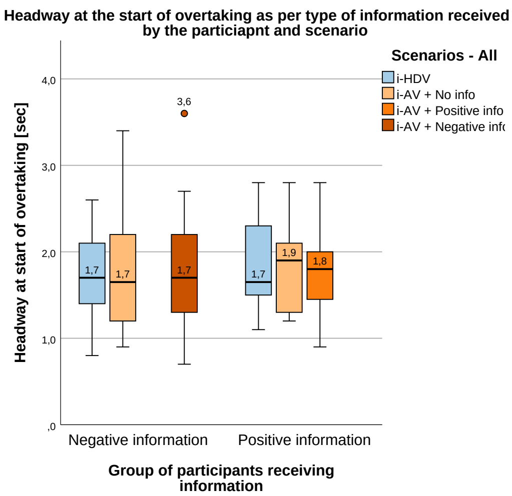




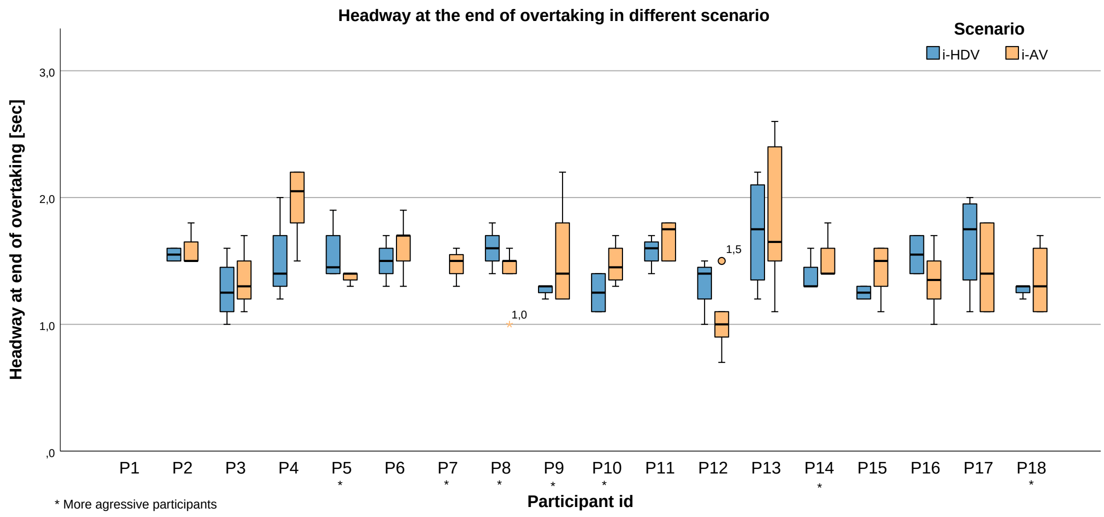


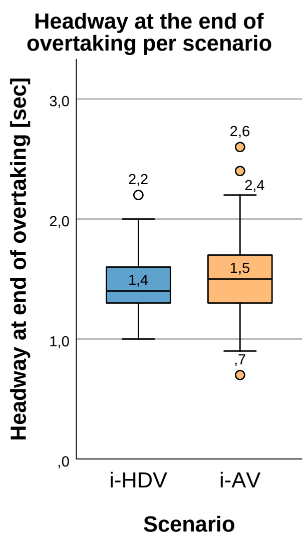


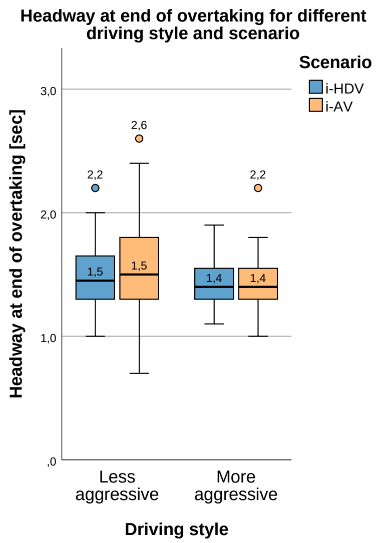


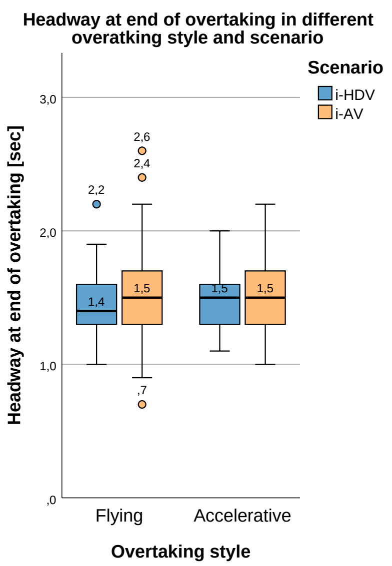


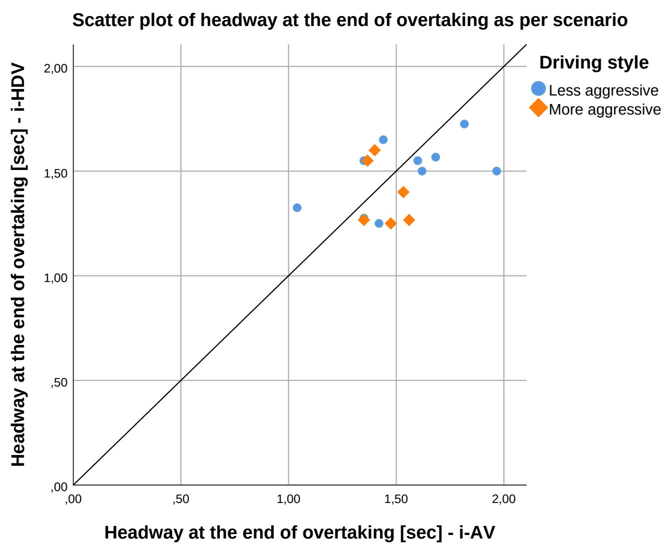
M.5. Headway at end of overtaking











N

Effect of scenario [H1]

Table N.1: Effect of scenario - Wilcoxon Signed Ranks test statistics: As per driving style

Test Statistics (a)					
Driving style	**Indicator**	**Scenario 1**	**Scenario 2**	**Z**	**Asymp. Sig. (2-tailed)**
Less aggressive	**Mean relative speed during overtaking [kmph]**	AV	HDV	-,051 (b)	0,959
More aggressive	**Mean relative speed during overtaking [kmph]**	AV	HDV	-1,153 (b)	0,249
a. Wilcoxon Signed Ranks Test					
b. Based on negative ranks.					

Table N.2: Effect of scenario - Wilcoxon Signed Ranks test statistics: As per overtaking style

Test Statistics(a)					
Overtaking style	**Indicator**	**Scenario 1**	**Scenario 2**	**Z**	**Asymp. Sig. (2-tailed)**
Accelerative	**Mean overtaking duration [sec]**	i-AV	i-HDV	-1,413 (b)	0,158
Flying	**Mean overtaking duration [sec]**	i-AV	i-HDV	-1,277 (c)	0,201
a. Wilcoxon Signed Ranks Test					
b. Based on positive ranks.					
c. Based on negative ranks.					

Table N.3: Effect of scenario on stress and trust (as per driving style): Chi-Square test

Chi-Square Tests							
Driving style	**Indicator**	**Scenario 1**	**Scenario 2**	**Pearson Chi-Square**	**df**	**Asymp. Sig. (2-tailed)**	**N of valid cases**
Less aggressive	**Stress during interaction with TV**	AV	HDV	4,060	5	,541	106
	Trust on interacting TV	AV	HDV	9,743	6	,136	105
More aggressive	**Stress during interaction with TV**	AV	HDV	4,376	4	,358	67
	Trust on interacting TV	AV	HDV	9,802	8	,279	67

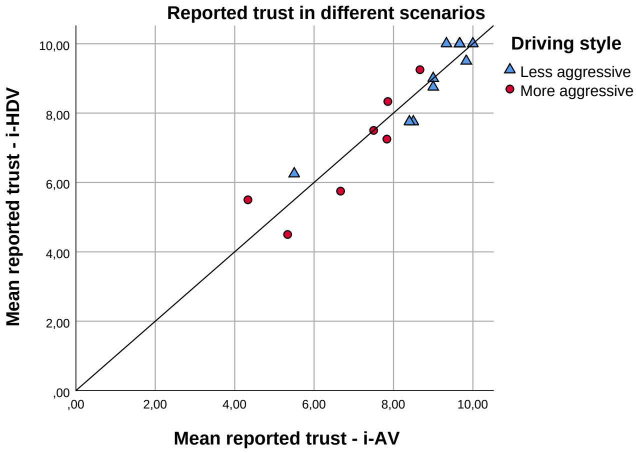


Figure N.1: Scatter plot of reported trust on TV in different scenarios

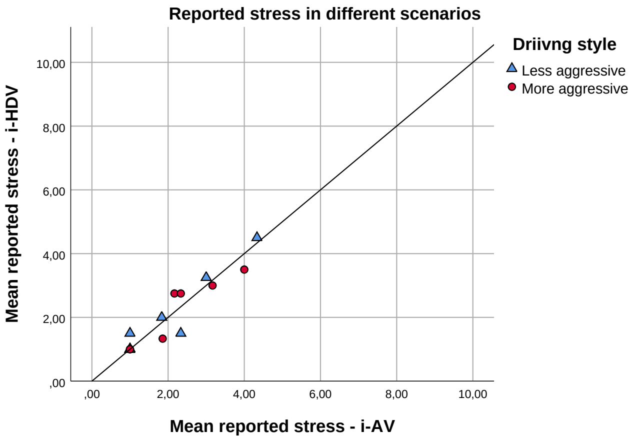


Figure N.2: Scatter plot of reported stress during interaction with TV in different scenarios

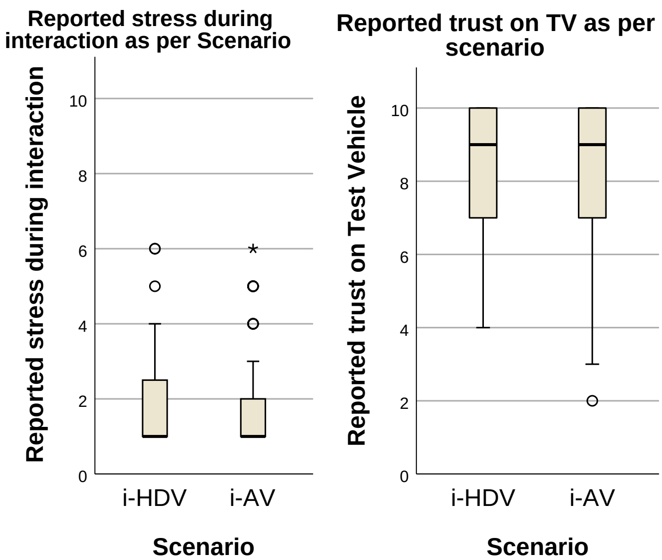


Figure N.3: Box plots of reported stress (left) and trust (right) in different scenarios

O

Effect of provided information regarding AVs (H2 & H3)

Table O.1: Independent-Samples Kruskal-Wallis Test Summary within positive and negative information groups

	Independent-Samples Kruskal-Wallis Test Summary								
		Positive information (H3)				Negative information (H4)			
Driving behaviour	**Indicator**	**Total N**	**Test Statistic**	**df**	**Sig. (2-tailed)**	**Total N**	**Test Statistic**	**df**	**Sig. (2-tailed)**
Gap acceptance	**Mean critical gap**	27	1,961 (a,b)	2	0.375	24	2,525 (a,b)	2	0.283
Car following	**Mean car following headway**	22	,233 (a,b)	2	0.890	24	,016 (a,b)	2	0.992
Overtaking	**Mean overtaking duration**	22	,182 (a,b)	2	0.913	24	1,025 (a,b)	2	0.599
	Mean overtaking lateral gap	18	,363 (a,b)	2	0.834	24	,020 (a,b)	2	0.990
	Mean relative speed during overtaking	22	,621 (a,b)	2	0.733	24	,454 (a,b)	2	0.797
	Mean headway at start of overtaking	22	,386 (a,b)	2	0.824	24	,167 (a,b)	2	0.920
	Mean headway at end of overtaking	22	4,488 (a,b)	2	0.106	24	5,882 (a,b)	2	0.053
a. The test statistic is adjusted for ties.									
b. Multiple comparisons are not performed because the overall test does not show significant differences across samples.									

Table O.2: Wilcoxon signed ranks test summary for comparison between scenario without and with information

Test Statistics(a)				
Indicator	**Scenario 1**	**Scenario 2**	**Z**	**Asymp. Sig. (2-tailed)**
Mean critical gap [sec]	Positve information	No information	-1,836 (b)	0.066
Mean relative speed during overtaking [kmph]	Positve information	No information	-,676 (b)	0.499
Mean overtaking duration [sec]	Negative information	No information	-1,820 (c)	0.069
a. Wilcoxon Signed Ranks Test				
b. Based on positive ranks.				
c. Based on negative ranks.				

Table O.3: Wilcoxon signed ranks test summary for comparison between scenario without and with information (between different driving styles)

Test Statistics (a)						
			Less aggressive		**More aggressive**	
Indicator	**Scenario 1**	**Scenario 2**	**Z**	**Asymp. Sig. (2-tailed)**	**Z**	**Asymp. Sig. (2-tailed)**
Mean critical gap [sec]	Positve information	No information	-1,521 (b)	0.128	-1,342 (b)	0.180
Mean relative speed during overtaking [kmph]	Positve information	No information	-,405 (b)	0.686	-,447 (b)	0.655
Mean overtaking duration [sec]	Negative information	No information	-1,826 (c)	0.068	-,365 (c)	0.715
a. Wilcoxon Signed Ranks Test						
b. Based on positive ranks.						
c. Based on negative ranks.						

P

Learning effect over multiple interactions with AVs (H4)

Table P.1: Correlation of driving behavior indicators with number of interactions with AV

Correlations				
		AV interaction number		
Driving behaviour	**Indicator**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**
Gap acceptance	**Indicated critical gap [sec]**	-0.090	0.379	98
Car following	**Car following headway [sec]**	0.030	0.801	75
Overtaking	**Overtaking duration [sec]**	0.147	0.196	79
	Overtaking lateral gap [meters]	-0.026	0.829	72
	Relative speed during overtaking [kmph]	-0.121	0.289	79
	Time headway at start of overtaking [sec]	-0.032	0.777	79
	Time headway at end of overtaking [sec]	-0.196	0.085	78

Table P.2: Correlations of driving behavior indicators with number of interactions with AV (as per driving style)

Correlations per driving style							
		AV interaction number					
		Less aggressive			More aggressive		
Driving behaviour	**Indicators**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**
Gap acceptance	**Indicated critical gap [sec]**	-0.084	0.527	59	-0.100	0.545	39
Car following	**Car following headway [sec]**	-0.017	0.908	47	0.129	0.512	28
Overtaking	**Overtaking duration [sec]**	0.144	0.314	51	0.232	0.235	28
	Overtaking lateral gap [meters]	0.012	0.935	47	-0.107	0.610	25
	Relative speed during overtaking [kmph]	-0.251	0.073	52	-0.007	0.970	27
	Time headway at start of overtaking [sec]	-0.137	0.331	52	0.209	0.295	27
	Time headway at end of overtaking [sec]	-0.179	0.209	51	-0.239	0.230	27

Table P.3: Correlations of driving behavior indicators with number of interactions with AV (as per provided information)

Correlation per information group of participants								
		AV interaction number						
		Negative information			**Positive information**			
Driving behaviour	**Indicators**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**	
Gap acceptance	**Indicated critical gap [sec]**	-0.024	0.875	47	-0.171	0.245	48	
Car following	**Car following headway [sec]**	0.006	0.972	40	-0.016	0.930	33	
Overtaking	**Overtaking duration [sec]**	0.125	0.442	40	0.200	0.243	36	
	Overtaking lateral gap [meters]	-0.097	0.553	40	0.108	0.578	29	
	Relative speed during overtaking [kmph]	-0.162	0.318	40	-0.162	0.346	36	
	Time headway at start of overtaking [sec]	-0.101	0.533	40	-0.006	0.972	36	
	Time headway at end of overtaking [sec]	-0.214	0.185	40	-0.238	0.169	35	

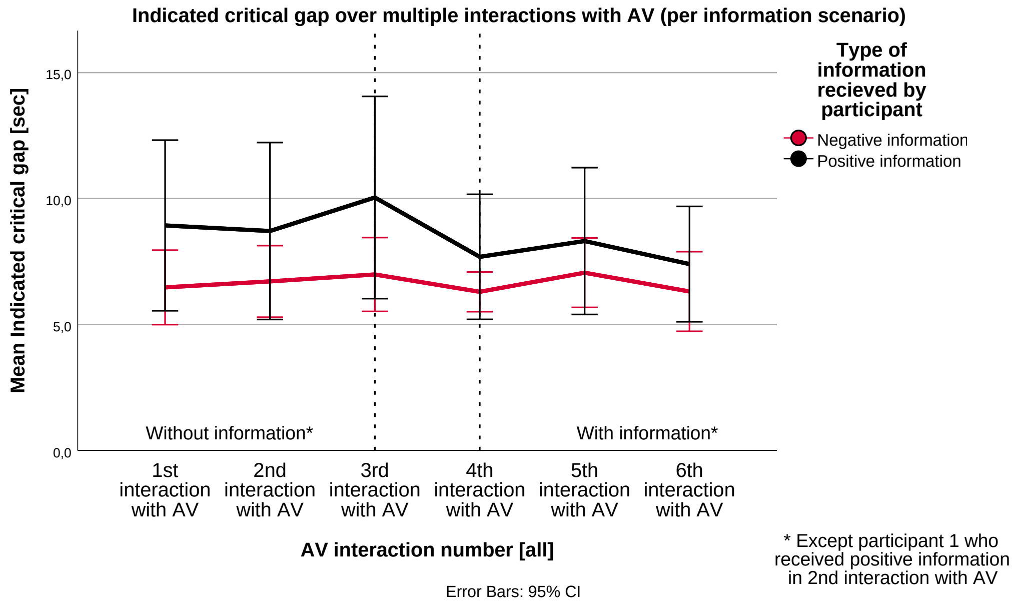


Figure P.1: Indicated critical gap over multiple interactions with AV (per information scenario)

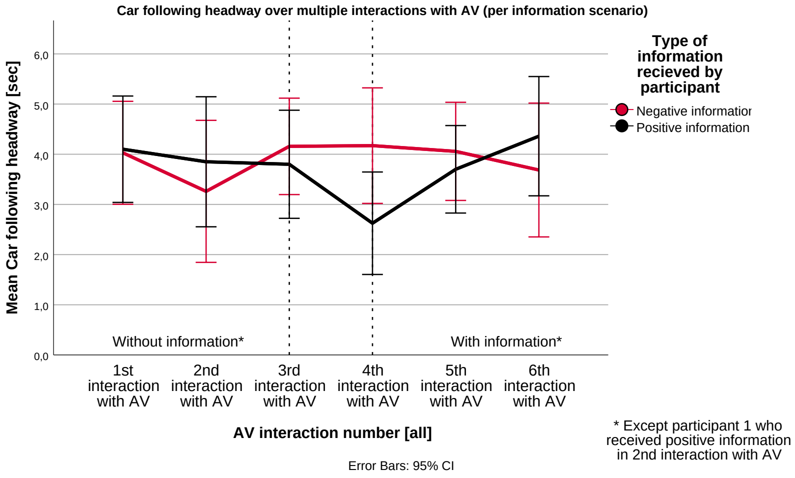


Figure P.2: Car following headway over multiple interactions with AV (per information scenario)

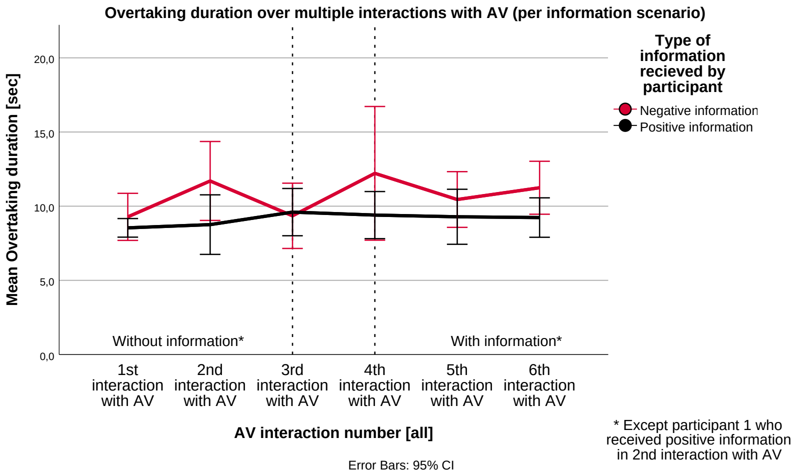


Figure P.3: Overtaking duration over multiple interactions with AV (per information scenario)

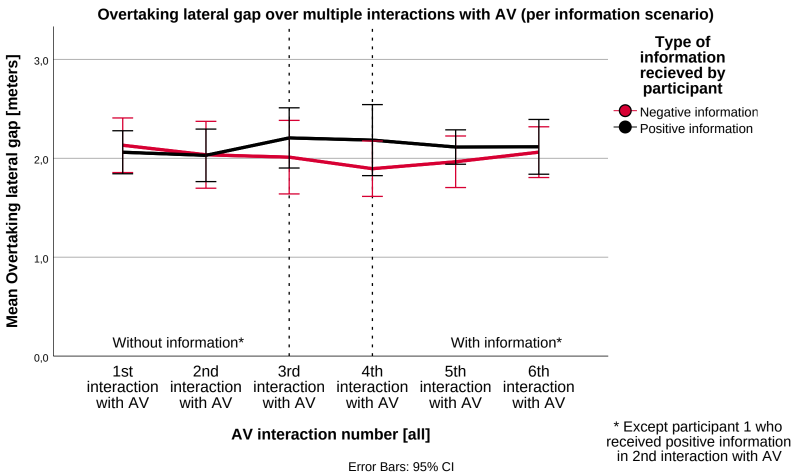


Figure P.4: Overtaking lateral gap over multiple interactions with AV (per information scenario)

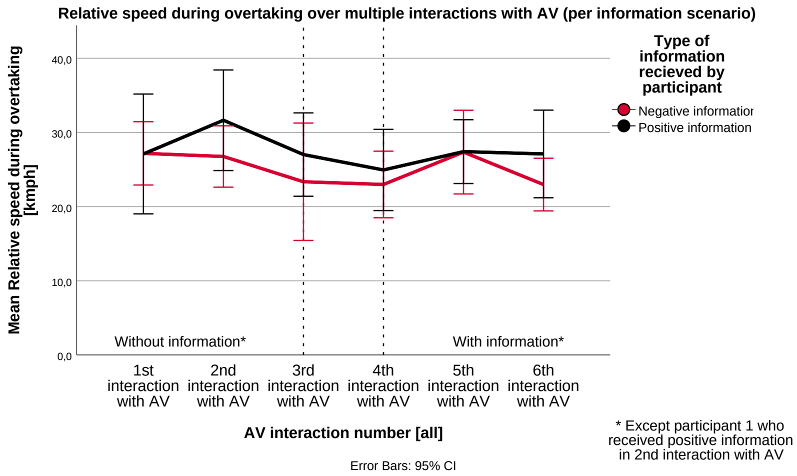


Figure P.5: Relative speed during overtaking over multiple interactions with AV (per information scenario)

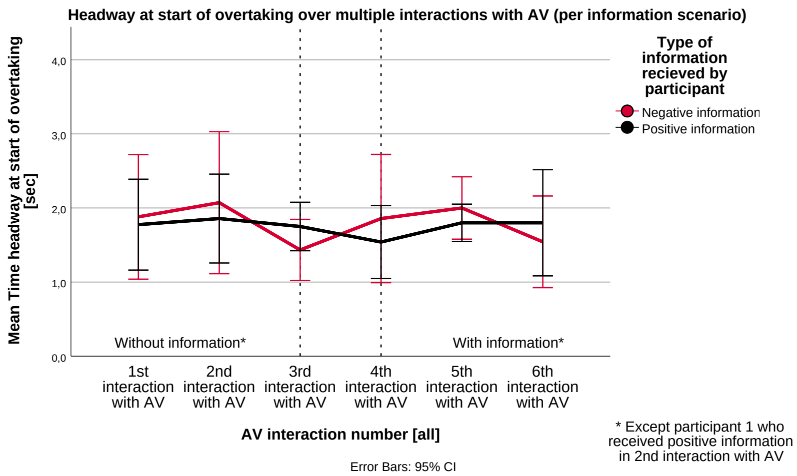


Figure P.6: Headway at start of overtaking over multiple interactions with AV (per information scenario)

Q
Stress and trust plots

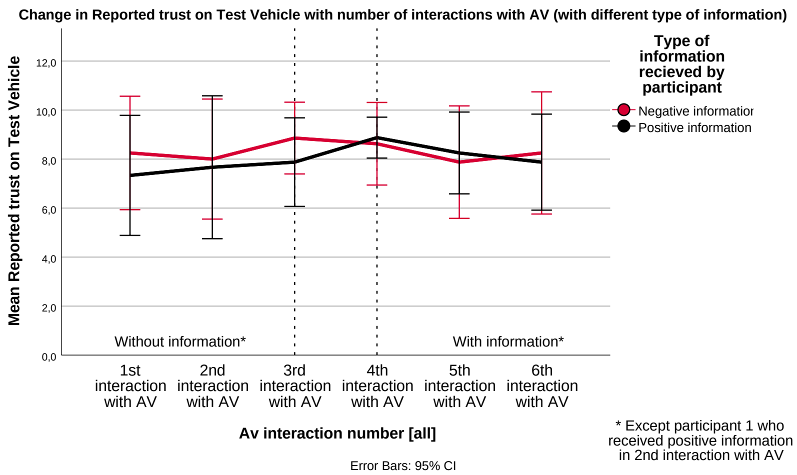


Figure Q.1: Change in reported trust over multiple observations (within information groups)

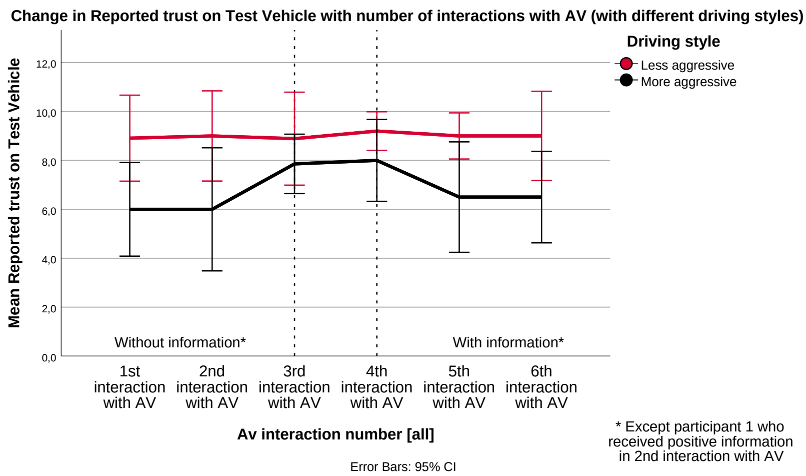


Figure Q.2: Change in reported trust over multiple observations (within driving style groups)

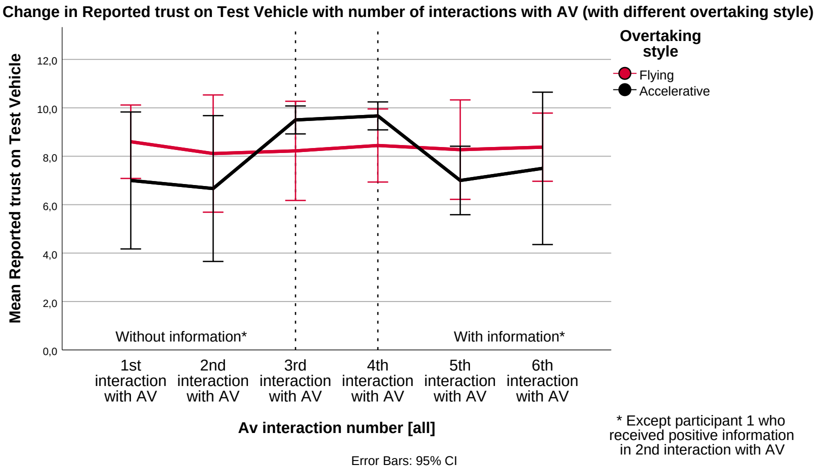


Figure Q.3: Change in reported trust over multiple observations (within overtaking style groups)

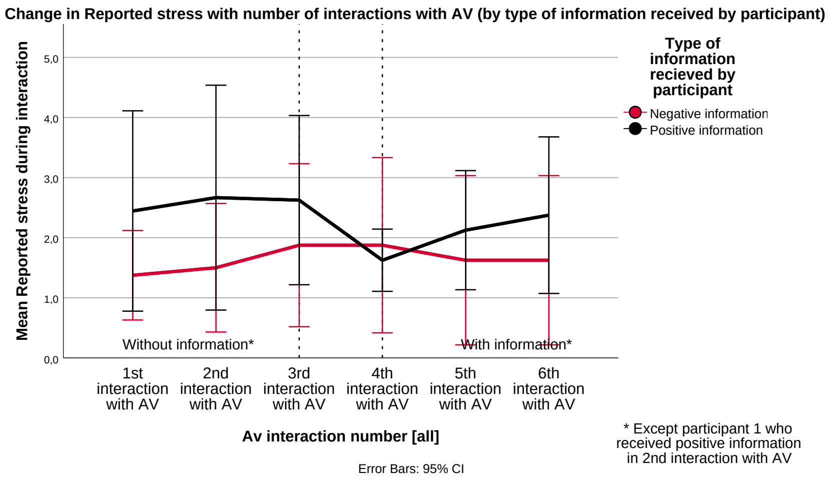


Figure Q.4: Change in reported stress over multiple observations (within information groups)

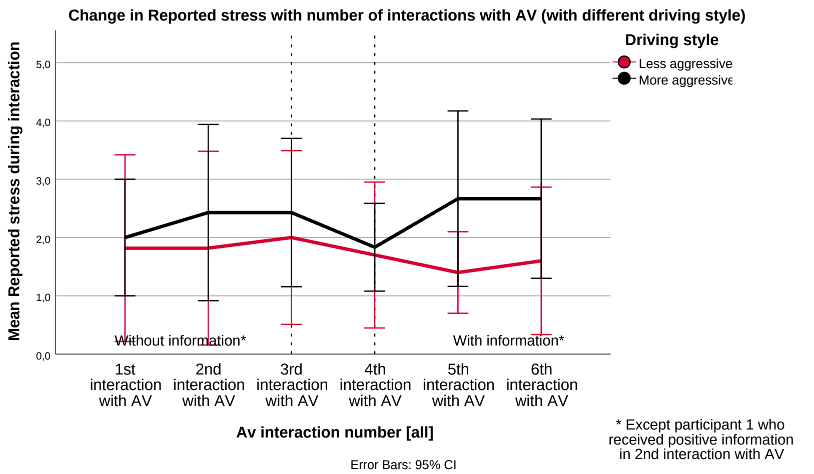


Figure Q.5: Change in reported stress over multiple observations (within driving style groups)

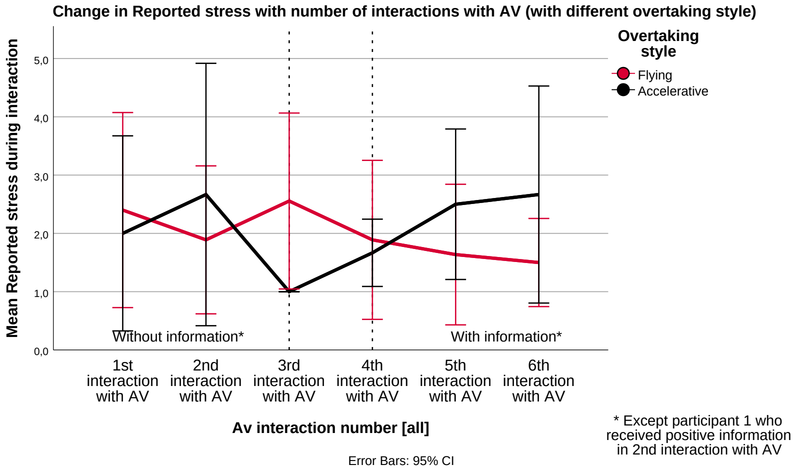


Figure Q.6: Change in reported stress over multiple observations (within overtaking style groups)

Table Q.1: Correlation of reported stress and trust over multiple interactions with AV

		Correlations					
		Reported stress during interaction			**Reported trust on Test Vehicle**		
	Groups	**Pearson Correlation**	**Sig. (2-tailed)**	**N**	**Pearson Correlation**	**Sig. (2-tailed)**	**N**
AV interaction number	**All**	0.000	0.997	102	0.083	0.412	101
	Negative information	0.066	0.655	48	-0.013	0.931	47
	Positive information	-0.068	0.634	51	0.168	0.239	51
	less aggressive	-0.097	0.456	62	0.025	0.847	61
	More aggressive	0.181	0.265	40	0.128	0.430	40