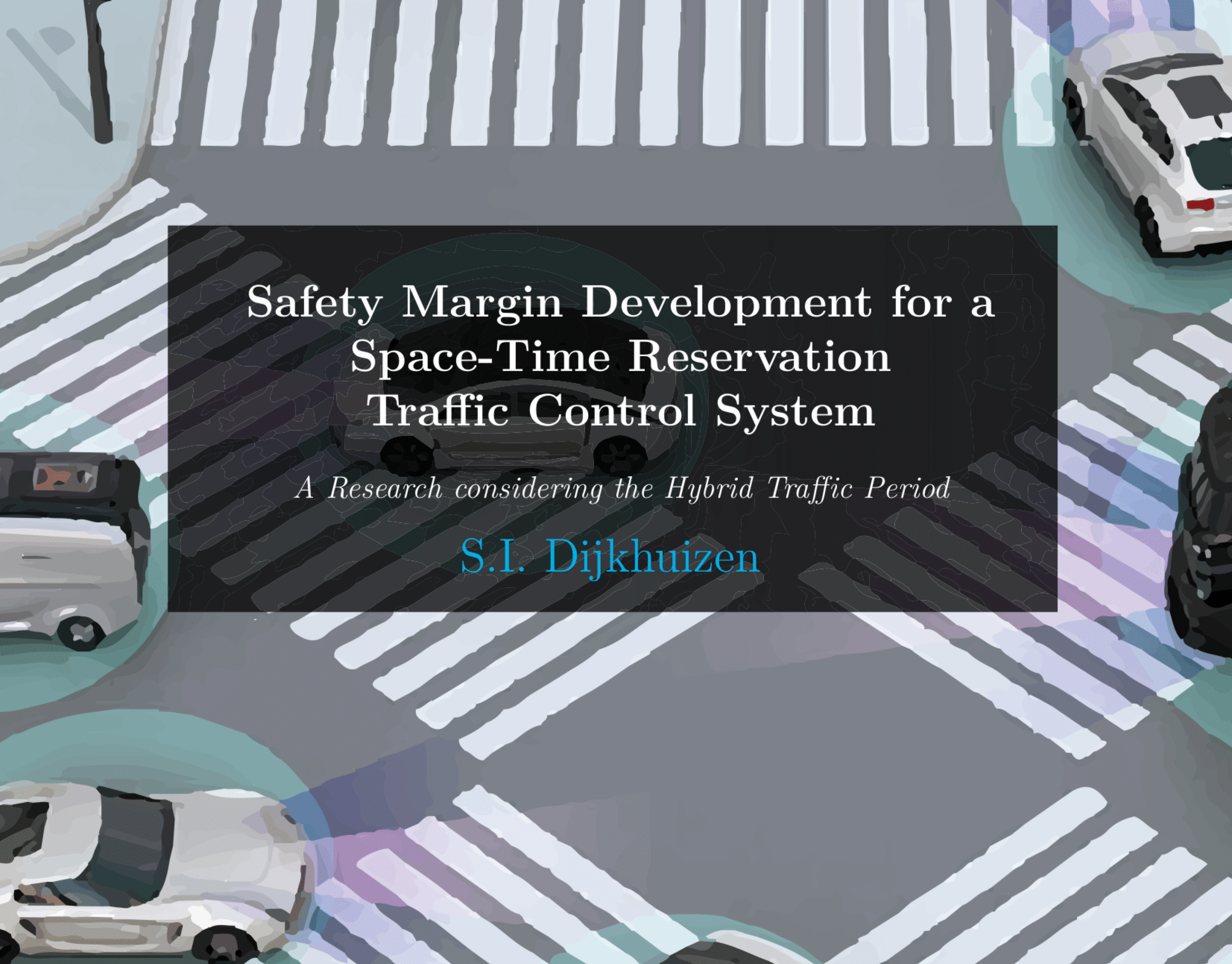

Safety Margin Development for a Space-Time Reservation Traffic Control System

A Research considering the Hybrid Traffic Period

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Transport, Infrastructure & Logistics

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by

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Preface

As a child I often fantasized about the city of the future. I asked myself what the main transportation mode would be. Each time my mother and I were stuck in a traffic jam I asked her why flying cars did not exist yet; then we would never suffer from traffic congestion again! Moreover, traffic lights would not be necessary anymore if all flying cars ’just’ fly at different height levels. My mother often reminded me about my wild fantasies during both my bachelors and masters, where I was regularly confronted with topics related to the city of the future and the traffic congestion problem. Now, 20 years after my first thoughts about the city of the future, I wrote a master thesis that contributes to the development of a traffic control system that aims to let connected and automated vehicles weave over urban intersections. This topic for my graduation project could not have been much more related to my interests in the city of the future.

The past nine months were informative, intensive, stressful, and gezellig. It took a couple of months longer than expected to define my final graduation project. During this period of searching what I could and wanted to research some ups and downs were experienced. I made many plans for suitable research topics. However, the most suitable research topic for me was found around the Summer of 2019. I would like to thank Maria and Andreas for intensively supporting me during this complex period of defining my research goals. Moreover, thank you both for meeting me every other week, and providing me with feedback every time I needed it. I would also like to thank Riender for the help to set up my experiment, as the only expert of my graduation committee regarding human interaction with automated vehicles. Finally, I want to thank Serge for all the support you could provide during my graduation period. I really appreciated your presence during my greenlight meeting. For the future I wish you good health.

Sweco was a great company to graduate in. I really enjoyed the walks I made through the forest almost every lunch break. I got to know a lot of Swecolleagues better here in the Bilt, which increased my joy in being involved in Sweco. Moreover, I really liked the many table football sessions that kept me focused. I would like to thank Jeroen for meeting me every week at Sweco, preferably at a place where the sun was shining. Luckily those places were available both inside and outside the building. Also thank you Coen for listening to me every time I was confused about the iSpaT concept, and for answering all my questions about the concept. I am really glad I could contribute to the future development of Smart Traffic. I am looking forward to the moment I am sitting in my connected and automated car that crosses the intersection by following its individual Space-Time reservations.

Finally, I would like to thank my friends, and especially my boyfriend Daniël for always supporting me during this process. You always managed to keep me positive, for which I am really grateful. I love having you on my side. Also my mother and brother deserve a special mention here. You stimulated me to always do what made me happy. Because of you I became the person I am today.

Dear reader, I am proud to share my work with you. I hope you enjoy reading!

Suzanne Dijkhuizen
Delft, 26th February, 2020

Terms and Abbreviations

Subscripts and Superscripts

back	Location safety margin: at the back of the vehicle
cc	CAV-CAV
ch	CAV-HDV
ds	Driver space
front	Location safety margin: in front of the vehicle
gap	Accepted time gap
hc	HDV-CAV
hh	HDV-HDV
I	Interaction scenario
max	Maximum
lat	Lateral
long	Longitudinal
O	Oncoming vehicle
p	Positioning inaccuracy
side	Location safety margin: at both sides of the vehicle
S	Vehicle side
ts	Time synchronisation
V	Vehicle type
vel	Velocity inaccuracy

Parameters and Coefficients

α	Parameter value for clock offset [s]
d	Preferred driver space around vehicle [m]
G	Accepted time gap by vehicle [s]
h	Preferred time headway [s]
M	Safety Margin [m]
p	Parameter value for location inaccuracy of vehicle [m]
T	Monitoring time step of the traffic control system [s]
u	Actual speed of vehicle [m/s]
$\bar{u}$	Average actual speed of vehicle [m/s]
v	Measured speed of vehicle [m/s]
w	Parameter value for velocity inaccuracy of vehicle [-]

Abbreviations

5G	Fifth Generation
Avg.	Average
CACC	Cooperative Adaptive Cruise Control
CAV	Connected and Automated Vehicle
FAV	Fully Automated Vehicle
FCFS	First Come First Serve
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDV	Human-Driven Vehicle
HMD	Head-Mounted Display
iSpaT	individual Space-Time Reservation
LbR	Left-before-Right
LTAP/LD	Left Turng Across Path / Lateral Direction
LTAP/OD	Left Turng Across Path / Opposite Direction
PCZ	Preferred Clearance Zone
POV	Possible Oncoming Vehicle
PVL	Potential Vehicle Location
RbL	Right-before-Left
Req.	Requirement
SD	Standard Deviation
SE	Standard Error
SPaT	Signal Phase and Timing
SV	Subject Vehicle
TC	Traffic Contoller
TTC	Time-to-Collision
V2V	Vehicle-to-Vehicle
V2I	Vehicle-to-Infrastructure
I2V	Infrastructure-to-Vehicle
VR	Virtual Reality

Summary

With the expected arrival of connected and automated vehicles (CAVs), new traffic control concepts emerge that let CAVs weave over intersections. Concepts that are described in the current literature often assume a traffic situation where only CAVs drive on the road. However, first a hybrid period will occur where vehicles with different levels of automation share the road. Other assumptions that are often made in these studies are related to the actual safety of the vehicles: for example, the assumption of perfect localization of all vehicles. However, before certain traffic control systems could be applied in real life,the actual safety of the vehicles must be ensured, preventing collisions. Various factors could influence the actual safety of these vehicles and their passengers. Moreover, also the perceived safety of the car users is important to consider before letting vehicles weave across the intersection. Namely, when the car users do not feel safe in their car, the question arises whether certain traffic control systems should be implemented.

Sweco, an engineering consultancy, owns a traffic control product that is able to dynamically control traffic at urban intersections: Smart Traffic. Their aim is to further develop Smart Traffic in order to optimize the throughput at intersections and to lower the emissions due to accelerating and braking behaviour around an intersection. The improved concept of Smart Traffic describes the idea of sending individual Space-Time (iSpaT) messages to CAVs. One message will inform the CAV with a personal trajectory that must be tracked to safely cross the intersection. The trajectory is described in terms of a series of iSpaT reservations: one reservation describes for a specific moment in time where the vehicle must be located on the road. The vehicle itself is expected to be able to adapt a suitable speed and acceleration profile. During the hybrid traffic period, Smart Traffic must plan the trajectories of the CAVs while also considering and predicting the driving behaviour of Human-Driven Vehicles (HDVs).

This research describes various factors that influence the actual and perceived safety of HDVs and CAVs, of which the impact must thus be considered before self-driving vehicles can be steered over an intersection while weaving through other traffic. The impact of these factors is described in terms of actual and perceived safety margins needed around a vehicle. This research defines the concepts Potential Vehicle Location (PVL) and Preferred Clearance Zone (PCZ), that follow respectively from the required size of the actual and perceived safety margins. The PVL of a vehicle describes the area on the road where the vehicle is possibly located, whereas the PCZ describes the zone around the PVL that must be free of other traffic to let the car occupants feel safe. The size of the PVL and the PCZ of one vehicle together represent the size required for one iSpaT reservation for that vehicle. In other words, the reserved space on the road for one iSpaT reservation must always be as big as the size of the PVL plus the PCZ of the corresponding CAV.

To determine the size of the PVL and PCZ, a literature study is applied to indicate all factors that influence the actual and perceived safety of the vehicles during the hybrid traffic period. The study distinguishes technical and non-technical factors. The impact of the factors is analysed, either qualitatively or quantitatively, and expectations are formulated considering a suitable size of the safety margins. The second part of this research describes a human experiment that was executed to define car users' preferred time gap, representing the time between a conflicting vehicle leaving and the subject vehicle entering their conflict area. Hence, the perceived safety margins in front of a vehicle during the hybrid traffic period were defined, and later compared to the expectations based on the literature. Due to time restrictions choices had to be made which side of the vehicle was considered during the human experiment.

This thesis answers two research questions, which are described as follows:

1. *While considering the hybrid traffic period, what mathematical formulation that expresses the impact of technical and non-technical factors, describes the required size of safety margins around a vehicle?*
2. *According to a human experiment, what is the value of the perceived safety margin that is required in front of a vehicle, considering the different interaction scenarios that appear during the hybrid traffic period, and how does this value relate to the values found in the literature?*

The literature study mainly focuses on the interaction between two HDVs to distillate the factors, to later make assumptions about the new vehicle interaction situations that can occur during the hybrid traffic period. Therefore, safety margins were defined for both HDVs and CAVs interacting with either an HDV or CAV. This defines four different interaction scenarios to consider: HDV-HDV, HDV-CAV, CAV-HDV, and CAV-CAV. Although iSpaT messages will not be send to HDVs, their expected perceived safety margins can be advantageous for Smart Traffic to use to predict the (near) future traffic situation at the intersection. The main reason for not sending iSpaT messages to HDVs is because HDVs are not expected to track such precise trajectory instructions. Moreover, the human driver must focus on his own driving behaviour and the presence of surrounding traffic, rather than on where it needs to drive in t seconds.

Furthermore, the technical and non-technical factors found in the literature can be distinguished based on whether their influence on the size of a safety margin varies with changing vehicle or environmental conditions (e.g. weather conditions). If these conditions are expected to influence the relationship between the factor and the size of the safety margin, then the relationship was often explained only qualitatively. Examples of certain qualitative relationships are 1) an expected decrease in safety margins due to an increase in trust in the automated vehicle, and 2) an increase in safety margins during bad weather conditions.

The literature study focuses on various crossing compositions that can occur at an intersection. It is preferred to know what distances vehicles keep to each other and when these distances would change. Eventually, for each side of the vehicle it is determined which factors determine the size of a safety margin and to what extent these factors have impact. This research explains six factors that form the basis of the PVL and PCZ. The size of the resulting margins can differ per vehicle per interaction scenario. The six factors are briefly explained as follows:

- Positioning inaccuracy of the vehicle (M_p): due to inaccuracies in vehicle positioning systems, a deviation exist between the actual and measured location of a vehicle;
- Trajectory tracking inaccuracy (M_{tt}): a vehicle will never be capable to exactly follow its assigned reservation. One example is the velocity inaccuracy of a vehicle;
- Time synchronisation inaccuracy (M_{st}): the internal clocks of the CAVs and the infrastructure will not completely be synchronized.
- Preferred time headway of the car user (M_h): an occupant of a passenger car can have a preferred time headway in front and behind its vehicle, which must be respected by the traffic control system;
- Preferred driver space (M_{ds}): a passenger or driver of either a CAV or HDV can have a preferred driver space around the vehicle, which must be respected by the traffic control system;
- Accepted time gap (M_{gap}): the minimum preferred time gap between one vehicle entering and one vehicle leaving a conflict area, which must be respected by the traffic control system.

The impact of the factors mentioned above are all described in terms of a certain distance around the vehicle. Therefore, their impact can be combined to determine the size of the PVL and PCZ of the vehicle. The PVL is a summation of M_p, M_{tt}, and M_{st}, while the PCZ is defined by taking the maximum value at each side of the vehicle of M_h, M_{ds}, and M_{gap}. Furthermore, three constraints are defined for the traffic control system to plan the vehicle trajectories: 1) the PVL of two vehicles may never use the same road space at the same time; 2) the PVL of one vehicle and the PCZ of another vehicle are not allowed to overlap in space and time either; 3) PCZs of different vehicles can use the same road space at the same time. These constraints were based on the fact that somewhere in a PVL a vehicle is located, and any PCZ must be free of traffic.

The second part of this thesis describes a human experiment that was executed to analyze the preferred time gap between a perpendicular crossing vehicle leaving a conflict area and the subject entering that area. Only interaction scenarios including at least one CAV were considered, since these interaction scenarios will be new on the road during the hybrid traffic period. The accepted gap help describing a perceived safety margin in front of the vehicle (either an HDV or CAV).

It was decided to execute a Virtual Reality (VR) study. In total, five time gaps were tested: 0.5, 1.0, 1.5, 2.0, and 4.0 seconds. All time gaps were tested during all combinations of the three interaction scenarios (**HDV**-CAV, **CAV**-HDV, and **CAV**-CAV) and the two crossing directions (left, right). Therefore, 30 different crossing situations were shown to the participant.

In total, 82 participants conducted the experiment. After each crossing situation, the participants had to orally indicate their feeling of safety using a 4-point Likert scale: 1) Very Safe, 2) Pretty Safe, 3) A little Unsafe, 4) Very Unsafe. When the participant was (virtually) driving an HDV, the participant held a (non-operational) steering wheel and placed his feet on (non-operational) gas and brake pedals. These measures were not used when the participant was sitting in a CAV.

The data collected from the experiment was tested on three hypotheses. First, the effect of different time gaps on the obtained scores was tested. A significant relationship was found, which indicated that the data collected was not random. The second test showed that no significant relationship existed between the crossing direction of the crossing vehicle and the scores given. Furthermore, the third test presented that no significant association was found between the scores given and all three interaction scenarios. Therefore, the initially six data sets (3 interaction scenarios × 2 crossing directions) were combined to one large data set. Based on this data set the second research question was answered.

From the data set the acceptance rates (scores 1 and 2 versus scores 3 and 4) were determined for all time gaps. This research does therefore not conclude with one value for a preferred time gap that would fit for every car user. It can be concluded that from 2.0 seconds, 99% of the road users would feel safe. 66% of the car users felt safe at the 1.0 second time gap. According to the literature, the accepted time gap values were expected for all three interaction scenarios to be higher than 2.0 seconds. The results of the experiment thus contradicted these expectations.

Based on the results, the discussion point arises from what acceptance rate a time gap value can be adopted by a traffic controller. A suggestion would be to start with 1.5 seconds as accepted time gap, a value that is accepted by 93%. The literature indicates that perceived safety margins will decrease with driving experience with and trust in automated driving. Therefore, the time gap of 1.5 s may decrease over time. Another concept may be that the drivers themselves could indicate their preferred safety margins to the car, and that the car would be able to communicate these values via V2I-communication.

The two main directions for future research are (1) quantifying the qualitatively described relationships between the scenario-dependent factors and the size of safety margins, and (2) testing to what extent the preferred time gap values found would change during a weaving traffic situation.

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Introduction

This chapter introduces the goal of this research. First, background information is provided on the future traffic situation that is expected to become a fully automated traffic situation (Section 1.1). Section 1.2 discusses the most relevant previous studies in this field, mostly related to new concepts of future traffic control systems, and presents the scientific relevance of this study. After the relevance and research gaps are explained, the research questions and scope are discussed in Section 1.3. Eventually, the structure of the research is explained in Section 1.4.

1.1. Background: Towards a Fully Automated Traffic Situation

Traffic light control systems are widely used to monitor and control the traffic flow at intersections, mostly in urban areas. They aim to realize an efficient but safe traffic flow on the transportation routes. However, since traffic congestion has become a major and global problem in larger urban areas, the challenge to keep intersections safe and efficient appears. To increase both of these ambitions, current research focuses on, for example, reduction in total vehicle delay, decreasing stress levels of car drivers during rush hours, and optimizing green times of traffic lights. Moreover, a rising research topic is how connected and automated vehicles can contribute to increase the safety and efficiency at intersections.

Also *Sweco*, the company this research was commissioned by, has ambitions for projects that focus on this challenge. Currently, Sweco has a product that improves the efficiency at intersections which is actually being used in various Dutch cities: *Smart Traffic*. Smart Traffic is a traffic control system that improves the throughput at intersections by increasing the reliability of SPaT (Signal Phase and Timing) messages. Certain messages describe the current phase at a signalized intersection, together with the residual time of the phase, for each lane of the intersection. Via in-car applications, drivers can receive this information while driving. However, regular SPaT messages are only reliable the last few seconds before the vehicle has arrived at the traffic lights. Namely, regular SPaT messages are based on real-time traffic data. Smart Traffic plans the phases on the traffic lights based on a traffic forecast, rather than on the real time traffic information. In other words, Smart Traffic predicts what the traffic situation will be, approximately, 10 seconds ahead. This means that the time to red or time to green will not change the last 10 seconds before the vehicle has arrived at the traffic lights, which ensures highly reliable SPaT messages. Human drivers can easily anticipate their driving behaviour on this information. First projects show a reduction of vehicle delay between 20 and 40 percent (Sweco, 2018).

Subsequently, Sweco wants to improve the throughput at intersections with the arrival of connected and automated vehicles (CAVs), by further developing their Smart Traffic product. For example, if certain vehicles could communicate parameters like speed and their planned route to the infrastructure and other vehicles, the demand could be known even further in advance, and traffic could be controlled more dynamically. Moreover, when 100% of the vehicles would be connected and automated, (physical) traffic lights may become unnecessary (Ferreira et al., 2010).

However, currently mainly human-driven vehicles (HDVs) are using the road network, which still need physical traffic lights. Moreover, slow traffic would also need physical traffic lights to safely cross an intersection. In 2009 Google started to design a self-driving car, currently known as Waymo, a self-driving taxi service (Gibbs, 2017). According to Waldrop (2015), the 2020s is the decade when driverless cars are predicted to become widespread. These vehicles are expected to be completely automated and would not need any manual control. Of course, the technique for these fully automated vehicles is still in progress. Though, automation in vehicles becomes more and more common today: for example, Cooperative Adaptive Cruise Control (CACC) where the movements of platooning vehicles are coordinated dynamically and automated, using V2V- and V2I-communication. Techniques having a lower level of automation, but that are more commonly applied today are cruise control, lane assistance, and automated parking.

It is important to mention that before all vehicles will drive fully automatically, first a hybrid traffic period will have to be faced. During this period, a combination of different levels of automation will appear on the road. Hence, the task of human drivers shall change too and the hybrid traffic period will become increasingly noticeable. Therefore, the literature study considered various levels of automation. However, for the second part of this report, the focus was on highly and fully automated cars that could communicate with their environment via V2V- and V2I-communication.

1.2. Scientific Relevance and Research Gap

To introduce the research gap, first some relevant literature is discussed. Thereafter, explanation about the concept of Sweco for a hybrid traffic control system is provided.

1.2.1. Current Research

The current literature already describes some traffic control systems that were designed for the future situation where highly and fully automated vehicles (level 4/5) will drive on public roads. Although these control systems are not ready to be implemented yet, they are inspiring in the field, presenting examples of how fully automated vehicles or a mix of human-driven vehicles and fully automated vehicles can be controlled in the future. The two most seen concepts for such traffic control systems were based on (1) a first-come-first-serve (FCFS) principle, and (2) optimizing the total vehicle delay. Both concepts considered a traffic situation with a 100% penetration rate of CAVs, and let CAVs ’weave’ over the intersection. Weaving traffic can be interpreted as vehicles approaching from all directions that pass each other closely on the crossing area of the intersection, just that no collisions occur. The FCFS principe was developed by Dresner and Stone (2004) and further explained in Dresner and Stone (2008). When applying the FCFS principle, vehicles are treated one-by-one based on their expected arrival time at the crossing area. Via V2I-communication, the automated vehicles broadcast their preferred trajectory, thus their preferred route (location) including their desired speed profile for that route (time), to an infrastructure manager. If this trajectory will not overlap with already planned trajectories, the request of the vehicle will be accepted, and the trajectory is reserved for that vehicle. Otherwise, the request will be rejected and the vehicle should send a new request with a different trajectory plan (with other reservation parameters).

Other approaches are minimizing the total vehicle delay or the average vehicle delay. Here, the vehicles are not treated according to their order of arrival, but their departure times are optimized according to the potential delay. Lee and Park (2012) manipulated the manoeuvre of each vehicle by imposing onto them an acceleration profile. Furthermore, instead of an acceleration profile, also a certain speed could be assigned to a vehicle (Chai et al., 2018). In that case, the vehicle must get enough time to reach this speed to traverse the intersection. Therefore, Chai et al. (2017) first introduced a configuration for an intersection so that vehicles receive their speed advice well before they reached the crossing area. These studies can be inspiring for Sweco as soon as all vehicles drive fully automated. However, when a fully automated traffic situation will come to exist is unclear (Fraedrich et al., 2015).

Only a small part of the literature focuses on the hybrid situation where Human-Driven Vehicles (HDVs) and Connected and Automated Vehicles (CAVs) share the road. A working design for a hybrid traffic control system does not yet exist - nor is it the case for the fully automated situation. One example to let both CAVs and HDVs function together on the same road was based on the FCFS concept (Dresner & Stone, 2006; Sharon & Stone, 2017). This concept assumes that HDVs are still controlled by physical traffic lights. CAVs still send requests to a traffic manager, and are therefore expected to be able to drive through a red light when possible. However, the infrastructure manager only accepts trajectory requests that do not conflict with *green light trajectories*. Green light trajectories represent all possible trajectories that could be driven by an HDV having green light.

Another concept for a hybrid traffic control system is proposed by Guler et al. (2014). In order to reduce car delay and the number of stops, this approach tries to estimate the driving behaviour of human drivers by creating platoons of vehicles starting and ending with a CAV. By knowing the speed and location of these CAVs, an estimation could be made of the number of HDVs in the platoon. Their behaviour will depend on the behaviour of the automated vehicles. Since the CAVs can communicate parameters like speed, acceleration, and location, the same parameters for HDVs could be estimated more easily and more reliably. The higher the penetration rate of automated vehicles, the more exact the location and other parameters of HDVs can be estimated. Having more accurate information of HDVs, more accurate green times can be planned. A follow-up study was presented by K. Yang et al. (2016): they estimate the trajectory of an HDV as accurately as possible by using road side units and by analysing the vehicle's turn signals.

1.2.2. Concept of *individual Space-Time Reservations*

With the arrival of connected and automated vehicles (CAVs), Sweco desires to expand their traffic control system (i.e. Smart Traffic) with the technique of assigning so-called *individual Space-Time reservations* to CAVs. The use case below describes the concept of individual Space-Time (iSpaT) reservations, and how they can lead CAVs over an intersection. Only CAVs are considered in this use case, since nothing will change for HDVs to cross an intersection: they can still receive SPaT messages generated by Smart Traffic and still need to follow the traffic signals. Namely, HDVs are not expected to be able to follow the orders of iSpaT messages and to focus on the surrounding traffic simultaneously. Letting human drivers track a specific trajectory is thus assumed to not be safe, not for the drivers themselves, neither for the surrounding drivers. Note that this use case represents the *desired* future situation in which Smart Traffic is capable of controlling both HDVs and CAVs on one intersection, and is capable of generating iSpaT reservations.

1. A CAV approaches an intersection and wants to cross it;
2. Via V2I-communication the CAV broadcast various parameters to the traffic control system: current position and speed, desired direction at intersection and vehicle characteristics (i.e. max. and min. acceleration and deceleration, max. speed, and the vehicle dimensions);
3. Based on this information, the traffic control system generates a set of iSpaT reservations that describe where on the road the CAV must be at what specific moment in time, in order to let the CAVs cross the intersection. The traffic control system must ensure that never two vehicles (either two CAVs or one CAV and an HDV) will be on the same location on the road.

4. Via I2V-communication, the traffic control system provides the CAV its unique series of iSpaT reservations.

5. The CAV itself determines a suitable speed and acceleration profile to track the assigned trajectory of iSpaT reservations.

6. The CAV tracks the trajectory and safely passes the intersection.

In addition to this use case, it was assumed that via V2V-communication, the CAVs will know all reservations of all vehicles. Moreover, it was assumed that CAVs would broadcast their location every 0.1 second, which is indicated by the ITS-G5 protocol as the maximum frequency. When the reserved location of the iSpaT reservation also changes every 0.1 second, all CAVs could check if the other vehicles are deviating from their reservation. This would increase the overall safety. Furthermore, in order to plan iSpaT reservations that do not conflict with HDVs, thus avoiding collisions between CAVs and HDVs, it is desired to know the route and location of HDVs as accurately as possible. As described in Chapter 3, this research assumes that HDVs could be tracked via 5G, which assures a high positioning accuracy. However, this research makes no statements about obtaining the planned route of HDVs. A possibility to obtain this route is to get access to route planning applications like *Flitsmeister*. A collaboration with such applications would be favorable in order to receive the planned routes of HDVs, and thus to plan iSpaT reservations more reliably. However, obtaining the routes of HDVs and how these could be used for planning iSpaT reservations would be a topic for further research.

Figure 1.1 shows a diagram on which the locations of one series of iSpaT reservations is visualized for one approach lane. Per 0.1 second, a new location on the road is reserved for the vehicle. The vehicle itself determines its own speed profile to be able to be at the reserved space at the right time. As can be seen, one reservation has a (minimum) length equal to the vehicle size: the vehicle must entirely fit within the reservation. Note that this diagram does not indicate exact positions on the approach lane, neither does it indicate real moments in time. In reality the X-axis would indicate specific moments in time (i.e. hh:mm:ss:msms), and the Y-axis the exact location on the road (e.g. by using coordinates).

In Section 3.1 it is explained that to guarantee the safety of the vehicles a reservation will need to be larger than the vehicle size only. Namely, a vehicle is expected to not be able to exactly follow its reservations. The extra space required for a reservation is determined on multiple required *safety margins* around a vehicle. Safety margins around a vehicle can be seen as a virtual growth of the vehicle, hence the vehicle also requires a growth in the reserved location of a Space-Time reservation. Therefore, the traffic control system will plan the Space-Time reservations based on the vehicle size plus the safety margins (= virtual size of the vehicle). Safety margins are needed due to technical and non-technical factors that influence, for example, the positioning accuracy of a CAV. Moreover, the feeling of safety of a car occupant is important to consider as a safety margin, otherwise the traffic regulation is expected to not be acceptable or successful. In Chapter 3 the safety margins are distinguished as *actual safety margins*, that describe the safety margins necessary to keep the vehicle actually safe from collisions, and the *perceived safety margins*, which are required in order to let the vehicle occupants feel safe within their car.

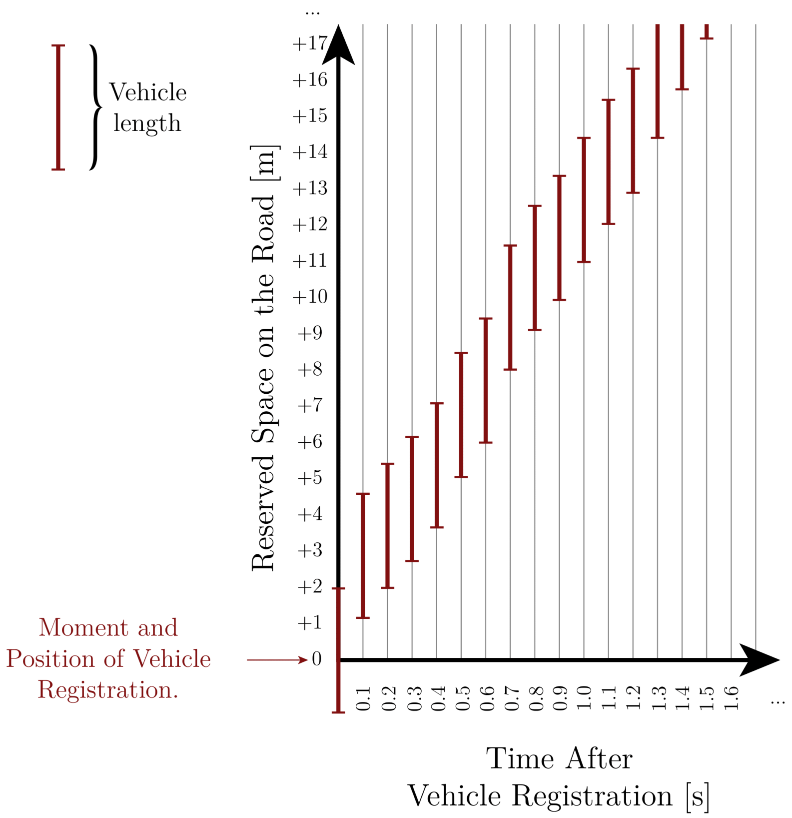


Figure 1.1: Series of individual Space-Time reservations of one vehicle.

1.2.3. Research gap

It may be clear that there are ideas to control traffic in both the fully automated and hybrid traffic situation. However, no concept is implemented in reality yet. This could be due to the fact that the technology of CAVs is not yet fully developed. A second reason is that current literature often assumes their vehicles to be actually safe, for example by assuming perfect knowledge of the vehicle locations. However, their assumptions do often not apply in practice, which gives rise to uncertainties and inaccuracies in the traffic control design. For a reliable traffic control system that can let self-driving vehicles weave across an intersection, these assumptions require research.

Moreover, also the concept of iSpaT reservations requires research about the *actual safety* of both HDVs and CAVs. When a vehicle is actually safe, collision avoidance is guaranteed. Besides the actual safety of the vehicles in the hybrid traffic situation, also the *perceived safety* of the car occupants is important to consider. Namely, without the occupants feeling safe in their car, either an HDV or CAV, letting vehicles weave through each other might not be a successful concept to implement.

The question arises which factors influence the actual and perceived safety of both vehicle types of the hybrid traffic period, and how these influences must be taken into account in order to provide a traffic control system that could guarantee actual and perceived safety for all vehicles and their occupants.

According to this question, the following research gap was distilled: it is unknown yet to what extent the actual and perceived safety of all vehicles in the hybrid traffic period will be influenced when vehicles will weave over the intersection. Besides, it is unknown how this influence will affect current concepts of hybrid traffic control systems.

1.2.4. Scientific Contribution

This research focuses on the first part of the research gap. Various factors that can influence the actual and perceived safety of HDVs and CAVs were summarized. Furthermore, their impact was discussed and was described as required actual and perceived safety margins around a (weaving) vehicle. These factors, and their influence on the safety of the vehicles during the hybrid traffic situation, form a framework that could be used in future research studies. The framework can help to improve existing and future hybrid traffic control concepts, among which Smart Traffic, and may debunk some of the currently existing assumptions about vehicle safety. The factors that influence the actual and perceived safety margins around a vehicle are the result of a literature study (Chapter 2) and are discussed in detail in Chapter 3. A distinction was made between technical and non-technical factors. Moreover, in the second part of this research, the influence of some of these factors on the perceived safety of human drivers was tested via a virtual reality experiment. During this experiment, the feeling of safety of the participants was indicated during various crossing scenarios between HDVs and CAVs, which makes the generated data set innovative in the currently existing literature.

1.3. Research Questions and Scope

The research presented in this thesis is split into two parts. First the research questions for both parts are presented, after which the scope of the research is explained.

1.3.1. Research Questions

This research is split into two parts, hence two research questions are formulated. The first part aims to indicate all factors that influence the required size of the actual and perceived safety margins around a vehicle in the hybrid traffic situation. A literature study will reveal these factors and their impact. The goal of the second part is to describe the perceived safety margins in front of both HDVs and CAVs, as a result of a human experiment. The values found from the experiment could be compared to the values found in the literature. Therefore, the two research questions are formulated as follows:

1. *While considering the hybrid traffic period, what mathematical formulation that expresses the impact of technical and non-technical factors, describes the required size of safety margins around a vehicle?*

2. *According to a human experiment, what is the value of the perceived safety margin that is required in front of a vehicle, considering the different interaction scenarios that appear during the hybrid traffic period, and how does this value relate to the values found in the literature?*

To be able to give a structured answer to the research questions, the following sub-questions are treated beforehand. Sub-questions 1.1 to 1.4 help to answer the first research question, whereas sub-questions 2.1 to 2.3 help to answer the second research question.

1.1. *What is the relationship between an individual Space-Time reservation, actual safety margins, and perceived safety margins?*

1.2. *Which factors result in safety margins around a vehicle required to plan individual Space-Time reservations, considering both HDVs and CAVs?*

1.3. *According to the impact of each factor on the safety of a vehicle, what size is required for all actual and perceived safety margins to establish safe Space-Time reservations?*

1.4. *To what extent could the required safety margins of two vehicles overlap while still ensuring the actual and perceived safety of all human occupants?*

2.1. *What would be a suitable set up for an experiment to find a person's preferred safety distance in front of a vehicle, considering the hybrid traffic interaction scenarios?*

2.2. *To what extent varies the preferred safety distance of a human driver with the direction from which a crossing vehicle is approaching the same intersection?*

2.3. *To what extent varies the preferred safety distance of a human driver with different vehicle interaction scenarios that can occur during the hybrid traffic period?*

1.3.2. Scope of the Research

This research focuses on the hybrid traffic situation. During this period, vehicles of multiple automation levels are expected to share the road. Therefore, various interaction scenarios will occur: interactions between fully automated, semi-automated, and non-automated (manual) vehicles. Moreover, new interactions between (semi-)automated vehicles and slow traffic will emerge. Due to time restrictions, not all interactions that exist in the hybrid traffic period could be considered during this research. For simplicity and as a result of the fact that iSpaT reservations are suggested to be followed by only fully automated vehicles, only HDVs and CAVs were considered in this research. Both vehicle types are assumed to be passenger cars. The vehicle types are explained as follows:

HDVs:	Manually driven vehicle that has no automated specifications. The vehicle cannot communicate with other vehicles or infrastructure. The vehicle can receive SPaT messages through in-car applications, provided these are available;
CAVs	No assistance from the driver is required to drive safely. The vehicle occupant is not able to intervene. Possibly a steering wheel, gas- and brake pedals (all non-working) are present to ensure a higher level of perceived safety. Furthermore, the vehicle is able to communicate with other vehicles and with surrounding infrastructure. These vehicles can receive and track iSpaT messages.

It may be clear that this research does not aim to model an (improved) traffic control system for the future hybrid traffic situation. Neither did this research explain how Smart Traffic must determine the most efficient crossing order of all approaching vehicles. This research assumes that the traffic controller is capable to determine SPaT messages for HDVs and iSpaT messages for CAVs.

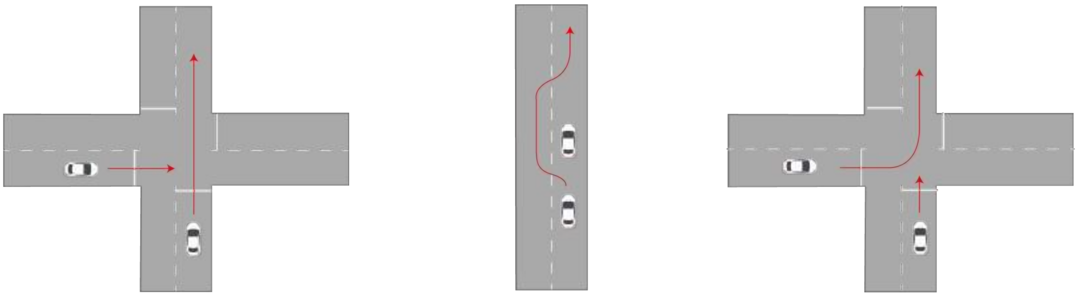
In total, four *interaction scenarios* were considered within this research to determine the actual and perceived safety margins for. They are itemized below. Note that the HDV-HDV interaction scenario will not be new on the road. However, this interaction scenario is broadly studied in the current literature, which can help determining the size of the safety margins during the new interaction scenarios. All four interaction scenarios were studied during the literature study. However, because of a combination of time restrictions and the aim for innovative data, only the first three interaction scenarios were considered during the human experiment.

- **CAV** - CAV: Interaction between two CAVs, experienced from a **CAV** perspective.
- **CAV** - HDV: Interaction between a CAV and an HDV, experienced from the **CAV** perspective.
- **HDV** - CAV: Interaction between a CAV and an HDV, experienced from the **HDV** perspective.
- **HDV** - HDV: Interaction between two HDVs, experienced from an **HDV** perspective.

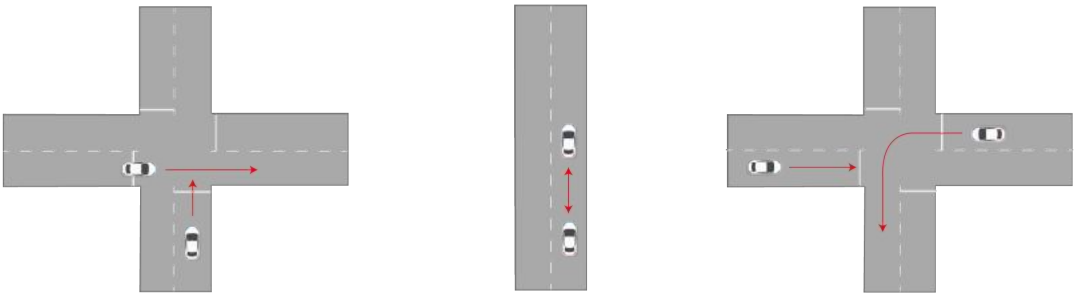
The interaction scenarios can occur during multiple traffic situations: for example, on and around intersections, om and around roundabouts, on highways, on urban roads, and more. This thesis only describes the interaction scenarios on and around intersections, since the concept of iSpaT reservations was conceived to let CAVs weave across signalized intersections. Moreover, only interactions between two vehicles were considered. Further research is desired to investigate the interaction between (semi-)automated vehicles and slow traffic, and to investigate the interaction of more than two vehicles.

The literature study focused on various traffic situations that can occur on urban intersections. Since no traffic control systems exist that allows (automated) vehicles to weave over the crossing area of signalized intersections, mostly non-signalized intersections were analysed to make statements about the actual and perceived safety. The traffic situations that were considered are illustrated in Figure 1.2, which could roughly be divided into the following categories:

- A 90-degree crossing situation: studied at non-signalized intersections to analyse the preferred time gap to cross the other vehicle. Both the left-before-right (no right-of-way) and right-before-left (right-of-way) situation were considered;
- Car-following situations: both car-following and overtaking situations were analysed in order to study the longitudinal time gaps between vehicles.
- Encroachment scenarios: one vehicle *encroaches* a second vehicle, which means that the first vehicle crosses the planned path of the second vehicle, while the first vehicle did not have the right-of-way (Smith et al., 2009).



90-DEGREE CROSSING RIGHT-BEFORE-LEFT OVERTAKING ENCROACHMENT 1



90-DEGREE CROSSING LEFT-BEFORE-RIGHT CAR-FOLLOWING ENCROACHMENT 2

Figure 1.2: Interaction Scenarios to Study

1.4. Research Structure

This research consists of two parts: (1) mathematically describing the required actual and perceived safety margins around a vehicle that help determining the size needed for one Space-Time reservation, and (2) gathering data via a human experiment that describes the perceived safety margins in front of an HDV and CAV. Eventually, the data gathered is compared to the expectations that were based on the literature.

In order to achieve the goal of the first part, first the relationship between individual Space-Time reservations, the actual safety margins, and the perceived safety margins is described in detail in Section 3.1. The definitions of these concepts were mainly based on the conceptual ideas of Sweco. However, also the outcome of the literature study is used to define the concepts. The explanation is the answer to the first sub-question.

Chapter 2 described the literature study applied. The goal of the literature study was to identify all factors that caused a safety margin, either an actual safety margin or a perceived safety margin, around the vehicle, and to quantify these margins. To structure the literature study, a distinction was made between technical and non-technical factors. The study considered the different vehicle interaction scenarios that were shown earlier on Figure 1.2.

With the framework describing all influencing factors that followed from the literature study, the first three sub-questions were answered in Sections 3.1 and 3.2. Thereafter, more explanation was provided about the interaction of individual Space-Time reservations of different vehicles. Hence, sub-question 1.4 is answered and illustrated in Section 3.3. With the answers to the first four sub-questions, the first research question is answered in Section 3.4.

The second part of this research describes a virtual reality experiment that was set up to research the perceived safety margins of human occupants in front of their vehicle during the various interaction scenarios. This human experiment was executed, since no data of real life hybrid traffic situations was available to compare the - according to part I - expected perceived safety margins with.

During the experiment the participants experienced the interaction scenarios of the hybrid traffic period and were exposed to various safety margin values in front of their vehicle. The participants had to indicate their feeling of safety for each combination of a safety margin and an interaction scenario. The outcome of the experiment must indicate what safety margins are preferred by the population to have in front of the vehicle.

Chapter 4 describes the design of the experiment and answers sub-question 2.1. Hence, Chapter 4 explains the experimental set up that was used to gather the data. It moreover presents the hypotheses that were tested and that were later compared to the expectations from the literature. To set up an appropriate experiment, a small literature study was executed and also experts from Delft University of Technology were asked for help. Eventually, a virtual reality study became the most appropriate method to apply. For the first set up of the experiment, a small number of people was asked to execute the experiment. Their results were analysed on, for example, the duration of the experiment, and on the clarity of what was expected from them. After improving in the experiment, the final experiment was defined. The answer to sub-question 2.1 is given in Chapter 4.

The results are presented and analysed in Chapter 5. This chapter explained the answers to sub-questions 2.2 and 2.3. These questions helped to determine whether or not the experimental set up was successful and to find out whether the results were statistically significantly different per interaction scenario. With the answers to the last three sub-questions, the second research question was answered in Section 5.2.

2

Literature Study: Factors for Safety Margins

The idea behind providing iSpaT messages to control an intersection autonomously, is not new in the literature. Various research has already been executed related to the optimization of the efficiency of (isolated) intersections during the future situation where connected and/or automated vehicles will be on the road. While the concepts presented in current literature seem to prevent traffic from any collision, none of these concepts is implemented in real life yet. This is (partly) due to the assumptions made in these studies. Researchers often assume perfect knowledge of a vehicle's location, no communication delay between the vehicles and infrastructure, and equal size and characteristics for each vehicle. In reality these problems actually exist, which make them important to actually take into account while designing a new traffic control system. Moreover, often human factors were not taken into account either, while this is also important, since the occupants of the vehicle must feel safe and comfortable within a vehicle in order to accept the new traffic control system.

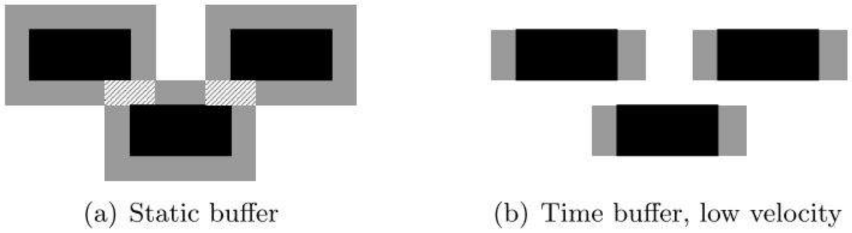
As introduced in Chapter 1, the main goal of this literature study was to identify all factors that influence the safety of a vehicle and its passengers during the hybrid traffic period. Moreover, the study also describes to what extent these factors result in safety margins: what size would be needed, and where around the vehicle would the safety margin be needed. During the research towards these factors, the different interaction scenarios (as introduced in Section 1.3, Figure 1.2) were kept in mind. The HDV-HDV situation was used as a basis scenario of which assumptions could be made about the influence of the factors in other vehicle interactions. Section 2.2 describes the non-technical factors that were found, whereas Section 2.3 focused on the technical factors. First, literature that did consider safety of vehicles during automated intersection management was highlighted in Section 2.1.

The methods applied to find and describe all factors that affect the safety margins around a vehicle, is explained as follows. First, a distinction was made between technical and non-technical factors. Based on this distinction, keywords were formulated to find literature that would describe the current (expected) safety of HDVs and CAVs on the road. Examples of keywords for the technical factors are: "fully automated vehicles:, "automated driving", "automated vehicles malfunctions", "safety engineering", "GPS accuracy", etc. Examples of keywords used to explain the non-technical factors were: "human driving behaviour", "human factors", "gap acceptance", "surrogate safety measures", "car following", "headway distance", "fatal car accidents", etc. Combinations of the keywords were used to find the first relevant literature studies in *Scopus*. These articles were read while searching how traffic safety could be or could not be guaranteed - keeping in mind the various conflict situations that could occur during the weaving traffic situation. Moreover, the questions covered how traffic safety was harmed and perceived as a result of current human driving behaviour.

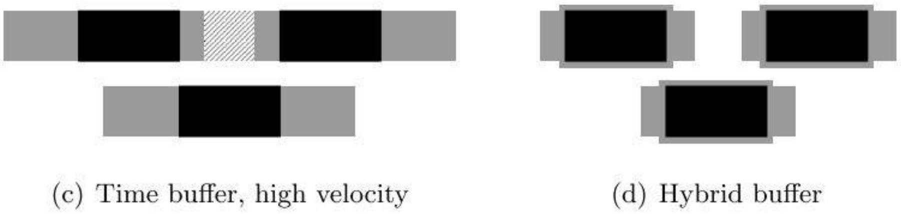
Furthermore, the factors that influenced the safety of a vehicle were categorised per vehicle side and per vehicle type. Thereafter, new keywords were formulated based on the keywords and research topic of the read literature. Furthermore, to find more relevant articles or keywords, the snowball method was applied - thus finding other relevant titles by searching the bibliographies - as well as the citation searching method - to search for newer publications that cited the literature read. Via these methods also new factors were found, and more information about one factor was found too. Eventually, a framework of factors resulted that help determining the size of the safety margins around a vehicle. This framework is shown in the following chapter, in Tables 3.1 and 3.2.

2.1. Safety in Current Automated Traffic Control Concepts

Being uncertain about the exact location of a self-driving vehicle can increase the risk on collisions or near-miss collisions during automated intersection control. Most literature that described a traffic control system for the future automated traffic situation, assumed perfect location knowledge of the self-driving vehicles. However, in fact, location inaccuracy exist, and should be considered at certain traffic control system designs. Though, not every research ignores the risks of location inaccuracy. Dresner and Stone (2008) mentioned the need for a safety buffer around each vehicle. They discussed three types of buffers: (1) static buffers, (2) time buffers, and (3) hybrid buffers. Static buffers have a constant size, whereas the size of time buffers depend on the velocity of a vehicle. Moreover, time buffers shall only shrink or grow in the same direction as the vehicle is moving. They conclude that hybrid buffers are the most suitable for a traffic control system that let automated vehicles weave over the crossing area of an intersection. The hybrid buffer scales with velocity, and has a small static buffer that protects against lateral positioning errors and serves as a minimum buffer for slow-moving vehicles. Figure 2.1 illustrates the buffer types, considering the time buffer for both a low and high velocity. The hatched areas show where buffers would cause reservation conflicts. According to this study, only one vehicle of each pair of conflicting vehicles would be granted a reservation to cross an intersection.



(a) Static buffer (b) Time buffer, low velocity



(c) Time buffer, high velocity (d) Hybrid buffer

Figure 2.1: Types of Safety Buffers according to Dresner and Stone (2008). Black box = Vehicle; Grey area = Safety buffer

Unfortunately, Dresner and Stone (2008) did not describe how these buffers changed their actual size over time. They only introduced the concept, but applied static buffers for their own simulation experiment. Besides, Chai et al. (2017, 2018) considered a similar concept. They discussed the need for a minimum safe distance between two automated vehicles in order to avoid rear-end collisions. A safe distance between two following vehicles could moreover be used by conflicting vehicles to cross the intersection. The study assumed a minimum safe distance of one vehicle length, that could be enlarged with extra meters to let conflicting vehicles pass through. However, the article said that further research is needed towards the specification of safe distances between automated vehicles.

It seems that current literature also asked for further development of safety buffers in order to let vehicles weave over the intersection. However, it is not clear yet how exactly the shape of a buffer must be determined. Only Dresner and Stone (2008) described that the shape of the (hybrid) buffer could change with velocity and may have a fixed minimum size around the vehicle. Based on this, it is expected that the size of the buffer has a minimum value which can expand due to changes in speed and changes in a vehicle's direction. According to Chai et al. (2018) also factors as the maximum deceleration and acceleration values, comfort of passengers, and the presence of human-driven vehicles, must be taken into account when ensuring a safe driving environment for automated vehicles.

In the following subsections both non-technical factors and technical factors are discussed that can contribute to the determination of the size of a space-time reservation. It is explained how these factors influence the margins and suggestions were made about a minimum dimension for the safety margins around the vehicle. Thereafter, a formulation can be provided to determine safety margins for each vehicle type in each traffic situation (see Chapter 3).

2.2. Non-Technical Factors

The margins required by non-technical factors often covered the perceived safety of the vehicle's occupants. Moreover, some required safety margins depended on environmental circumstances, like the weather conditions or the traffic density. Other margins were only needed during emergency or unexpected situations. While this study does not focus on the latter situation in the following chapters, these factors are taken into account in this chapter in order to provide a complete overview of all non-technical factors.

This section first describes the current traffic situation, where only HDVs interact (Subsection 2.2.1). This subsection first described the literature that resulted in the *preferred longitudinal distance*. In other words, here the factors are described that were expected to influence the perceived safety margins at the longitudinal sides of a vehicle. Thereafter, the studies were discussed that resulted in a *preferred lateral distance* on both sides of the vehicle. In subsection 2.2.2 the factors found were summarized. Thereafter, in Subsection 2.2.3 literature about the interaction between human-driven vehicles and automated vehicles was discussed. This subsection mainly focused on the user acceptance of automated driving, and discusses how user acceptance influences the size of the required safety margins. Assumptions were required to make, since sufficient knowledge on how people want to be driven in highly automated vehicles is missing (Elbanhawi et al., 2015; Bellem et al., 2018; Rossner & Bullinger, 2019). Finally, in Subsection 2.2.4, a conclusion was provided about the impact of the arrival of automated vehicles on the currently required safety margins due to non-technical factors.

2.2.1. Interaction between Human-driven Vehicles

As said before, first the interaction between human-driven vehicles was considered, which could later be used to generate safety margins for automated vehicles. Safety margins are required in front and behind a vehicle, referred as the longitudinal margins, and are required on both the left and right side of the vehicle during a crossing manoeuvre, called the lateral safety margins. Thus, safety margins consist of a longitudinal distance and a lateral distance. Below, these distances are discussed separately.

Preferred Longitudinal Distance - Preferred Driver Space

The longitudinal margins were expected to exist both in front of the vehicle and behind the vehicle. Hennessy et al. (2011) and Zhang et al. (2019) did research about the *driver space preference*, which is defined as a personal space extending from the driver to surround the vehicle in traffic (Marsh & Collett, 1987). According to these researches, drivers desire some personal space both in front and behind their vehicle. However, the size of this space can be influenced by several factors, both human factors (e.g. mood, age, gender) and environmental factors (e.g. time of day, weather conditions, traffic conditions). Zhang et al. (2019) researched the effects of emotional status and driving experience and Hennessy et al. (2011) investigated the influence of age, gender, and level of congestion, on the driver space preference. Both articles concluded that there was a desire for a certain fixed headway distance that would not be dependent on the velocity of the vehicle. Moreover, it was concluded that angry people had a wish for a larger front space, compared to the happy and neutral drivers. Furthermore, people who were involved into a collision in the past 3 years, wanted a larger front space too. Both articles used the same approach to determine the preferred front and rear headway distance: people were asked to draw one vehicle in front and one vehicle behind a subject vehicle on a drawing of a vehicle on a road with scale $1:1000$. On the drawing the lane width was 24 mm, so 2.4 meters in real life. Hennessy et al. (2011) found an average front driver space of 4.18 mm, and a rear driver space preference of 4.30 mm, which thus equaled respectively 41.8 and 43.0 meter. Zhang et al. (2019) found for the neutral driver a desired front space of 53.59 meter and a desired rear space of 54.08 meter. Furthermore, both articles said that no significant difference could be found between the driver front and rear space preference. However, a critical note must be made about the research method. Namely, neither of them included moving vehicles in the experiment, but the participants had to imagine driving in a vehicle wand had to draw their preferred space around the vehicle that was clear of other traffic, on a piece of paper. This method was assumed not to be comparable to methods where people were sitting in a (virtual) car to experience real traffic situations. So, according to these articles it could be said that there is a wish for a fixed distance around the vehicle, but it is questionable if the values found for the preferred driver space were suitable to adopt for the safety margin development of this research.

Preferred Longitudinal Distance - Preferred Time Headway

Besides expressing a safety space around the vehicle in terms of distance, often this space was expressed in terms of time. Studies that focus on safe time headway values could be distinguished in studies that focused on guaranteeing a passenger's safety on the road, and studies that analysed at what time headway value drivers felt safe. Thus, a distinction can be seen in actual safe time headway values and perceived safe time headway values.

An actual safe time headway always has a larger value than the break reaction time in a certain situation. A generally adopted safe time headway is known as the '2-second rule' (SWOV, 2012; Tennessee Coalition for the Safety of Senior Drivers, 2018). This rule claims that a headway of 2 seconds is the minimum safe distance between vehicles. However, this value can differ per country or authority. For example, in Germany a headway of 1.8 seconds is assumed to be safe (Vogel, 2003), while Wang (2009) mentioned a safe time headway between 2 and 3 seconds. As soon as the time headway value equals 4.0 seconds or higher, the vehicle is a leading vehicle, since those vehicles were assumed to not follow another vehicle (Wasielewski, 1979).

Apart from the different values that could be applied as actual safe time headway values, an interesting question is what time headway people *experience* as safe. Various studies have been executed to answer this question. These answers help to create a safety margin in the front of a vehicle. However, it must be noted that time headway is generally measured from the front-end of the leading vehicle to the front-end of the following vehicle. The studies considered in this literature study described the time headway value as the time period between the rear-end of the leading vehicle passing a certain point and the front-end of the following vehicle passing that point. Below different studies are explained that focused on the perceived safe time headway, and describe which factors possibly influenced the perceived safety.

A study executed in Tennessee, United States, examined three different urban roads (~ 65 km/h) and 12,393 vehicles. They found an average time headway value of 2.11 seconds, having a standard deviation (SD) of 0.85 seconds (Michael et al., 2000). This study considered the distance between the front-ends of both the leading and following vehicle. To find the time gap between both vehicles, it is important to subtract the length of the leading vehicle divided by the driven speed, from the time headway value. Figure 2.2 shows the following distance in seconds compared to the percentage of drivers. Note that these values are thus a bit higher than the time gap between two vehicles. Overall, the most common headway taken laid between 1.4 and 2.2 seconds, and only 49.4% of the vehicles were in compliance with the 2-second rule. Furthermore, it was observed that 933 drivers took a headway of less than a second. This was considered as tailgating, and was judged as 'aggressive driving'. According to this study, it could be assumed that the majority of the drivers does not keep an actual safe time headway on the road.

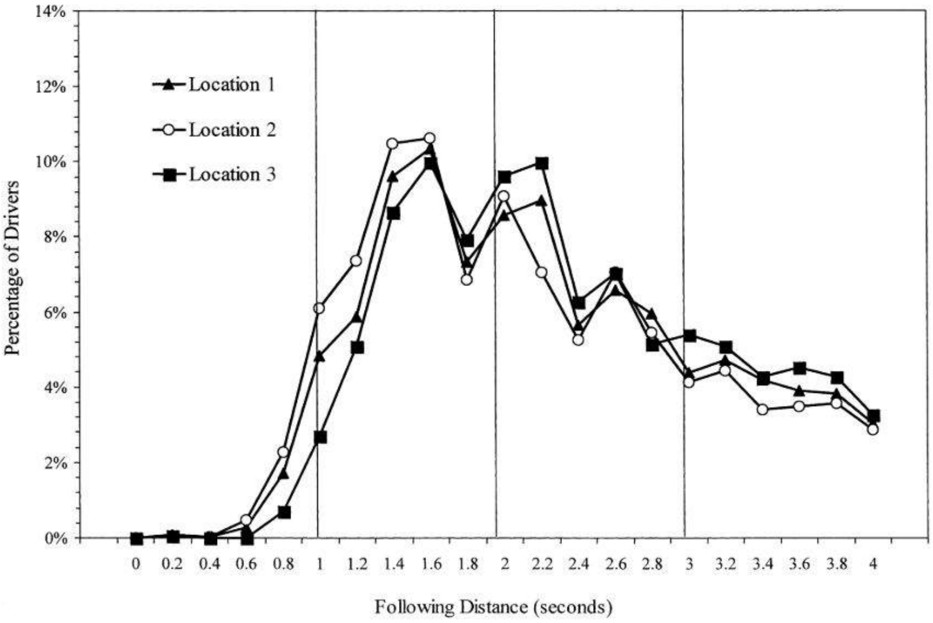


Figure 2.2: Following Distance held by Drivers (Michael et al., 2000)

More interesting to study is the actual time headway (or: time gap or following distance) between vehicles, thus measured from the rear-end of the leading vehicle and front-end of the following vehicle. A research of Taieb-Maimon and Shinar (2001) asked 30 (Israeli) drivers to first drive with a safe time headway behind another vehicle (this article assumed 1.4 seconds to be an actual safe time gap where collisions could be avoided). Thereafter, drivers had to take a time headway that felt *comfortable* to them. The participants had to keep both time headway values for 10 seconds. The preceding vehicle drove with different speeds, varying from 50 to 100 km/h. Across all speeds, the average minimum time headway was 0.66 seconds (SD = 0.26 s). Moreover, less than 5% held an (assumed) safe time gap smaller than 0.26 seconds, whereas also less than 5% held an (assumed) safe time gap higher than 1.04 seconds. The median was 0.68 seconds. 93.3 % maintained an assumed safe time gap of less than 1.0 seconds.

Furthermore, the study found a comfortable time headway, varying only from 0.94 to 1.00

seconds, independent of the speed of the preceding vehicle. The study translated these comfortable time headway values to comfortable headway distances per velocity. Figure 2.3 shows these values in a graph and distinguished the gender of the participants. Moreover, Taieb-Maimon and Shinar (2001) concluded that the drivers felt safe in their vehicle at following distances that would not have been safe during an emergency situation.

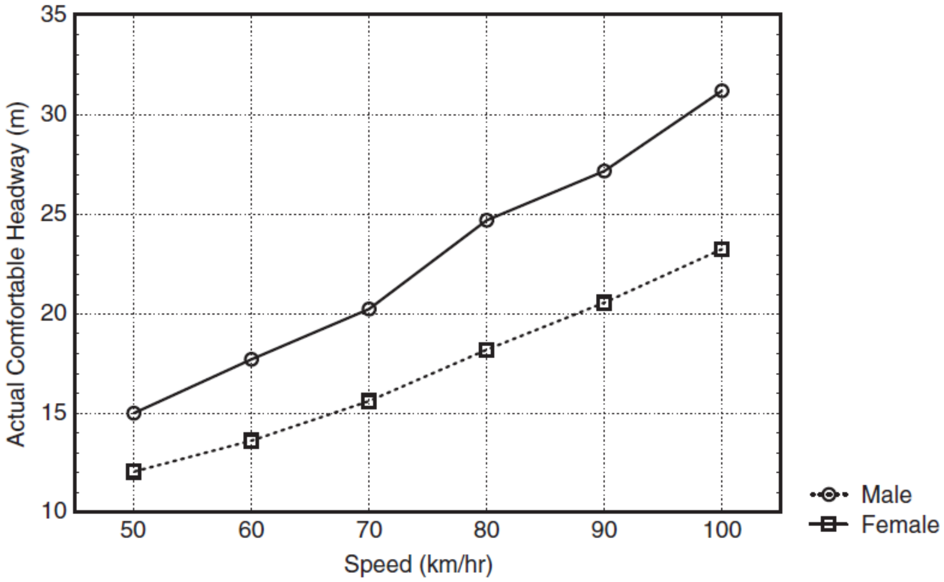


Figure 2.3: Comfortable Headway Distances per Velocity (Taieb-Maimon & Shinar, 2001)

Remarkably enough, more studies conclude values for a comfortable time headway smaller than 2 seconds. The following studies also defined the headway distance as the distance from the rear bumper of the leading vehicle to the front bumper of the following vehicle. Duan et al. (2013) found a comfortable following distance of 1.48 seconds (SD = 0.38 s) at 45 km/h and 1.78 seconds (SD = 0.66 s) at 90 km/h. Similar to the study of Taieb-Maimon and Shinar (2001), this study also asked the drivers to drive a minimum safe distance. The average values found for this requirement were respectively 0.70 (SD = 0.31 s) and 0.92 seconds (SD = 0.44 s). So, also this study found a difference between a comfortable and a minimum safe distance. In both studies most participants thought that they were driving a safe time headway when driving their comfortable time headway.

Also Sayer et al. (2003) studied the comfortable headway values. Based on 1698 observations (from 70 drivers) made in the United States, they found an average time gap of 1.60 seconds (SE = 0.05 s) between two cars driving around 65 km/h. This value would fit in the range of Duan et al. (2013).

Finally, the research of Broughton et al. (2007) focused on the difference in time headway when considering different speeds and different weather conditions. He found average time headway values of 2.0 and 2.6 seconds for respectively 50 km/h and 80 km/h during clear weather conditions. The speed limit of 80 km/h during foggy weather conditions ensured a huge increase in the time headway taken: the time headway increased to more than 8 seconds, having a visibility limit between 93 and 41 meters. On the contrary, it found a lower time headway value of 1.7 seconds at the lower speed (50 km/h) during foggy weather compared to clear weather conditions.

Preferred Longitudinal Distance - Overtaking Manoeuvres

Besides literature about comfortable and safe time headway values, literature about overtaking manoeuvres also helps to find factors that influence the size of safety margins in front of and behind a vehicle. Namely, the question that arises is when a vehicle starts an overtaking manoeuvre, and when it moves back to the initial lane. Hegeman et al. (2004) presented observations of overtaking manoeuvres on a two-lane Dutch rural road in order to understand the driver behaviour prior to, during, and after an overtaking manoeuvre. By the use of an instrumented vehicle the researchers were able to observe naturalistic overtaking manoeuvres. Their results showed that for almost one fifth of the overtaking manoeuvres, the prior distance between vehicles was less than 10 meters. The shortest distance measured equaled a value of 7.7 meters, which corresponded in that case to 0.35 seconds (at 80 km/h). The research described certain driving behaviour as dangerous and may be described as aggressive according to previous research. Considering the average speed of 80 km/h, the mean headway at the start of the manoeuvre was 17.8 meters (= 0.80 seconds). This was much smaller than the average headway distance after the overtaking manoeuvre, which had a value of 32.5 meters (= 1.46 seconds). This is remarkable, especially since shorter headway distances at the end of an overtaking manoeuvre may be experienced as less dangerous, because then the speed of the overtaking vehicle is higher than the speed of the overtaken vehicle. However, further research should be necessary in order to draw reliable conclusions about the difference in time headway before and after an overtaking manoeuvre.

A much older, but similar research was executed by Crawford (1963). He concluded that the headway distance after overtaking did not vary significantly with speed. This research concluded a comfortable headway of 40 ft. (~ 12.19 meters) after overtaking. The velocities considered varied from 40 miles/hr (~ 65 km/h) to 90 miles/hr (~ 145 km/h), which gave time headway values of respectively 0.67 and 0.30 seconds. These values seemed to be very low, especially at such high speeds. Crawford (1963)'s research stated that the headway distance at the back of a car, after an overtaking manoeuvre, was not dependent on the speed.

Besides, Mahmud et al. (2018) provided results of a more recent and similar study in Bangladesh where 535 overtaking manoeuvres were considered on a road where speed varied between 55 and 90 km/h for passenger cars. It found that for more than one-third of the overtaking manoeuvres, the prior headway distance was less than 10 meters with a corresponding time headway of less than a second. The shortest headway distance observed was 2 meters (= 0.13 seconds). However, this distance was measured between two trucks that drove with a speed of 55 km/h. 41 % of the manoeuvres started overtaking at a headway distance between 10 and 20 meters. After overtaking, the average headway distance was 22.4 meters. 27% of the headway distances after overtaking equaled a value of less than 10 meters, equaling a time headway of 0.65 seconds.

A final factor that could possibly influence the desired longitudinal distance is the reaction time of the human driver. Of course this value can depend on different factors, like familiarity with the surrounding, expectations, and the driver's physical and mental condition. How these factors influence the value of the reaction time of a human driver is not considered in this literature study, since this factor is covered by emergency factors, which is not the scope of this research. An average reaction time of 1 second can be assumed according to Openbaar Ministerie (2018).

Table 2.1 provides an overview of each research that studied a comfortable headway between human-driven vehicles and shows which factors were considered in the research. Later in this literature study their possible influences on safety margins were summarized and explained.

Table 2.1: Overview Preferred Headway Values, measured from rear-end of leading vehicle to front-end of following vehicle

Paper	Research Country	Data gathered via	Road type considered	Possible (Main) Influencing Factors	Avg. Time Headway or Headway Distance found
Hennessy et al. (2011)	USA	Static Experiment	Fictional road, 2 lanes, drawn on paper	Age, Gender, Vehicle Density	Fixed headway distances. Front: 41.8 meter; Rear: 43.0 meter
Zhang et al. (2019)	China	Static Experiment	Fictional road, 2 lanes, drawn on paper	Emotional Status, Driving Experience	Fixed headway distances. Front: 53.59 meter; Rear: 54.08 meter
Michael et al. (2000)	USA	Road Observation	Urban Streets, 2 and 4 lanes; 40 mph / 65 km/h	-	Between 1.4 and 2.2 sec (including vehicle length)
Taieb-Maimon and Shinar (2001)	Israel	On-Road Experiment	Highway, 4 lanes; 50, 60, 70, 80, 90, or 100 km/h	Speed, Gender	Between 0.94 and 1.00 sec
Duan et al. (2013)	China	Simulation Experiment	Virtual road, 2 lanes; 45 km/h / 90 km/h	Speed, Size of leading vehicle, Presence of surrounding traffic	Between 1.48 and 1.78 sec
Sayer et al. (2003)	USA	Vehicle Observation	Different type of roads	Speed, Size of leading vehicle	Average time headway: 1.60 sec
Shinar and Schechtman (2002)	Israel	Vehicle Observation	Different type of roads	Age, Gender, Speed, Time of Day	Around 1.0 sec
Broughton et al. (2007)	USA	Simulation Experiment	Virtual road, 50 km/h and 80 km/h	Speed, Visibility	Clear conditions - 30 km/h: 2 sec; 50 km/h: 2.6 sec. Foggy conditions - 30 km/h: >2 sec; 50 km/h: <8 sec
Hegeman et al. (2004)	Netherlands	Road Observation	Rural road, 2 lanes; 70, 80, 90, 100 km/h	Speed, Presence of surrounding traffic	Start overtake: 0.80 sec; End overtake: 1.46 sec
Crawford (1963)	England	On-Road Experiment	Straight two-lane road along the edge of an airfield; speed varying between 30 and 80 km/h	Speed	Fixed headway distance in front of car: 40 ft. = 12.19 meters
Mahmud et al. (2018)	Bangladesh	Road Observation	Highway, 2 lanes: speed varying between 30 and 120 km/h	Speed, Vehicle Type	Start overtake: 10 - 20 meters; End overtake: < 10 meters

Discussion of Literature regarding Longitudinal Distances between Cars

The previously discussed studies were valuable to describe the safety margins in longitudinal direction. Moreover, the results gave suggestions for quantitative values for each factor. However, below three critical notes about these studies are discussed:

- The studies mentioned various factors that may influence the time headway taken by passenger cars. However, these factors could take different conditions, which could lead to an even higher number of combinations between these conditions. Thus, the results of the different studies considered were hard to compare and to draw conclusions about the question whether the time headway values found would fit for the scope of this research. Therefore, it was not possible to generate one value for a comfortable time headway that would always fit for longitudinal safety margins.

- This research focused on urban intersections. However, none of the previously discussed studies focused on this traffic situation too. All considered straight roads. However, these studies had to be considered to form an idea of how a comfortable headway distance would apply on the future traffic situation where vehicles weave over intersections.

- The studies often describe the distances between two following vehicles. However, when vehicles will weave over the intersection, vehicles will cross other vehicles in front or at the back. Literature was found about the minimum time gap one vehicle requires to encroach another vehicle (see 2.2.1), however, these studies always considered the perspective of the encroaching vehicle. Thus: not from the (desired) perspective of the vehicle where another vehicle crosses in front of. Therefore, the factors found by these studies were assumed to also apply for the situation at intersections where vehicles cross in front of each other. The experiment presented in Chapter 4 helped to draw conclusions about these assumptions.

Preferred Lateral Distance - Gap Acceptance Vehicle not on speed

Besides a preferred longitudinal distance, it is also important to define a preferred lateral distance. Where the longitudinal distances describe the preferred distances at which another vehicle can cross in front of or behind the subject vehicle, the lateral distances describe the comfortable distances on both the left and right side of a vehicle. Possibly some factors that asked for lateral safety margins only applied on the conflict area.

The literature considered to find lateral safety margins, focused on the gap acceptance between vehicles at unsignalized intersections. An important difference between the studies is whether or not the subject vehicle was already driving a (maximum) speed when entering or crossing a traffic flow. If the subject vehicle was waiting behind a stop line, the gap should be larger compared to the situation where a vehicle was already on speed. For this study, the time gap between two vehicles through which a vehicle that is on speed can go, is mainly interesting to consider, because that situation is most comparable to the future situation where traffic shall weave through each other.

Kaysi and Abbany (2007) studied the gap acceptance of drivers coming from a minor road that wanted to enter a major road. The vehicle speed varied between 40 km/h and 75 km/h. In this case, traffic was coming from the right, and the subject vehicle needed to go left (See Figure 2.4). In total, 266 observations were made, of which 85 (32 %) were characterized as aggressive actions. Aggressive meant in this case, that traffic on the major road had to decelerate as soon as an aggressive driver cut in. 28 of these aggressive drivers forced themselves into a gap of less than 5 seconds. This thus includes the time for the subject vehicle to accelerate to the maximum speed. The behaviour of aggressive drivers cannot be compared with a suitable safety margin, since it is not desired to make other vehicles need to brake.

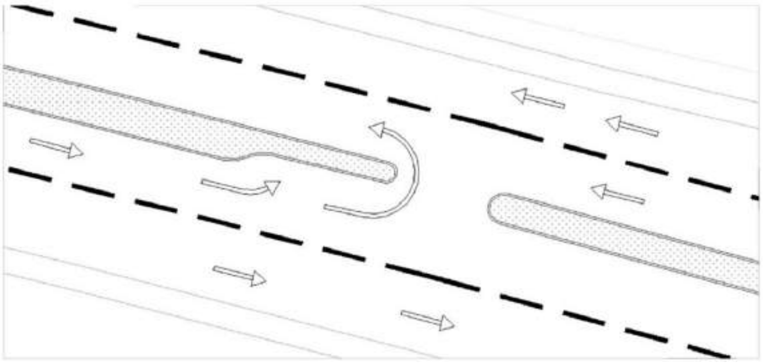


Figure 2.4: Road Configuration Studied by Kaysi and Abbany (2007)

Many factors play a role in the determination of the gap acceptance. For example, Hamed et al. (1997) distinguishes the traffic flow, time of day, maneuver type, intersection geometry, and major-road speed as important factors that determine the critical gap value. Also Zhou et al. (2017) mention the importance of considering traffic factors like the number of lanes to be crossed, the presence of left-turn lanes, and the speed and density of oncoming traffic, while determining the critical gap of drivers. Moreover, both articles mention that the difference in gap acceptance could also vary over socioeconomic characteristics, like gender, age, expected waiting time, and trip purpose. It therefore may be clear that individual driver's gap acceptance behaviour may change with time and conditions, just like the time headway does. It was therefore important to understand that the values for gap acceptance given in the literature were not general, but probably specific for a combination of various traffic conditions (e.g. (time of) day, road, country, person, etc.).

Ashalatha and Chandra (2011) estimated values for the critical gaps at T-intersections in India, by applying various methods. Data was collected via real life observations at urban roads with a speed limit of 40-45 km/h. On the major road the traffic flow varied between 600 and 2000 vehicles per hour, whereas on the minor road this value varied between 300 and 1000 vehicles per hour. Two situations were considered: right turns from the minor road, and right turns from the major road. Traffic in India considers a left side driving practice. The situations studied are shown in Figure 2.5, where Inafoga stands for Influence Area for Gap Acceptance.

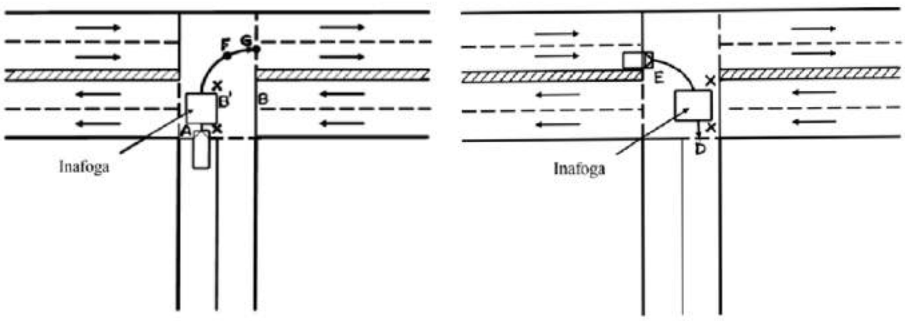


Figure 2.5: Schematic Representations of Intersections considered by Ashalatha and Chandra (2011). Left: right-turn on minor road; Right: right-turn on major road.

Moreover, their research found various values for the critical gap that depended on the intersection that was observed, the method that was applied to determine a critical gap, and the road type that was considered. Moreover, the article presented a new concept: a vehicle can be assumed to have cleared the intersection as soon as it crosses the Inafoga. Considering the right turn from the minor road, 4 (one per observed intersection) significant critical gaps were found: 4.30, 5.10, 5.40, and 5.25 seconds (average: 5.01 seconds). On the major road, the average critical gap had a value of 3.68 seconds. The number of lanes to cross highly contribute to this difference in gap acceptance: more lanes asked for a higher time gap (obviously).

Besides, Suzuki and Yamada (2011) performed a driving simulator study where drivers had to make a right turn (left side driving situation considered) while being exposed to four different gaps: 60 m (4.32 sec), 80 m (5.76 sec), 100 m (7.20 sec), 120 m (8.64 sec). The oncoming vehicles were driving a constant speed of 50 km/h on a two-way four lane intersection. It seemed that 90% of all subject vehicles made the right turn when the headway between two vehicles was 100 meters (7.20 sec). A time gap of 5.76 seconds was accepted by almost 60%. The gap of 4.32 seconds was accepted by only 20%. The research does not provide an average value for the gap acceptance, since it considered fixed time gaps. However, the value of 5.76 seconds was accepted by more than half of the drivers, and therefore it may be said that the majority accepts this value as a comfortable time gap. This study was similar to the study of Ashalatha and Chandra (2011) where vehicles from the major road also had to make this right turn. This study found an average value of 3.68 seconds for the same case. This value would, according to Suzuki and Yamada (2011), be accepted by less than 20% of the drivers. An important difference is that Suzuki and Yamada (2011) performed a driving simulator study, whereas the results of Ashalatha and Chandra (2011) were based on real life observations. Maybe this could have made a significant difference in gap acceptance. Of course, other factors as mentioned before, influenced the traffic situation and value for gap acceptance too. For example, the nationality could have significant influences: Ashalatha and Chandra (2011) considered the traffic situation in India, whereas the participants of the study of Suzuki and Yamada (2011) were from the USA.

Preferred Lateral Distance - Vehicle on speed

However, the previously discussed research all considered a situation where a vehicle stopped prior to cross the intersection. Less data was found for the situation where drivers turn without stopping. Cody et al. (2007) mentioned the boundaries where vehicles would always stop before crossing, and when they would certainly not stop before crossing. Considering the situation shown on Figure 2.6, where both vehicles were on speed, a time gap of less than 3 seconds let drivers from the subject vehicle (SV) always stop, whereas a time gap greater than 8 seconds would let these drivers certainly pass without stopping. Between these values, a higher acceptance rate was obtained for longer time gaps (Ueno, 1991).

The study of Cody et al. (2007) contributes to the question when a subject vehicle makes the decision to turn (or not) in front of an oncoming vehicle (see Figure 2.6). A field test (in the USA) observed the time to the conflict area for both the subject vehicle (SV) and the Possible Oncoming Vehicle (POV), and at what time value the subject vehicle decided to cross in front of the POV. Figure 2.7 illustrates the observations where the subject vehicle crosses in front (accepted) or not by either only lowering its speed (rejected no stop) or make a full stop in front of a stopping line (rejected stopped). The graph shows that the length of the lag (distance to the conflict area) is not the only predictor for determining whether a driver will stop or not, but that also other variables play a role: the presence of a vehicle behind the POV, and the gap between the leading POV and following vehicles. Moreover, the average time difference between the arrival of the SV and the arrival of the POV at the zone of conflict is 4.27 seconds (SD = 3.06).

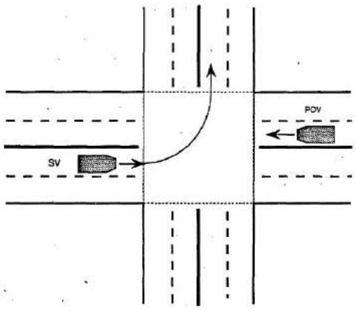


Figure 2.6: Left turn scenario considered by Ueno (1991); Chovan et al. (1994), where SV = Subject Vehicle and POV = Possible Oncoming Vechile

Before Cody et al. (2007), also Chovan et al. (1994) considered a similar situation as the situation illustrated in Figure 2.6. This research distinguished two moments in time when the SV make a left turn: (1) the deceleration time to slow down to the maximum turning velocity in order to be able to really make the turn without skidding, and (2) the clearance time of the zone of conflict, defined as the time between the start of the turning movement and the leaving the conflict area. Assuming a velocity of 50 km/h, Chovan et al. (1994) states a value of 2.55 seconds to decelerate to a velocity of 28.5 km/h (= 26 ft/s), and 2.43 seconds for the clearance time, which in this case thus started from the beginning of the (right) turn, and ended as soon as the vehicle had left the conflict area. In total, it would cost the SV 2.55 + 2.43 = 4.98 seconds to prepare and make the right turn. Thus, in order to avoid a collision, the POV would have to clear the SV travel path before 2.55 seconds from the start of the SV deceleration, or not enter it until 4.98 seconds from the start of the SV deceleration. When referring to the 3 seconds boundary introduced by Ueno (1991), if the SV starts to make its turn, and the POV is 3 seconds away, there would be 3.0 - 2.43 = 0.6 seconds to spare. According to Chovan et al. (1994), this spare time must perhaps be increased when considering psychological factors. In the future weaving traffic conditions, the safety margin could perhaps be defined as this spare time. The deceleration time and clearance time are thus important time values to consider while determining if a time gap is safe to use, when the vehicle is already at a certain speed. According to Cody et al. (2007), when the SV is going to make its turn, the POV is, on average, 4.27 seconds away having a standard deviation of 3.06 seconds. A clearance time of 2.43 seconds at 50 km/h would provide a safety margin of 4.27 - 2.43 = 1.84 seconds. Thus, in general, the safety margin is determined by subtracting the clearance time and the deceleration time of the accepted gap.

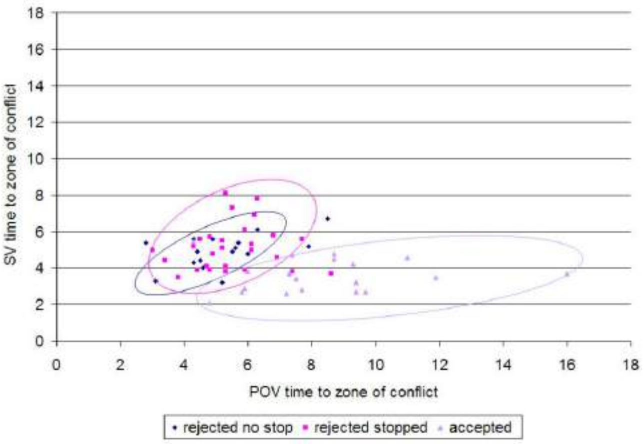


Figure 2.7: Accepted and rejected lags (Cody et al., 2007)

Smith et al. (2009) also studied a comfortable time buffer between two crossing vehicles at a simple intersection with a maximum speed of 50 km/h. They observed two crossing scenarios, which are shown in Figure 2.8. For the LTAP/OD situation a safety buffer of 2.32 seconds was found, whereas for the LTAP/LD safety buffer a value of 1.99 seconds was found. These time values were defined as the time between the moment the vehicle with the right-of-way has passed the conflict area, and the second vehicle enters this area.

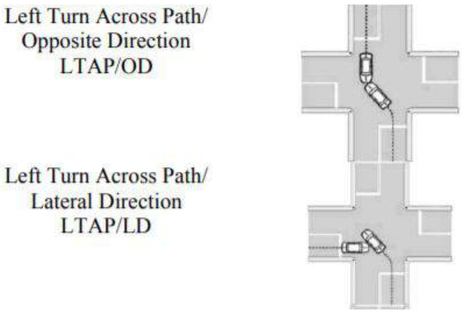


Figure 2.8: Crossing Manoeuvres considered by Smith et al. (2009)

Discussion of Literature regarding Lateral Distances between Cars

The literature that was studied in order to find the factors and suggestions for their impact considering lateral safety margins, also had a couple of discussion points. They are itemized below.

- The most important distinction found in the literature was related to the question whether the crossing vehicle was already at speed before it crosses in front of another vehicle. Safety margins that are required for the Space-Time reservations can be based on the situation where the crossing vehicle was already at a certain speed. Therefore, the most valuable literature came from Cody et al. (2007), Chovan et al. (1994), Ueno (1991) and Smith et al. (2009). The other literature discussed was valuable in a way that it described many factors that influenced the choice of a driver for a certain time gap.

- The literature studies found many factors that could influence the gap acceptance of a human driver. However, often only the fact that these factors could influence the gap acceptance was mentioned, rather than an explanation about their influence on the gap acceptance. Moreover, no concrete information about the relationship between several socioeconomic factors could be found. Finding correlations between the factors is advised for further research in order to draw conclusions about their impact on the gap acceptance values.

- Considering the future weaving traffic situation: as soon as a vehicle is driving on the conflict area, a Time-to-Collision (TTC) can be calculated indicating the time gap between the vehicle on the conflict area and the approaching vehicle on its left or right side. This situation was most comparable to the studies executed by Smith et al. (2009) and Cody et al. (2007): they analysed the encroachment behaviour of drivers. According to their results and assuming that the experiments were executed under normal circumstances (i.e. nothing unusual), it was assumed that crossing vehicles in the future weaving traffic situation perhaps will feel safe with a time gap (or: TTC value) between 1.8 and 2.3 seconds. However, it is important that these time gaps will be tested in future research (and for the experiment of Part II of this research) to validate them.

2.2.2. Conclusion Interaction HDVs

It is now clear that various factors can influence the preferred longitudinal and lateral distance between human-driven vehicles. These are summarized below, presented in a random order.

Factors - Longitudinal Distance

Age,
Characteristics of surrounding traffic,
Visibility,
Driving Experience,
Reaction time,
Gender,
Speed of surrounding traffic,
Weather conditions,
Time of day,
Speed
Vehicle Density,
Presence of surrounding traffic,
Vehicle type,
Mood,

Factors - Lateral Distance

Presence of surrounding traffic,
Vehicle density,
Age,
Gender,
Speed of surrounding traffic,
Nationality,
Mood,
Intersection geometry
Trip purpose,
Time of day,
Driving experience,

Table 2.2 summarizes factors found in the literature and their effect on a safety distance around a vehicle. In the ideal situation, for each factor a parameter value would be established that correspond with the influence it has on the average safety margin. However, in order to generate reliable parameter values, significant literature was lacking. Therefore, these descriptions provide only a modest idea about how the average safety margins can be influenced. Moreover, as can be seen, not all factors that were found in the literature were considered here. Only the factors for which a conclusion could be drawn based on the literature found were described here. The relations found were expected to apply for both longitudinal and lateral margins. Note that when a factor was not described here, it did not mean that no relationship would exist. A relationship probably still exist, however, the literature described in this study could not find significant relationships.

For future research it would be interesting to further investigate these factors and to define and validate parameter values. Moreover, it would be interesting to study if this list is complete. A factor that was not discussed thoroughly is visibility. This factor could possibly elaborated with literature regarding the design of the infrastructure. This probably play a role, but is not considered in this report, since this report assumes a simplified intersection with a minimal number of lanes. Other potential factors are vehicle types and the type of vehicles of the surrounding traffic (as already was highlighted in the studies of Sayer et al. (2003) and Mahmud et al. (2018)). This research only considered passenger cars.

Table 2.2: Expected relationships between non-technical factors and the safety margins

Factor	**Influence**	**Source**
Traffic Density	The more dense the traffic flow, the shorter distances are accepted by human drivers. This factor is related to the time of day. During rush hours, the traffic flow is higher than outside the peak hours, and thus shorter distances will be accepted. However, the average speed is also lower during peak hours.	Hamed et al. (1997), Ashalatha and Chandra (2011)
Speed	The time headway possibly depend on speed: the literature contradicts. Often no significant relationship was found between speed and time gaps. Considering vehicle following situations, some literature stated that higher speeds resulted in smaller time headway values.	Various studies, among which: Taieb-Maimon and Shinar (2001), Duan et al. (2013) Ashalatha and Chandra (2011), Zhou et al. (2017), Kaysi and Abbany (2007), and Suzuki and Yamada (2011)
Weather conditions	Weather can play an important role in when considering the preferred distance between vehicles. Fog can for example result in smaller headway values at low speeds, or larger headway values at high speeds. Wet roads also result in larger headway values, due to a longer braking distance.	Broughton et al. (2007), Siebert and Wallis (2019)
Gender	Most studies concluded a more conservative driving style for female drivers compared to male drivers. However, other studies found smaller values for the time headway for female drivers. Due to these inconsistencies, no conclusion was drawn about the influence of gender on safety margins	Taieb-Maimon and Shinar (2001), Zhou et al. (2017), Shinar and Schechtman (2002), Hennessy et al. (2011)
Age	No significant results could be found considering the driver's age according to the literature found.	Zhou et al. (2017), Shinar and Schechtman (2002), Hennessy et al. (2011)
Mood	The most popular mood studied in the current research was aggressiveness. Aggressive drivers mainly keep shorter distances, which is not always perceived as safe by other road users. Moreover, this behaviour is not safe according to the 2-second rule.	Hennessy et al. (2011), Zhou et al. (2017)
Visibility	The visibility on the road can be influenced by the traffic density, weather, and size or presence of surrounding vehicles. Less visibility result in larger safety margins.	Broughton et al. (2007), Siebert and Wallis (2019), Duan et al. (2013), Hegeman et al. (2004)
Driving Experience	Consequences of past driving experiences can influence the driver space preference. Events as collisions ask for a larger driver space around the vehicle.	Zhang et al. (2019)

2.2.3. Interaction Vehicles during Hybrid Situation

As explained before, during the hybrid traffic situation, both HDVs and CAVs will drive on public roads. Subsection 2.2.1 considered the current interaction between HDVs. However, during the hybrid scenario more interactions need to be considered. Here, automated vehicles can interact with each other or HDVs. This last interaction can be studied from the perspective of either the automated vehicle or the HDV. This subsection describes how the values found before can change according to human factors.

With the arrival of the automated driving technology, the role of the driver may fundamentally change. The driver will become a supervisor, rather than an operator (Boelhouwer et al., 2019). Drivers may be allowed to read a book or watch a movie while being driven. However, before this can become reality, first the user must accept automated driving. A major factor that influences user acceptance is *trust* (Choi & Ji, 2015). The question arises how trust influences the current safety margins. Also the driving style and driving experience are expected to influence the preferred safety margins, which is further explained in this subsection.

User Acceptance: Trust

As long as the majority of the vehicles does not drive (fully) automated, it is difficult to draw reliable conclusions on how the non-technical factors will exactly influence the safety margins in the hybrid traffic period. Based on the existing literature, which were often driving simulator studies, it was possible to make assumptions about the impact of automated driving on the perceived safety level of human drivers.

To create trust in automated driving for its occupants, it was expected that larger safety margins were desired in front of automated vehicles, especially at automated vehicles from level 3, where mainly the vehicle controls the steering. A study executed by Frison, Wintersberger, and Riener (2019) found that the feeling of being out of control ensures less trust with automated driving. The participants of this study declared that they assessed their own driving performance to be better than the performance of an automated vehicle. However, the traffic intensity had an influence on this opinion: During light traffic automated driving, the majority of the participants felt safe and comfortable. The heavier the traffic became, the less comfortable people felt. Another study added the conclusion that trust issues emerge in more complex environments (Frison, Wintersberger, Liu, & Riener, 2019). Therefore, at urban intersections it is expected that people become distrustful to the automated vehicle and prefer larger safety margins compared to the margins adhered during their own driving style. Moreover, according to Mackay et al. (2019), to ensure trust for the passengers, a passenger of an automated vehicle must be sure that the system is aware of its surroundings and is able to decide its course of action accordingly.

Beside studies that considered lower levels of automation, also a study related to the feeling of trust in highly automated vehicles was executed (Siebert & Wallis, 2019). This study concluded that a comfortable time headway in highly automated driving decreases with speed increase. Within an urban environment, the margins are thus expected to be larger than on rural roads and highways. According to the results of Siebert and Wallis (2019), a comfortable time headway in the urban environment (50 km/h) may lay between 1.5 and 4.0 seconds considering clear weather conditions. A value of 1.5 seconds was accepted by 50% of the participants of the experiment, whereas more than 70% of the participants accepted the margin of 4.0 seconds. Considering a similar environment with less visibility, 50% of the participants accepted a time headway of almost 2 seconds; 60% felt comfortable at 4.0 seconds. According to this study, perhaps a time headway of 4.0 seconds could be implemented in an urban environment for highly automated vehicles, at least at the starting phase.

Moreover, an earlier study presented in Siebert et al. (2014, 2017) focused on the preferred time headway towards any kind of vehicle by an occupant of a semi-automated vehicle. Factors as comfort and risk were evaluated during different car-following scenarios. It appeared to be that the transition from 2.0 seconds to 1.5 seconds equaled the transition from a pleasant to an unpleasant feeling for the occupant at a speed of 50 km/h. No real danger was experienced at time headway values between 4.0 and 2.5 seconds, which is in contrast with the highly automated vehicle situation.

Besides the possible desire for some extra space around automated vehicles, probably also human-driven vehicles prefer more space between their vehicle and an automated vehicle. Tennant et al. (2016) concluded something remarkable: human drivers think that automated vehicles can drive more safe than human drivers, however, the human driver also feels uncomfortable in boarding or driving alongside an automated vehicle. No real difference was found in the level of comfort when comparing the situations of boarding or driving alongside automated vehicles. On the contrary, the study also found that human drivers become more comfortable the longer they are exposed to automated driving. Although this may suggest that this has the potential to reduce the concerns of human drivers towards automated vehicles, still most of the people have doubts about this technology. The greatest fears of human drivers about automated vehicles are malfunctioning and the missing ability to interact with human drivers. On average, human drivers who already use some technology in their car, for example cruise control, are more open to use the automated vehicles (Tennant et al., 2016).

User Acceptance: Preferred Driving Style

For drivers to accept automated driving, it is also important that the driving style meet the expectations and that human drivers are still (partly) in control (Tennant et al., 2016). Griesche et al. (2016) considered the question whether drivers prefer their own - or at least a similar - driving style when driving in an automated vehicle. First, different driving styles were distinguished by executing a driving experiment with manually driven vehicles. These styles were later applied to automated vehicles and tested by participants. The results showed that most of the participants preferred their own driving style when applied to the automated vehicle. A few did prefer a different style, but as soon as a driving style had small safety margins and a high acceleration profile, none of the participants felt comfortable. This may suggest that the safety margins found earlier may not need to change drastically, at least not in the initial phase of automated driving. However, a driving style is defined by more factors than the time headway taken. An experiment would be valuable that test the required safety margins and to see if they can be equal to those found in the HDV-HDV situation. Possibly, margins can become smaller as soon as more and more automated vehicles will drive on public roads.

User acceptance: Driving Experience

It is expected that trust in automated vehicles will increase with more experience in automated driving, despite the remaining fears of this technology. Dixit et al. (2016) expect that when (fully) automated vehicles will make more driving hours, occupants will trust the technology more and more. They concluded this based on an increase in reaction time of the driver in an automated vehicle: when trust increases, distraction by the driver also increases, and the reaction time will also increase. Pereira et al. (2015) confirms this expectation. They studied the preferred time headway of drivers of semi-automated vehicles over time. They found that smaller safety margins became preferred with the increase of automated driving experience.

Finally, also smaller safety margins are expected with the increase of driving experience, based on the results of the study executed by Gouy et al. (2014). They concluded that human drivers adjust their behaviour according to the behaviour of other traffic. They found that human drivers also decreased their time headway value when the time headway of a platoon of trucks driving next to them, drove with a small time headway.

2.2.4. Conclusion Hybrid Traffic Situation

According to the previously discussed literature, it is expected that with the arrival of semi-automated vehicles, where the human driver can still control the vehicle, no significant changes will occur in the preferred time headway compared to the current traffic situation. However, with the arrival of highly and automated vehicles, where the human driver looses its ability to take over control, an increase in safety margins is expected. Perhaps this increase can take values up to 4.0 seconds (Siebert & Wallis, 2019).

As soon as human drivers or occupants of (semi-) automated vehicles get more experience with automated driving, the required safety margins will possibly decrease. However, no concrete values were found in the current literature that could quantify this expectation. Possibly the distance between CACC vehicles could be used as a reference point for the lower bound value. Currently, CACC trucks can already drive at a 0.3 second headway distance, which may be applied to CACC passenger cars too (Janssen et al., 2015).

2.3. Technical Factors

A basic traffic control system performs three steps: (1) detecting vehicles, (2) modelling their trajectory, and (3) sending instructions to a vehicle to follow the modelled path. These steps are repeated each time interval of the traffic controller. However, per step, inaccuracies can occur that affect the safety of the vehicle. These inaccuracies are explained in this subsection, in the same order as these three steps of the traffic controller. Eventually, the impact of actuator accuracy, reaction time, and time synchronisation are explained as the inaccuracies of the automated vehicles themselves. This section mainly describes technical factors related to automated vehicles, since their driving behaviour depends on technical factors, whereas the behaviour of human-driven vehicles mostly depend on human factors.

2.3.1. Measurement Inaccuracies

The first step to control traffic is to detect the vehicles. During this process two important inaccuracies can occur. These are discussed below.

Positioning Inaccuracy

It is desired to know the location of a vehicle as precisely as possible in order to plan its trajectory over the intersection. However, location determination is not perfect. A prominent positioning system is the Global Positioning System (GPS). GPS can determine a vehicle's speed and three-dimensional position quite consistently over time. Moreover, it has the advantage that its accuracy is not dependent on weather conditions or the country where the vehicle is located. However, in an urban area is it almost impossible to realize continuous localization due to the fact that the signal of satellites can be obstructed by tall buildings, trees, or tunnels (Shengbo et al., 2003; Mao et al., 2003).

To decrease the positioning inaccuracy of an (automated) vehicle, it is desired to apply more than one positioning system. For example, Q. Yang and Sun (2007) presented a design for an integrated location system based on GPS (Global Positioning System) and INS (Inertial Navigation System). INS is also able to determine the position and speed of a vehicle, but has the advantage that it is independent of external disturbances, since the system (accelerometers) is mounted on the vehicles itself. Their system design found a great improvement of the location accuracy compared to a GPS system without INS accuracy: location errors had a maximum value of 0.30 meters. Without integrating the INS system, the location errors increased to a value of 30 meters. Another example of a positioning system is described by Galileo (2018). This study confirms that a combination of technologies is necessary to meet safety requirements for automated driving. They state that combining camera images and lidar and radar data with high definition maps already allows vehicles to position themselves with high accuracy (roughly 10 cm). However, according to (Galileo, 2018), these systems alone are not reliably enough to make a driver unnecessary. The arrival of the 5G network offers opportunities for self-driving vehicles: according to del Peral-Rosado, Saloranta, et al. (2018), the exploitation of the fifth generation (5G) centimeter-wave and millimeter-wave transmissions will ensure high-accuracy positioning for self-driving vehicles. The expected arrival of 5G in 2020, and especially the arrival of 5G in the Netherlands in 2023 (Nando Kasteleijn, 2020), complement the availability of Global Navigation Satellite Systems (GNSS) in harsh environments, such as in dense urban cities (del Peral-Rosado, Saloranta, et al., 2018): Using 5G location precision with less than a meter error could be guaranteed. When applying centimeter-waves, the position accuracy lays around 6 meters in dense urban areas. However, when applying millimeter-waves, the accuracy could improve to values between 1 and 15 centimeters. The number of satellites and 5G-base stations that can be reached influence this value.

Besides the vehicle location accuracy of the vehicle, the accuracy of the map used by the controller is also of great importance. As soon as the digital map does not correspond to the real intersection topology, the space-time reservations cannot be scheduled correctly and safely. Currently the correctness of the topology files of all Dutch intersections are checked (Willekens & Stolz, 2018). To apply safety margins to space-time reservations according to the inaccuracy of the intersection topology files is an interesting topic for future research and shall not be further considered.

Concluding, when the system of (Q. Yang & Sun, 2007) would be used as the positioning system of Smart Traffic, a safety margin of only 0.30 meter would be necessary around the entire vehicle. However, with the arrival of 5G within the coming years, a much higher precision is expected to be guaranteed, even for self-driving vehicles. By applying millimeter-waves, a positioning accuracy of less than 10 centimeters can be guaranteed with only one base station available. Moreover, when the number of base stations will increase, this value could decrease to a value of only 2 centimeters (del Peral-Rosado, Saloranta, et al., 2018). A value of 2 centimeters around the entire vehicle would be negligible as safety margin.

Velocity Inaccuracy

The speed that is shown by a speedometer of a human-driven vehicle differs from the speed the vehicle is driving in reality by a percentage between 4 and 10% (ANWB, 2015). The speedometer of a car does not measure the speed based on the vehicle's position, but it calculates the speed according to the rotation of the vehicle's wheel, axle or driveshaft. However, the diameter of the vehicle's tires can change due to wear. New tires will have a larger diameter and can increase the tire pressure. On the other hand, worn tires result in a smaller diameter and low air pressure. Per vehicle rotation, the actual speed of a vehicle is higher for new tires, since the vehicle then travels a longer distance. However, the speedometer will not show speed differences between these two cases, since it determines the speed based on the number of wheel rotations per time unit (WeWantAnyCar, 2016).

Péter et al. (2019) confirms that it is important for automated vehicles to know its tire pressure, in order to be able to determine an accurate speed value: determining the speed per wheel (expressed in rounds per minute) is only reliable when the tire pressure is taken into account. Moreover Péter et al. (2019) claims that according to EU directives, all new vehicles should be sold with a built-in tire pressure monitoring system.

Speedometers based on GPS are more accurate, since they determine the vehicle's speed based on the time in which a vehicle travelled a certain distance. However, the accuracy of such navigation systems is determined based on the satellite signal quality and also on the terrain the vehicle is driving (namely, GPS navigation systems do not take changes in vertical direction into account). Moreover, GPS based velocities always represent an average speed, since it is determined according to measurements of two moments in time. Therefore, navigation systems that use data from the vehicle itself and integrate this with the GPS signal have an improved accuracy (WeWantAnyCar, 2016). Nie et al. (2018) confirms that the tracking accuracy of speed plays a significant role in the automated vehicle's control and safety management. They found that inaccuracies could be either higher of lower than the actual speed. It is important to note here that a CAV monitors its speed regularly. The time interval on which the *vehicle controller* monitors this speed, will also result in a certain safety margin, since the speed of the vehicle can be lower of higher than the assigned speed.

To conclude, when assuming that automated vehicles base their velocity value on their location (via GPS or 5G), instead of calculating the speed via wheel rotations, the location accuracy and velocity accuracy will probably correlate, and velocity accuracy will maybe not play a significant role in the role of safety margin determination. On the other hand, when assuming that they will not correlate, safety margins will be required in (at least) longitudinal direction in order to cover for the velocity inaccuracy of both HDVs and CAVs. Further research to the correlation between these values is required.

2.3.2. Model Inaccuracies

After detecting traffic, the vehicle trajectories are modelled and the order at which the vehicles may cross the intersection is determined. The potential inaccuracies for this part of the control system are related to the communication between the vehicles and infrastructure, and to the computation time of the model. These inaccuracies are discussed below.

This research assumed that an automated vehicle 'asks' for a time slot to cross the intersection via V2I-communication. The intersection communicates a trajectory plan for the vehicle. Until that moment, no unsafe situations will occur due to model inaccuracies. Only during emergency situations, when vehicles need to brake unexpectedly and space-time reservations therefore must be rescheduled, potential communication delays between the vehicle and the infrastructure are important to consider in the safety margins. Likewise, the computation time of the model and reaction time of the vehicles shall only be important to take into account during emergency situations. However, since the emergency situation is not the scope of this research, these factors will not be further discussed after this subsection.

Latency of communication

Considering the future situation where automated vehicles receive a space-time reservation from the traffic controller Sweco Nederland (2018), there are two moments of communication: when the automated vehicle communicates its location and other parameters to the traffic controller; and when the traffic controller communicates the space-time reservations to the automated vehicle. For both moments a certain delay will exist between the moment of sending and receiving the message. The value of the delay will depend on the network type used. As explained before, currently the 5G network is being developed. A requirement of this network is to minimize the value of latency to 1 millisecond (ms) (Park, 2018). Currently, the 4G network is used for V2I communication with a communication delay around 20 ms (Tao, 2018). The delay in communication is especially important to consider during emergency situation. Namely, if an automated vehicle is driving according to its space-time reservation, but suddenly it needs to brake or divert, it is not driving according to the space-time reservation anymore. This could have an impact on the possibilities for other traffic to stay within their reservation. In order to lead the other traffic safely through the intersection, fast communication between the vehicles and infrastructure is essential. Assuming a communication delay of 20 ms, the total time between an unexpected move of an automated vehicle, and receiving new driving instructions by the surrounding vehicles of the TC, will cost at least 20 ms + computation time of model (see next factor). These inaccuracies could be added as safety margins. However, the question is if these values are high enough to actually require a safety margin.

Computation Time Traffic Model

The traffic model also needs a certain computation time in order to determine the Space-Time reservations for each vehicle (and to determine the traffic light phases). However, no value was determined for the computation time of the improved Smart Traffic control system. Neither is a certain time described in other automated traffic control concepts. Currently the computation time of Smart Traffic varies between the 2 and 3 seconds. Considering Smart Traffic, as soon as a vehicle is registered it will be included in the following forecast cycle. In worst case, a vehicle is registered just at the beginning of a new cycle. In that case, the computation time is twice the cycle time. The best case scenario hold a computation time equal to one cycle time. When a vehicle is waiting for its iSpaT message, it is uncertain for the traffic model how the vehicle will behave. The iSpaT message must cover for the computation time of the traffic model and the possible speed profiles of the vehicle, to ensure that the vehicle will be able to track the assigned trajectory.

2.3.3. Vehicle Inaccuracies

Also inaccuracies of the automated vehicles can lead to the desire of safety margins around the vehicle. They are summarized below.

Actuator Accuracy

When a vehicle is planning to make a right or left turn, it is important to consider that not every vehicle will use the same space in order to make that turn. The angle of the turn can differ per vehicle according to the size of the vehicle, the speed of the vehicle, the maximum acceleration, and deceleration. Moreover, vehicles will always swing out, meaning that the width of the curved path driven by the vehicle is wider than the width of the vehicle itself. This effect has a positive relationship with the vehicle's size causing larger vehicles to swing out more and thus requiring even more extra space at the crossing area than smaller vehicles. Furthermore, their speed is expected to be lower while making a turn, which results in a longer period of making the turn. Finally, steering errors will also require a safety margin around the entire vehicle. Steering errors can be the result of technical errors in the vehicle or can occur due to external influences, for example due to heavy wind.

Reaction Time

Apart from the inaccuracies that can occur during the vehicle control stages, another important technical factor of the vehicle must be considered: its reaction time. This factor is also important to take into account during the the safety margin determination because of possible emergency situations. For example, when a child unexpectedly crosses the street, the automated vehicle must be able to brake without leaving its space-time reservation. The time it takes for a vehicle before it starts braking is the reaction time of the vehicle.

The reaction time varies per vehicle type. As said before, the reaction time of a human driver is assumed to be 1 second Openbaar Ministerie (2018). However, this value increases when the vehicle is partly automated, since the driver can be more distracted (as explained in Section 2.2). A fully automated vehicle is expected to have a lower reaction time than a human driver: if vehicles are connected to each other and are automated, a reaction time of 0.1 second can be established (Talebpour & Mahmassani, 2016, 2016). However, the reaction time can be influenced by its environment and the penetration rate of connected vehicles (Talebpour & Mahmassani, 2016). According to Park (2018), within the 5G network, the reaction time between connected and automated vehicles may be decreased to a value of 1 ms. To make reliable conclusions about the reaction time of a human driver, more literature research would be necessary. A safety margin due to the vehicle's reaction time would be required in front of the vehicle, since it needs enough space in front when it needs to react to something unexpected. It possibly also requires some extra space at the back of the vehicle to cover for the decrease in speed when the vehicle brakes.

Time Synchronisation
Since an individual Space-Time reservation will inform a CAV where it needs to be at what specific moment in time, it is desired that the internal clocks of the CAV and the traffic control system are aligned. However, as a result of the nature of time keeping technology, two clocks will rarely indicate the exact same time at every moment: thus the clocks of the CAVs and the clock of the traffic control systems are expected to occasionally be out of alignment as well. Hence, it could happen that two vehicles will be at the same position at the 'same' time (i.e. a collision occurs). However, according to those vehicles, they would be at that location at different moments in time (or would be at different locations at that time). Thus, to generate a series of individual Space-Time reservations that will not cause any collision, the traffic control system must know what time it is at the corresponding CAV. In order to deal with this possible offset, the traffic control system can attempt to synchronise its clock with that of an entering CAV. Several advanced synchronisation techniques have been developed in prior research that reduce any possible offset as much as possible (Hasan et al., 2018). However, complete certainty of the total absence of any offset can never be achieved. Latency in determining internal time in one of the agents (here either a CAV or the traffic controller) in the system, in decoding the time in a message to be sent to another agent or in sending a message to another agent are extremely hard to determine with a satisfactory amount of certainty. This results in, however small, a possible offset of the clock in the CAV with respect to the clock in the traffic controller, the size and direction of which is unknown. Depending on whether the internal clock of the CAV is ahead or behind the clock of the controller, an extra safety margin is thus required in front of or behind the vehicle. Namely, when the clock of the CAV is ahead of the clock of the controller, the CAV will be at the reserved location earlier than was planned by the traffic control system. Contrarily, when the clock of the CAV is behind, a safety margin is required at the back of the CAV.

2.4. Conclusions according to the literature

Below the main conclusions from the literature study are itemized. The factors that do not change with variations in environmental conditions or human characteristics are explained in more detail in Chapter 3.

- The technical and non-technical factors explained, asked for either a fixed space (e.g. preferred driver space or positioning inaccuracy) or a flexible space (e.g. preferred time headway or velocity inaccuracy) around the vehicle.
- Non-technical factors that can cause safety margins mainly cover factors that depend on the perceived safety of human drivers. It appeared that the distances currently kept on public roads, often not guarantee actual safety to the road users.
- When (fully) automated vehicles will be on the road, it is expected that first people need to gain trust in not having control over the vehicle anymore, before daring to drive with small distances towards surrounding traffic. When the trust increases (by time and experience), the safety margins are expected to be able to become smaller than the current margins held.
- Also technical factors can result in required safety margins around a vehicle. These occur due to inaccuracies that can occur at the traffic control system (i.e. measurement- and model inaccuracies), and due to technical inaccuracies of the vehicles themselves (e.g. actuator inaccuracy). The safety margins that follow from these technical factors all result in guaranteeing the actual safety of the vehicle.

3

Determination Safety Margins

This chapter describes the impact of all factors that were found during the literature study on the minimum required space that must be reserved for Space-Time reservations. All four interaction scenarios that exist in the hybrid traffic period were considered. After all factors and their impact were described, the first research question could be answered.

3.1. Description "individual Space-Time Reservations"

Considering the literature described in Chapter 2, the first sub-question could be answered: *What is the relationship between an individual Space-Time reservation, actual safety margins, and perceived safety margins?*. The answer is provided by presenting and explaining the definitions of these concepts as follows:

- **Individual Space-Time reservation:** A spatial area on the road that is reserved for only one vehicle during a specific moment in time. The entire vehicle must occupy the assigned area at the indicated time in order to safely cross an intersection. The size of a reservation is based on the vehicle size, which is communicated by the vehicle itself to the traffic controller. The required size of this area grows due to the *actual safety margins* and *perceived safety margins* around the vehicle. As soon as the vehicle receives an *iSpaT message* from the traffic controller, it gets assigned a personal trajectory that includes a series of Space-Time reservations that must be tracked by the vehicle. However, the spatial area that is communicated to the CAV only consist of the vehicle size (See Figure 3.1 - A). The traffic control system plans all reservations by considering both the actual and perceived safety margins (See Figure 3.1 - C). Equal to the maximum frequency at which a CAV can broadcast its current location to the traffic controller, each 0.1 second one reservation must be available for the vehicle. Consequently, checking whether the CAV is tracking the trajectory correctly is easy for the traffic controller.

- **Actual Safety Margins:** Several factors can influence the reliability of the current position of a CAV and the reliability of the CAV being able to track its trajectory. These inaccuracies are important to take into account while determining the dimensions of the spatial area that must be reserved for that vehicle. The impact of factors that influence these inaccuracies are translated to certain actual safety margins around the vehicle location that is communicated by the vehicle. These actual safety margins make the vehicle virtually grow. When adding all actual safety margins to the communicated vehicle location, an area occurs in which the vehicle must be located. This area is called the *Potential Vehicle Location* and is thus a summation of all actual safety margins plus the vehicle size. The traffic control system thus communicates iSpaT reservations to the vehicles equal to the vehicle size, but it knows that the vehicle might not be able to strictly follow these reservations. Though, the traffic controller knows that the vehicles will drive closely to these reservations (as illustrated in Figure 3.1 - B). Actual safety margins can be the result of both technical and non-technical factors.

  - *Location Inaccuracy:* Due to multiple factors, mostly technical factors, the location communicated by a vehicle is not fully reliable. Nor is there a guarantee that the vehicle will track its trajectory perfectly. It is important to take these uncertainties into account in order to avoid two or more vehicles being in the same spatial area at the same time. Actual safety margins will thus avoid collisions from occurring;
  - *Potential Vehicle Location:* The real vehicle size plus the size of all actual safety margins around the vehicle. This spatial area describes the space where the vehicle is (expected to be) located (See Figure 3.1 - B).

- **Perceived Safety Margins:** Similar to the actual safety margins, also the perceived safety margins result in a required space around the vehicle: the *Preferred Clearance Zone*. However, the space following from the perceived safety margins is not based on the location inaccuracy of the vehicle, but on the feeling of safety of its occupants. The goal of these margins is to let people feel safe in their car, especially when they have no control of their vehicle anymore (i.e. CAV). The perceived safety margins are added to the actual safety margins, which let the virtual vehicle size grow even more. The size of a perceived safety margin may vary at different conflict situations.

  - *Preferred Clearance Zone* A spatial area around the PVL free of other traffic in order to let the car occupants feel safe (See Figure 3.1 - C);

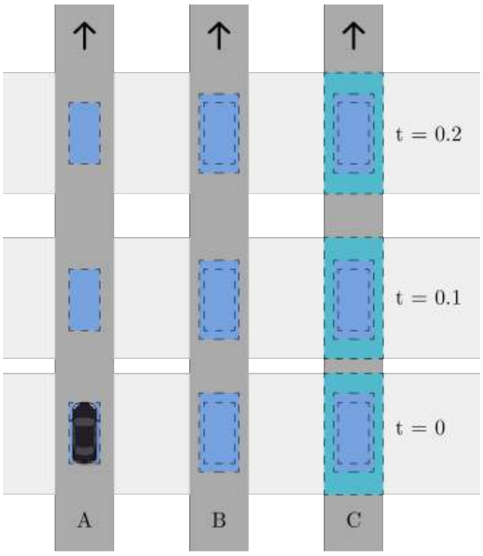


Figure 3.1: Sizes of iSpaT Reservations. A) Vehicle size: communicated reserved locations to the vehicles; B) PVL of the vehicle while tracking the trajectory; C) Size used by the traffic control system to plan all iSpaT reservations: PVL + PCZ

As became clear from the literature, multiple factors, both technical- and non-technical, can result in required safety margins around a vehicle. Tables 3.1 and 3.2 provide an overview of all factors found in the literature that influence the size of the safety margins. These tables moreover give the answer to the second sub-question: *Which factors influence the safety margins for the*

Space-Time reservation considering both HDVs and CAVs? As can be seen in the tables, a distinction was made between the technical and non-technical factors and between HDVs and CAVs. Another distinction was made based on whether the influence of a factor on a safety margin was dependent on the speed of the vehicle and / or dependent on specific (environmental) scenarios. When a factor was dependent on a specific scenario, the impact of the factor depended on for example environmental conditions, like weather conditions, road conditions, like traffic density, or the mental conditions, like mood or level of trust. Furthermore, when the influence was not dependent on the speed of the vehicle, the corresponding margin was later described as a fixed distance around the vehicle. If the influence was dependent on speed, the size of the margin could vary with speed differences. Note that this table does not yet make a distinction whether a factor contributes to the size of actual safety margins or perceived safety margins. Whether a factor resulted in an actual or perceived safety margin is explained in Section 3.2.

To conclude, there is a difference in the Space-Time reservations that are communicated to the CAV and that are used by the traffic control system. The CAVs will get assigned Space-Time reservations having a size equal to their vehicle size. Besides, the traffic control system plans the reservations of all CAVs by also taking into account the PVL and PCZ. Section 3.2 explains how the actual and perceived safety margins must be combined to form a PVL and PCZ, and Section 3.3 explains if and how the PVL and PCZ of one vehicle can overlap with those of other vehicles.

Table 3.1: Overview of Technical Factors that influence the Safety Margins around a Vehicle. References: [1]: del Peral-Rosado, Saloranta, et al. (2018), [2]: ANWB (2015), [3]: Tao (2018), [4]: Park (2018)

	Technical Factors	
	Human-Driven	*Automated*
Independent of Speed, Independent of Scenarios	**Location Inaccuracy:** Hard to predict for HDVs. Assume each HDV to be traceable via a 5G electronic device.	**Location Inaccuracy:** Depends on location system. 5G network enables 0.10 m accuracy [1].
Dependent of Speed, Independent of Scenarios	-	**Computation Time Model:** During an emergency / unexpected situation, the AV will shortly continue driving without knowing its (new) reservation.
	-	**Sampling Time:** The automated vehicle will regularly check its driving speed to its desired speed. In case of a deviation, the vehicle can drive faster or slower than desired.
	Velocity Inaccuracy: Difference between measured and actual speed. Actual speed of HDV is often 4 to 10% higher than its measured speed [2].	**Velocity Inaccuracy:** Difference between measured and actual speed. Actual speed of CAV can be either higher or lower than its measured speed.
	-	**Communication Delay V2I and V2V:** Similar to Computation Time Model.
	-	**Reaction Time:** Considering CAVs: 4G has a reaction time of 20 ms [3]; 5G of 1 ms [4]. Reaction time will increase when human intervention is necessary. Applicable during emergency situations.
	-	**Time Synchronisation:** Because of inaccuracies in synchronisation of clocks in CAVs and the traffic controller, inconsistencies can occur between the tracking path of the CAV and the tracking path expected by the traffic controller.
Independent of Speed, Dependent of Scenarios	**Acutator Accuracy:** While making a turn, the vehicle needs extra space depending on the angle of the turn and the size of the vehicle.	**Actuator Accuracy:** While making a turn, the vehicle needs extra space depending on the angle of the turn and the size of the vehicle.
Dependent of Speed, Dependent of Scenarios	-	**Driving Experience:** More driving hours of AV's result in more 'reference material' that yields a better perception and prediction of surrounding traffic. Hence, AV's learn how to interact with other traffic.

Table 3.2: Overview of Non-Technical Factors that influence the Safety Margins around a Vehicle. References: [5]: Openbaar Ministerie (2018)

	Non-Technical Factors	
	Human-Driven	*Automated*
Independent of Speed, Independent of Scenarios	**Preferred Driver Space:** Fixed Space around the vehicle desired by human driver.	**Preferred Driver Space** Fixed Space around the vehicle desired by human occupants.
Dependent of Speed, Independent of Scenarios	**Reaction Time:** Assumed to be 1 second for a human driver [5]. Can increase in partly automated vehicles, when driver feels less responsible while driving. Applicable during emergency situations.	-
	Preferred Time Headway: Clear distance preferred to have in front of the vehicle, measured from rear-end followed vehicle to front-end following vehicle.	**Preferred Time Headway:** Clear distance preferred to have in front of the vehicle, measured from rear-end followed vehicle to front-end following vehicle.
	Accepted Time Gap: Clear space accepted to have at both sides of the vehicle, while crossing in front or at the back of another vehicle. May depend on own driving style.	**Accepted Time Gap:** Clear space accepted to have at both sides of the vehicle, while crossing in front or at the back of another vehicle. May depend on trust and comfort of driving style of CAV.
Independent of Speed, Dependent of Scenarios	-	-
Dependent of Speed, Dependent of Scenarios	**Driving Experience:** Bad driving experiences (accidents) leads to a desire for more space around vehicle. Possible good experiences result in a desire for less space around the vehicle.	**Driving Experience:** More experience with driving in AVs leads to more trust in the vehicle and daring smaller margins.
	Trust: Drivers lose trust with the feeling of behing out of control. In HDVs people control their own vehicle. People mostly trust their own driving style (i.e. acceleration profile, max. speed, etc.).	**Trust:** At starting phase, higher time headway value is required. User acceptance leads to lower time headway values and comes with experience and penetration rate.
	Traffic Density: More dense, shorter accepted time headway values.	-
	Weather Conditions: On average, time headway increases with bad weather conditions (less visibility (fog) and wet road surface (rain)).	**Weather Conditions:** CAVs will suffer less during bad visibility because of their sensors. However their braking distance also increases on wet roads.
	Mood: Aggressive drivers accept shorter gaps and time headway values	-
	-	**Preferred Driving Style:** Mostly prefer own driver style (max. acc, dec, speed). People do not prefer small safety margins or a high acceleration profile.
	Visibility: Less visibility results in uncertainty and thus higher time headway values and larger gaps.	-

3.2. Safety Margins per Factor

This section answers the third sub-question: *What safety margins, either actual or perceived, does each influencing factor individually require to establish safe space-time reservations?*.

An important distinction made in Tables 3.1 and 3.2 is the distinction whether or not the influence of a factor depends on a specific scenario. Namely, these factors require further research to find their precise impact on the size of safety margins. Especially research on how the different (environmental) conditions correlate is necessary in order to generate correct parameter values that describe the quantitative relationship between the size of the safety margin due to that factor and the variation of the (environmental) conditions. Factors that were dependent on a specific scenario were therefore not considered in the mathematical description of the safety margins. Table 3.3 summarizes the qualitative relationships found between the scenario-dependent factors and the required safety margin size. Possibly more factors could be added after further research.

Table 3.3: Qualitative explanation of expected relationships between scenario-dependent factors and the size of a safety margin. Vehicle perspective and expected type of safety margin indicated.

Scenario-dependent factor	**Vehicle perspective**	**Actual / Perceived safety**	**Relationship with safety margin size**
Driving Experience of CAV	CAV	Actual	The more driving hours a (C)AV makes, the more its perception and prediction of other traffic behaviour improves, and the smaller the necessary safety margins are expected to be.
Driving Experience of human driver	HDV	Perceived	More bad driving experiences leads to larger safety margins.
Driving Experience of human occupant	CAV	Perceived	More good driving experiences in (C)AV, leads to smaller safety margins.
Trust	HDV	Perceived	The higher the feeling of being out of control in traffic (themselves or conflicting vehicles), the larger safety margins are required.
Trust	CAV	Perceived	More trust in the (C)AV leads to smaller safety margins.
Traffic Density	HDV	Perceived	A more dense traffic stream, leads to smaller safety margins.
Weather Conditions	HDV	Both	Bad weather conditions lead to larger safety margins.
Weather Conditions	CAV	Both	Bad weather conditions lead to larger safety margins. However, a decrease in visibility might not play a role anymore.
Mood	HDV	Perceived	The more aggressive the driver, the smaller the safety margins can be.
Preferred Driving Style	CAV	Perceived	Often people prefer their own driving style for the (C)AV (i.e. acceleration profile, max. speed, etc). Another style may lead to larger margins.
Visibility	HDV	Perceived	Less visibility results in larger safety margins.

3.2.1. From safety margins to PVL and PCZ

Subsection 3.2.2 explains the influence of multiple factors that require either an actual safety margin or a perceived safety margin around the vehicle. It shows how and where around the vehicle the impact of the various factors could result in a safety margin, and it describes the possible differences in outcome for the four interaction scenarios. In total, 6 factors are discussed, which influence the size of either the PVL or the PCZ. They are summarized below.

Factors determining the PVL:	*Factors determining the PCZ:*
Positioning inaccuracy M_p	Preferred time headway M_h
Trajectory tracking inaccuracy M_{tt}	Preferred driver space M_{ds}
Time Synchronisation M_{ts}	Accepted time gap M_{gap}

However, this subsection first explains how these factors must be combined to determine the PVL and PCZ and provides impressions of both the PVL and PCZ around the vehicle.

All actual safety margins cover for the worst case scenario that can be the result of their corresponding factor. For example, the positioning inaccuracy appears to be maximum 0.10 m for CAVs using the 5G network, thus their actual safety margin due to positioning inaccuracy is 0.10 m. Furthermore, Subsection 3.2.2 also explains on what side of the vehicle the safety margin is required. Namely, not all safety margins are required on each side of the vehicle. Neither are all safety margins required during each interaction scenario. Table 3.4 presents an overview which safety margin is required during which interaction scenario. Besides, Table 3.5 shows where around the vehicle the safety margin is required.

The PVL is formed by actual safety margins. Since all these factors can result in a worst case scenario, the size of the PVL equals the summation of all actual safety margins in order to guarantee the actual safety of a vehicle.

Table 3.4: Overview which formula can be applied to which interaction scenario

	HDV-HDV	**HDV**-CAV	**CAV**-HDV	**CAV**-CAV
M_p	x	x	x	x
M_{tt}			x	x
M_{ts}			x	x
M_h	x	x	x	x
M_{ds}	x	x	x	x
M_{gap}	x	x	x	x

Table 3.5: Overview of location around vehicle where each safety margin value is required

	Front	**Back**	**Left**	**Right**
M_p	x	x	x	x
M_{tt}	x	x		
M_{ts}	x	x		
M_h	x	x		
M_{ds}	x	x	x	x
M_{gap}			x	x

On the other hand, to guarantee each car user feeling safe, the perceived safety margins are not required to be added up. Applying the largest perceived safety margin at each side of the vehicle is sufficient to guarantee a safe feeling for each car occupant.

According to the previous statements, Equation 3.1 describes the summation of the actual safety margins in order to determine the size of the PVL. Furthermore, Equation 3.2 shows from which perceived safety margins the maximum value must be taken to find the PCZ. The equations are described for each interaction scenario and each side of the vehicle.

$$\mathrm{PVL}^{is} = M_p^{is} + M_{tt}^{is} + M_{ts}^{is} \qquad \forall i \in I, \forall s \in S \tag{3.1}$$

$$\mathrm{PCZ}^{is} = \max\{M_{ds}^{is}, M_h^{is}, M_{gap}^{is}\} \qquad \forall i \in I, \forall s \in S \tag{3.2}$$

$I = \{\text{HDV-HDV, HDV-CAV, CAV-HDV, CAV-CAV}\}$
$S = \{\text{FRONT, BACK, LEFT, RIGHT}\}$

Furthermore, Figure 3.2 illustrates the actual (dark blue) and perceived (cyan) safety margins around a vehicle as a result of the various factors. As can be seen, the PCZ is illustrated as a space around the entire PVL, in order to cover for vehicles approaching from all directions. Furthermore, note that this figure only illustrates the construction and location of the PVL and PCZ, but that the margins were not drawn to scale. Moreover, as is explained in the following subsection, according to the literature study, no certainty could be provided about possible symmetry of safety margins. Therefore, although this figure illustrates symmetry in the safety margins, this statement would require further research to provide a reliable conclusion about symmetry.

3.2.2. Formulation Safety Margins per Interaction Scenario

As became clear, various factors determine the Potential Vehicle Location (PVL) and the Preferred Clearance Zone (PCZ). Three inaccuracies determine the PVL of a vehicle: the positioning inaccuracy, the trajectory tracking inaccuracy, and the inaccuracy of the time synchronisation. All inaccuracies are defined as a maximum deviation that could occur. Hence, a vehicle was expected to never drive outside the PVL. The PCZ was defined based on the preferred time headway, the

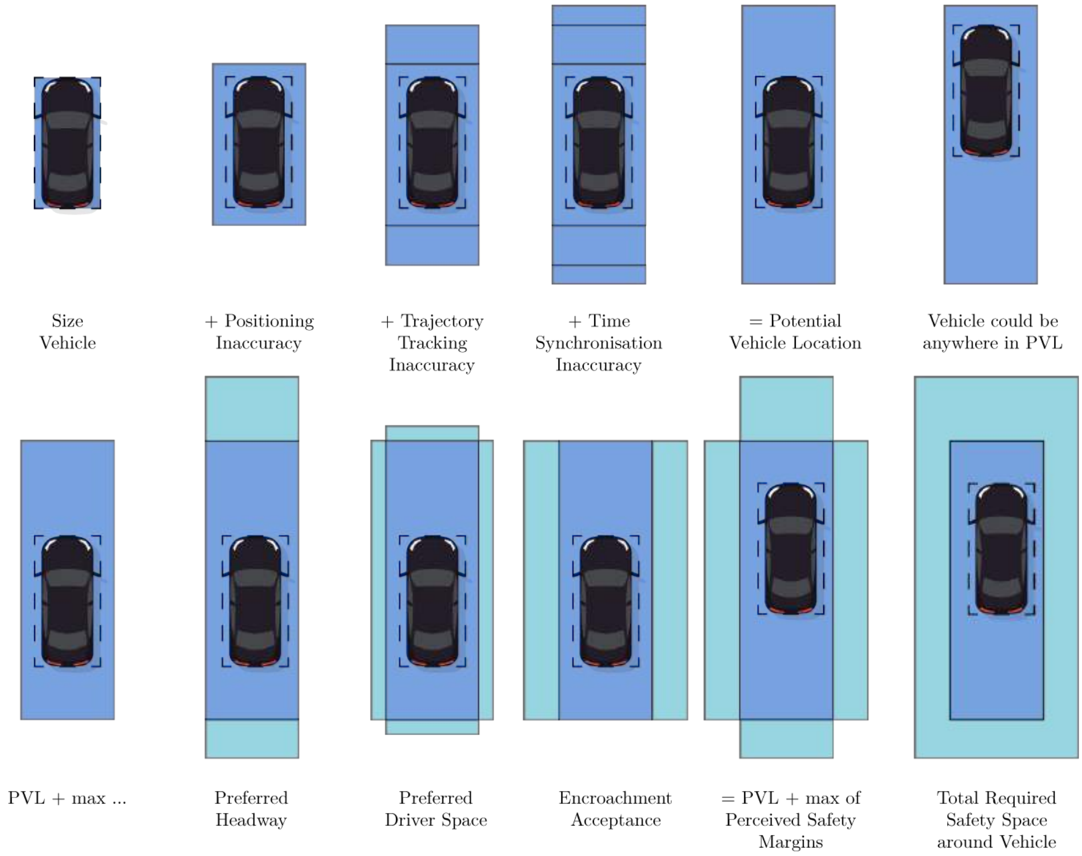


Figure 3.2: Positioning of safety margins around the vehicle. Blue illustrates the PVL, Cyan illustrates the PCZ around the vehicle.

preferred driver space, and the gap acceptance of a car occupant. Below the impact of the factors on the size of the PVL and PCZ is discussed, and whenever possible, a corresponding formula is presented that describes the required size of either an actual safety margin or a perceived safety margin.

Actual Safety Margins - Positioning Inaccuracy

The positioning inaccuracy is described as the maximum difference between the real position of a vehicle and the assumed position via, for example, GPS or, as expected for 2023, 5G positioning systems. The inaccuracy of the exact position of a vehicle is categorised as an actual safety margin, since this factor contributes to the definition of the possible area where the vehicle could possibly be located.

Since the concept of iSpaT messages is developed for urban intersections, the positioning inaccuracy of vehicles within the urban area was researched. With the current applied technology of GPS, realizing continuous localization of vehicles in urban areas is almost impossible due to the fact that the signal of satellites can be obstructed by tall buildings, trees, or tunnels (Shengbo et al., 2003; Mao et al., 2003). With the arrival of the 5G network, high positioning accuracy is possible, even in tunnels or indoor (del Peral-Rosado, Granados, et al., 2018). The exact positioning error will depend on the number of base stations that can detect the vehicle. When considering millimeter waves, and only one base station, an accuracy of less than 10 centimeters could be achieved in the urban area in 90% of the time. More base stations could decrease the inaccuracy to only 2 centimeters in an urban area (del Peral-Rosado, Saloranta, et al., 2018). This research assumes that 5G is expected to be rolled out prior to the concept of iSpaT reservations working on the Dutch roads, hence the research also assumes that the position of both HDVs and CAVs could be determined using the 5G network. Considering CAVs, their communicated position was assumed to equal the center of the vehicle. Hence, the positioning inaccuracy value applies around the entire vehicle. However, when considering HDVs it could not be assumed that the position broadcast equals the center of the vehicle, since this position was determined based on an 5G connected electronic device assumed to be present in the vehicle, which in fact could be located anywhere in the vehicle. The deviation of the center point of the HDV therefore equals in longitudinal direction a maximum value of 0.10 m + half the size of the car length, and in lateral direction 0.10 m + half the size of the car width. However, the exact vehicle size of HDVs will be unknown to the traffic controller. To define a more exact positioning inaccuracy value for HDVs, methods should be found to be able to reliably determine the size of HDVs. When assuming a passenger car size of 1.7 m x 4.00 m (e.g. Suzuki Belano), respectively the lateral and longitudinal location inaccuracy values would be 0.95 m and 2.1 m. However, also passenger cars of 5.7 m length (i.e. Cadillac Escalade ESV) or having a width of 2.1 m (i.e. Chrysler Crown Imperial) can drive on the public roads. Assuming these dimensions as the worst case scenario, a longitudinal safety margin of 2.95 m would be required, and a lateral safety margin of 1.15 m.

This research considers the worst case scenarios. Therefore, the positioning inaccuracy of CAVs would result in a safety margin around the entire vehicle of only 0.10 m. However, for HDVs the longitudinal margin could rise up to a value of 2.95 m, and a lateral margin of 1.15 m. Equation 3.3 represents the safety margin required to cover for the positioning inaccuracy of vehicle V at side S.

$$\mathrm{M}_p^{Vs} = p^{Vs} \tag{3.3}$$

Where:

M_p^{Vs}	=	Safety margin required by positioning inaccuracy of vehicle $V \in \{HDV, CAV\}$	[m]
p^{Vs}	=	Positioning inaccuracy of vehicle V at vehicle side $s \in \{front, back, left, right\}$	[m]

Actual Safety Margins - Trajectory Tracking Inaccuracy

As explained earlier, each CAV will get assigned a trajectory that describes where on the road the CAV is allowed to drive per time step (of 0.1 s). However, inaccuracies can occur while the vehicle is tracking its trajectory. To ensure that the vehicle will arrive at each assigned location in time, the reserved location per time step must be larger than the vehicle size. In other words, the vehicle could arrive later or earlier at an assigned location than was prescribed by the trajectory, hence actual safety margins are required to cover for these deviations in time of arrival. Various factors could influence whether a vehicle arrives earlier or later at the intended location. Further research is necessary to find all these factors and to explain the magnitudes of the inaccuracies. However, two factors that were found through the literature study that influence the accuracy with which a vehicle can track its trajectory, are described in this subsection: (1) the velocity inaccuracy of the vehicle, and (2) the sampling time of a CAV during which it checks its measured speed with its desired speed. Other factors that could influence the trajectory tracking accuracy, but which need further research, include the total weight of the vehicle, the cruise control mechanism of the vehicle, the quality of the road surface, and the slope of the road. These factors influence the acceleration and deceleration capability of the vehicle, and possibly depend on the reaction time of the vehicle. Below, the influence of the velocity inaccuracy and sampling time on trajectory tracking are described.

As explained before, via V2I-communication the CAV will communicate several parameters to the traffic controller in order to let the traffic control system determine a suitable trajectory for that vehicle. One of these communicated parameters is the current speed of the vehicle. This speed equals the speed measured by the vehicle itself. However, this speed (i.e. measured speed) can deviate from the actual vehicle speed. Subsequently, the difference in speed asks for an actual safety margin and will thus influence the PVL.

Chapter 2 descirbes the inaccuracy in the speed measured by an HDV to often result in 4 to 10% higher value than the actual speed of the vehicle (ANWB, 2015). An HDV is therefore expected to never drive faster than measured. Hence, the HDV would always drive slower than the speed that would be known to the traffic control system. Therefore, a safety margin is required at the back of the HDV, which compensates for the fact that the vehicle will probably arrive later at a space-time reservation.

On the other hand, CAVs also deal with velocity inaccuracies. Current research shows that the velocity measured can be both higher and lower than the actual speed of an automated vehicle (Nie et al., 2018). These speed deviations are mainly the case at speeds below 60 km/h (Tejado et al., 2011). However, no quantitative value was found that could express the maximum and minimum velocity inaccuracy. Therefore, the same percentages as for HDVs were assumed. Though, further research would be desired to find a more reliable value for this inaccuracy.

It was assumed that a parameter w^V for the velocity inaccuracy of vehicle V could be expressed as a percentage of the measured speed, calculated as follows: $\frac{v^V}{u^V} - 1$, where v^V is the measured speed of vehicle V, and u^V is the actual speed of vehicle V. Depending on the actual value, which is in fact unknown, the outcome, or velocity inaccuracy parameter w, can be either positive or negative. A negative w would indicate a safety margin required at the back of the vehicle, whereas a positive value requires the safety margin in front of the vehicle.

To express the velocity inaccuracy in terms of an actual safety margin, the monitoring time T of the traffic control system can play an important role. Namely, each time the control system refreshes the traffic model, the location of all vehicles was communicated again. In that case, the consequences of the velocity inaccuracy (in terms of distance) begin from 0 meters again. This means that this actual safety margin can only increase its size (due to velocity inaccuracy) within the duration of one monitoring time step T. M^V_{vel} expresses the actual safety margin that is required to cover for these velocity inaccuracies.

Moreover, an automated vehicle itself will regularly check its current speed with the speed it desires to drive to track its trajectory. The time between two of these checks is called the sampling time τ. If the current speed does not match its desired speed, the automated vehicle will change its speed by accelerating or decelerating. When the vehicle is not driving according to its desired speed, the vehicle will deviate from its intended position in the longitudinal direction. In combination with control errors, also lateral positioning errors can occur. M^V_{st} expresses the actual safety margin that must cover for the positioning deviations that can occur during one sampling time. When assuming no control errors, these margins would only be necessary in front of and at the back of a CAV.

According to the previous statements, it may be clear that a vehicle will need actual safety margins to ensure that the vehicle will be on the right location at the right time. These safety margins, referred to as M^V_{tt}, are described by, for example, M^V_{vel} and M^V_{st}. However, how these actual safety margins correlate or depend on the characteristics and quality of the road, or on the vehicle characteristics, is left for further research. Therefore, no equation was created to determine the size of M^V_{tt}.

Actual Safety Margins - Time Synchronisation Inaccuracy

As was explained in the previous chapter, the internal clock of the traffic control system needs to synchronise with the clock of each CAV in order to generate iSpaT reservations with a time indication that fits the internal clock of the CAV. Moreover, it was concluded that an extra safety margin is required in front of the CAV when its clock is ahead of the clock of the traffic controller, and at the back otherwise. Namely, in those cases, the vehicle could arrive earlier or later at the reservation than was expected by the traffic control system. These required safety margins were categorised as actual safety margins, since these margins represent a location on the road where the vehicle could actually be. Therefore, the safety margins are part of the Potential Vehicle Location.

To what extent the timing of the clock of the CAV was successfully estimated by the traffic control system will mainly depend on the synchronisation method applied. Several methods were described in Hasan et al. (2018). Moreover, major factors that can cause a wrong estimation are the unknown latency during V2I- and I2V-communication, the unknown time it will cost for the traffic controller to decode the registration of the CAV and to calculate the difference between the timing of the clocks. Further research is necessary to quantify the maximum difference between these timings. Equation 3.4 describes how this maximum difference can be translated to a safety margin value. Note that it was assumed that the traffic control system could estimate the average speed of the CAV $\bar{u}^V$ over one Space-Time reservation. Equation 3.6 explains how to calculate $\bar{u}^V$, and in the following subsection it is explained why this average speed could be assumed.

$$M_{ts}^V = \alpha \cdot \bar{u}^V \tag{3.4}$$

M_{ts}^V	=	Safety margin required to cover for inaccuracies in time synchronisation between the traffic controller and vehicle V;	[m]
α	=	Maximum clock offset after time synchronisation;	[s]
$\bar{u}^V$	=	Average speed of vehicle V over one space-time reservation (0.1 second);	[m/s]

Perceived Safety Margins - Preferred Time Headway

As the literature clearly shows, the time headway maintained at public roads does not always equal an actual safe time headway, which means that collisions would possibly occur during emergency situations. Therefore, this report identified the time headway kept at public roads as the *preferred* time headway of a car user. The preferred time headway was measured from the rear-end (i.e. rear bumper) of the preceding vehicle to the front-end (i.e. front bumper) of the following vehicle, and is added as a perceived safety margin both in front of a vehicle and at the back of a vehicle. For simplicity it was assumed that the preferred time headway value is constant in the urban area, and is independent of the acceleration or deceleration value of a vehicle.

Since the vehicles get assigned a series of locations where it needs to be every 0.1 second, and the vehicle determines its own speed profile to track the trajectory, it is uncertain to the traffic control system when exactly a vehicle will accelerate, decelerate, or cruise. Moreover, it is unknown to the traffic controller to what extent the vehicle will accelerate or decelerate. To express the preferred time headway in a distance for the perceived safety margin, it was therefore assumed that the traffic model is able to reliably predict the beginning and ending speed of a vehicle every 0.1 second. Therefore, an average speed $\bar{u}$ could be determined for the vehicle to drive during one space-time reservation. To express the preferred time headway h of a vehicle V the basic formula $s = v \cdot t$ was used, see Equation 3.5.

$$\mathrm{M}_h^{Vs} = h^{Vs} \cdot \bar{u}^V \tag{3.5}$$

Where:

M_h^{Vs} = Safety margin required to cover for the preferred time headway of a car user of vehicle V at vehicle side S [m]
h^{Vs} = Preferred time headway h of car user in vehicle V at vehicle side S [s]
$\bar{u}^V$ = Average actual speed of vehicle V over one space-time reservation (0.1 s) [m/s]

$\bar{u}^V$ could be calculated as follows:

$$\bar{u}^V = \frac{u^V(t) + u^V(t+0.1)}{2} \tag{3.6}$$

Where:

$u^V(t)$ = Actual speed u of vehicle V at time t, estimated by traffic controller [m/s]
$u^V(t+0.1)$ = Actual speed u of vehicle V at time $t+0.1$, estimated by traffic controller [m/s]

Chapter 2 concluded that there may also exist a minimum preferred headway distance at the back of the vehicle, which would not vary significantly with speed. Therefore, Equation 3.5 also applies to calculate the preferred time headway at the back of a vehicle. However, further research is required to answer the question whether there is a significant difference between the headway distance in front of, and at the back of a vehicle. The studies presented in Chapter 2 occasionally contradicted one another with respect to the preferred headway values in front of and at the back of a vehicle. Therefore, this research could not make reliable statements about a possible difference in THW value between the two locations.

Although no difference was assumed between the preferred headway distance in front of and at the back of a vehicle, there is reason to assume a difference in their value for the different interaction scenarios. 1.5 seconds may be valid for the current traffic situation, both in front of the vehicle (Michael et al., 2000; Sayer et al., 2003; Duan et al., 2013), and at the back of a vehicle (Mahmud et al., 2018; Hegeman et al., 2004), however truck platooning is currently possible with a time headway of 0.3 seconds (Janssen et al., 2015). Furthermore, Janssen et al. (2015) expects this time headway to become real for platooning between passenger cars too. On the other hand, Siebert and Wallis (2019) found a preferred time headway of 4.0 seconds between two highly automated vehicles. So, no clear value could be assigned to the preferred time headway where one or multiple (highly) automated vehicles were involved. The experiment presented in Chapter 4 helped to define the preferred headway distance in the future automated traffic situation. However, more research is valuable in order to draw more conclusions about the preferred time headway when automated vehicles are involved.

Perceived Safety Margins - Preferred Driver Space

According to the literature study, there is a desire for a fixed space free of other traffic around the vehicle: the preferred driver space (Marsh & Collett, 1987; Hennessy et al., 2011; Zhang et al., 2019). Hennessy et al. (2011); Zhang et al. (2019) investigated the value for this space in both longitudinal directions. However, their applied method was criticised as not being a sufficient method. Therefore, the values found in their particular research were not adopted as reliable. The study of

Tang et al. (2014), also mentioned the concept of a basic desire of a fixed space free of other traffic around the car. This study assumed a value of 8.7 meters at a speed of 55 km/h. Despite the fact that more research would be valuable in order to suggest a value with more reliability, this value could be assumed as a minimum free space in front and at the back of a vehicle during car following situations, and on both sides of the vehicle at a crossing situation.

Furthermore, no literature was found about a preferred driver space during the hybrid traffic situation, or during the fully automated traffic situation. Though it was assumed that this space would also exist in the hybrid traffic scenario. It was found that the preferred time headway values of human occupants may increase to a value of 4.0 seconds (Siebert & Wallis, 2019), or possibly decrease to 0.3 seconds (Janssen et al., 2015). To what extent the preferred driver space would change was not found in the literature. However, because of the expectation that at the starting phase of automated driving, human occupants will have less trust in the behaviour of automated vehicles compared to their own driving behaviour (Frison, Wintersberger, & Riener, 2019), it was expected that the preferred driver space will be larger compared to during the current **HDV**-HDV situation. The required safety margins might become smaller if trust would increase when two CAVs could communicate. Overall, further research should show the existence and the value for a preferred driver space in the **HDV**-CAV, **CAV**-HDV and **CAV**-CAV interaction scenarios.

Equation 3.7 shows the determination of the safety margins according to the preferred driver space in different interaction scenarios.

$$\mathrm{M}_{ds}^{V} = d^{V} \tag{3.7}$$

Where:

M_{ds}^{V} = Safety margin required to cover for the preferred driver space; [m]

d^{V} = Preferred driver space s around vehicle V. [m]

Perceived Safety Margins - Accepted Time Gap

The encroachment time represents the time value that is accepted by a human driver to cross in front of another vehicle, while it had not the right-of-way. Where two routes of conflicting vehicles intersect, is called a conflict area. The time between the first vehicle leaving the conflict area and the second vehicle entering the conflict area, is called the time gap between the two vehicles. According to the results of Cody et al. (2007) and Smith et al. (2009), an accepted time gap for the crossing vehicle would lay between 1.8 and 2.3 seconds, considering the current **HDV**-HDV traffic situation.

The expected accepted time gaps for the **HDV**-CAV, **CAV**-HDV, and **CAV**-CAV interaction scenarios were based on this interval. Considering the **CAV**-CAV situation, an accepted time gap of 2.05 s was assumed. This time gap lays in the middle of the interval, because of the expectations that drivers feel less safe when they have no control of the vehicle anymore, but more safe because the vehicles can communicate.

The other two scenarios include both an HDV and a CAV. The expectation is that no real difference will be experienced related to the gap acceptance, since vehicles cannot communicate, and one of them is not controlled by a human. Therefore, for these cases the 2.3 second gap acceptance may be a sufficient estimated value.

It is important to emphasize that these suggested values are speculations. The experiment presented in Chapter 4 took these values as the hypothesized accepted time gaps.

The safety margin to cover for the accepted time gap is only required when other vehicles can approach the subject vehicle sideways. In other words, this margin is only required at the crossing area of the intersection.

To express the required safety margin on both sides of the vehicle, the speed of the oncoming vehicle must be taken into account. However, since this speed is not necessarily constant, again the average speed was considered. Therefore, a similar equation as Equation 3.5 was formulated. Equation 3.8 shows the formulation to determine the safety margin that is required on both sides of the vehicle V during the various interaction scenarios I. Note that no clarification was found to assume a difference regarding the preferred time gap comparing the two vehicle sides. However, it may be the case that a larger time gap is preferred on the vehicle side that is approached by another vehicle, because oncoming traffic may be experienced as more dangerous than vehicles that are driving away. However, more research would be necessary to make reliable conclusions about the difference in perceived safety on both vehicle sides during a crossing situation.

$$\mathrm{M}^{V}_{gap} = G^{V} \cdot \bar{u}^{O} \tag{3.8}$$

Where:

M^{V}_{gap} = Safety margin required to cover for the accepted time gap of car user of vehicle V; [m]
$\bar{u}^{O}$ = Average actual speed of oncoming vehicle; [m/s]
G^{V} = Accepted time gap of vehicle V. [s]

3.3. Overlap Safety Margins of Different Vehicles

The previous section showed how and where around the vehicle the impact of various factors could result in a safety margin, and described the possible differences in outcome for the four interaction scenarios.

This section answers sub-question 1.4: *To what extent could the required safety margins of two vehicles overlap while still ensuring the actual and perceived safety of all human occupants?*. The answer was found by reasoning:

- When 2 PVLs would use the same road space at the same time, it is highly likely that a collision would occur. This must be avoided, so no overlap is allowed between PVLs;
- When 1 PVL and 1 PCZ of different vehicles would use the same road space at the same time, it is highly likely that the PCZ would not be free of other traffic. Therefore, the car user could feel unsafe, which is desired to be avoided. So, overlap between a PVL and a PCZ of different vehicles must not be allowed;
- When 2 PCZs would use the same road space at the same time, both PCZs would still be free of other traffic. No feeling of unsafety would occur among the car users, hence overlap between PCZs is allowed and even favorable in the context of efficient use of road space.

Figure 3.3 illustrates an example scenario at a crossing area where the preferred clearance zones of different vehicles overlap.

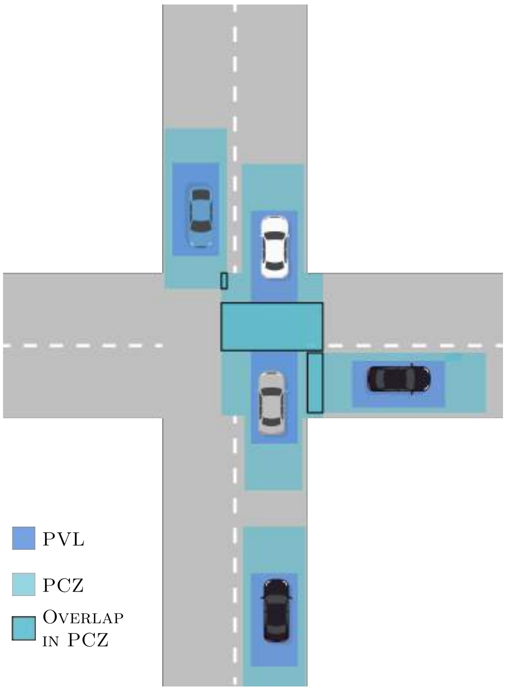


Figure 3.3: Overlap illustrated between required clearance zones (not on scale).

3.4. Mathematical Formulation Space-Time Reservation

This section answers the first research question: *While considering the hybrid traffic period, what mathematical formulation that expresses the impact of technical and non-technical factors, describes the required size of safety margins around a vehicle?*. The required size of the safety margins around a vehicle, equals the size of the PVL and PCZ together, which is used by the traffic control system to determine safe trajectory plans for all vehicles.

Equations 3.9 and 3.10 are the answer to the first research question. Equation 3.9 describes the size of the safety margins at the longitudinal sides M_{long}^{is} of a vehicle during a certain interaction scenario, whereas Equation 3.10 describes the safety margins required on the lateral sides M_{lat}^{is}, also during all interaction scenarios. Note that the lateral margins perhaps increase in size when the vehicle is on the crossing area of the intersection. Since the formulations apply for all interaction scenarios, they also apply for both vehicle types. Furthermore, using these equations, it is not possible yet to determine concrete safety margin values. Namely, M_{tt} cannot be calculated yet. Further research is required to determine a sufficient equation for this safety margin. Furthermore, neither provides this thesis a sufficient value to assume for the maximum clock offset between a CAV and the traffic control system. More research would be necessary to provide this value. Namely, the value depends on certain time delays during the V2I and I2V-communication for which also value must be estimated. Therefore, the equations are mainly useful to understand which factors influence the size of the safety margin, and how these must be combined.

Generating reservations for the **HDV**-HDV and **HDV**-CAV traffic situation is beneficial too in order to optimize the prediction of their driving behaviour in the traffic model. Especially the perceived safety margins are useful to implement to improve the prediction of the driving behaviour of human drivers. Moreover, maybe, in the future it will be safe to send iSpaT messages to HDVs too, hence it would be beneficial to already determine their Space-Time reservations.

The equations thus apply for both CAVs and HDVs. The first steps to calculate the safety margins around a vehicle are explained in Section 3.2. Note that various parameter values were suggested for the various interaction scenarios, but that not for every safety margins all parameter values could be estimated. More research is required in order to determine the size of the safety margins due to trajectory tracking inaccuracies and due to the time synchronisation deviations. Hence, it is not possible to calculate the size of the PVL yet.

Table 6.2 provides an overview of all suggestions that were made according to the literature study in Chapter 2. Only the value for T was based on the current traffic model of Sweco. Furthermore, it is important to note that the values suggested for G are higher than the values found during the experiment (as described in Chapter 5). According to the results of the experiment, a time gap of 1.5 seconds was accepted by 93% of the drivers, independent of the interaction scenario. The goal of the second research question is to compare the results of the experiment with the expectations based on the literature.

Note, the safety margins required around a vehicle determine the desired size of a space-time reservation. To the vehicle only a reservation having a size equaling the vehicle size will be communicated. However, the traffic control system itself will calculate with the size of the PVL and PCZ together.

Below the formulations are presented that describe the safety margins needed around the vehicles of the hybrid traffic situation. Equations 3.1 and 3.2 were used to create the formulations.

$$\mathrm{M}_{long}^{is} = \mathrm{M}_{p}^{is} + \mathrm{M}_{tt}^{is} + \mathrm{M}_{ts}^{is} + \max\left(\mathrm{M}_{ds}^{is}, \mathrm{M}_{h}^{is}\right) \qquad \forall i \in I, \forall s \in S \tag{3.9}$$

$$\mathrm{M}_{lat}^{is} = \mathrm{M}_{p}^{is} + \mathrm{M}_{tt}^{is} + \max\left(\mathrm{M}_{ds}^{is}, \mathrm{M}_{gap}^{is}\right) \qquad \forall i \in I, \forall s \in S \tag{3.10}$$

$I = \{$HDV-HDV, HDV-CAV, CAV-HDV, CAV-CAV$\}$

$S = \{$FRONT, BACK, LEFT, RIGHT$\}$

Table 3.6: Assumed values for safety margins based on literature research

Safety Margin	***Variable***	**HDV-HDV**	**HDV-CAV**	**CAV-HDV**	**CAV-CAV**
M_p	p_{long}	2.95 m	2.95 m	0.02 - 0.10 m	0.02 - 0.10 m
	p_{lat}	1.15 m	1.15 m	0.02 - 0.10 m	0.02 - 0.10 m
M_{vel}	w^V	0.04 - 0.10	0.04 - 0.10	-0.10 <w <+0.10	-0.10 <w <+0.10
	T	1 to 3 sec	1 to 3 sec	1 to 3 sec	1 to 3 sec
M_h	h_{front}	1.5 sec	2.0 sec	2.0 - 4.0 sec	0.3 - 4.0 sec
	h_{back}	1.0 sec	1.5 sec	1.5 - 4.0 sec	0.3 - 4.0 sec
M_{ds}	s_{long}	8.7 m	8.7 m	8.7 m	8.7 m
	s_{lat}	8.7 m	8.7 m	8.7 m	8.7 m
M_{gap}	G	1.8 s	2.3 s	2.3 s	2.05 s

4

Design of Experiment

In order to provide a more reliable advise about safety margin values that will feel safe to each car user, some suggestions for suitable values for the safety margins that were presented in Chapters 2 and 3 were compared to data following from a human experiment. Ideally, this comparison would be executed by comparing the suggestions with data from a field experiment. However, data about perceived safety margins in the future hybrid traffic situation was lacking in the current literature. This was not striking, as the technology of highly and fully automated vehicles is still being developed, and because few of these vehicles are currently driving on public roads.

This Chapter describes the design process and the final experimental set up of the human experiment that was executed in order to find the preferred time gap in front of an HDV and CAV during the hybrid traffic situation. The accepted time gap was defined as the time between a crossing vehicle leaving and the subject vehicle entering their conflict area (i.e. the area where their planned routes overlap). The chapter moreover presents the expected outcomes according to the literature research.

4.1. Decision for a Suitable Method

Four vehicle interaction scenarios were distinguished earlier: HDV-HDV, HDV-CAV, CAV-HDV, and CAV-CAV. However, the situation where two HDVs weave will not happen according to the purpose of iSpaT traffic control. Therefore, this interaction was not further investigated during the experiment. Secondly, the interaction between HDVs and CAVs, where two different interactions were considered: HDV-CAV and CAV-HDV; the difference between these two interactions lies in the perspective from which the situation is experienced. The perspective equals the first mentioned vehicle type, which means that during the CAV-HDV interaction scenario, the situation is experienced from the CAV occupant's perspective. The last interaction distinguished was between two CAVs, where both vehicles can communicate with each other and with the infrastructure, and where humans cannot control the vehicle.

4.1.1. Requirements of Experiment

The goal of the experiment was to find the preferred time gap in front of a vehicle during the future hybrid traffic situation. The value found could be compared to values found in the literature. The values found in the literature were used to determine the variation of time gaps to test in the experiment.

A suitable method had to be chosen in order to conduct an experiment where various time gap values could be tested. The requirements of the experiment are enumerated below:

1. The test environment must be safe for all people involved;
2. The test environment must feel as realistic as possible to gather responses that are comparable to responses in a real life situation;
3. The total duration of the experiment, including its preparation, cannot take longer than 2 months;
4. There is no budget for the experiment.

4.1.2. Possible Methods and Chosen Method

According to these requirements, a couple of methods were interesting to apply: a driving simulator study, a 360 degree photo or video study, a 2D photo or video computer study, and a virtual reality study. All methods could provide a safe environment for participants to perform the experiment (req. 1), and it was expected that all methods could be applied without involving (too high) costs (req. 4). However, requirements 2 and 3 did not apply to each method.

The use of a driving simulator would be suitable, since it can provide a test environment in high resolution which ensures the possibility to distinguish different objects in the simulated environment very well (Blissing & Bruzelius, 2018). This can contribute to a more realistic experience of the test environment (req. 2). Besides, a driving simulator can provide a realistic experience of the traffic situation, because of the presence of a car seat, steering wheel, and gas and brake pedals. However, there are also disadvantages to this method. The programming of the test environment was expected to be time consuming and complex given few simulation experience (req. 3). Furthermore, only one participant would be able to conduct the test at a time. Moreover, the possibility to execute the experiment depends on the availability of a driving simulator.

On the contrary, a 2D photo or video study was expected to be more flexible to execute, since it could be examined behind a computer screen, which can be done from any location. Also multiple participants were expected to be able to partake in the experiment simultaneously (req. 3) (Verhoeven et al., 2006). However, being a participant in the experiment, it would be less easy to empathise with the traffic situation, since distraction of surrounding activity could easily occur. Therefore, the feeling of being in that environment could be missing (req. 2) (Verhoeven et al., 2006).

A technique that provides the feeling of really being in another environment is virtual reality (VR). This feeling of being present in the simulated environment in a VR study is even stronger than in a driving simulator (Blissing & Bruzelius, 2018). When using VR, the real world is not visible anymore, which ensures a very high level of empathy and more realistic results (req. 2). A VR environment, in a majority of cases, is a simulated environment. Simulation can be time consuming (req. 2), but once properly done, it is easy to create many different scenarios quickly. However, Burns et al. (2019) executed an experiment similar to VR, but with 360° videos of a real life situation. The videos were filmed from the perspective of a pedestrian standing in an urban environment where a fully automated vehicle (FAV) was driving past the pedestrian. The participants experienced the videos via a virtual reality head-mounted display (HMD). The experiment was successful because of the highly realistic videos and the HMD: the test persons really felt like they actually were present in that environment (req. 2). However, when choosing this method for the human experiment, filming crossing vehicles (with a 360° camera) from the driver's perspective would form a significant challenge. Therefore, maybe a 360° photo study would be a sufficient alternative. Via the HMD, a time lapse of 360° photos could be shown to the participants. However, an important disadvantage would be the static images.

Another advantage of both driving simulator and VR-studies was the possibility to test situations that are hazardous or infeasible in real life, something which was not possible by means of real life videos or photos. Disadvantages of simulation studies were the risk of motion sickness, which is mainly caused by a delay between the movement of a participant and its reaction in the virtual environment (Blissing & Bruzelius, 2018). Moreover, the horizontal field of view of an HMD is smaller than in real life. The value of this angle lays between 90 and 110 degrees, while the horizontal field of view of a human is around 180 degrees. Therefore, while wearing an HMD, it is necessary to rotate the head more often than in reality to oversee the situation (Blissing & Bruzelius, 2018). According to the Commission Directive 2009/112/EC, the field of view must be at least 120 degrees to be allowed to drive. These disadvantages were unfavorable considering the second requirement.

To conclude, Table 4.1 summarizes the suitability of each method according to the four requirements. According to this table the 360 degree video study would be the most favorable. The second best option was a virtual reality study. Both methods were considered to set up a test environment for the experiment. However, it appears that it was not possible to drive and film from the driver's perspective simultaneously. Therefore, the 360° photo study appeared to be an unsuitable method. To apply the virtual reality method, help from Sweco was obtained to model the environment within the time period.

Table 4.1: Suitability of all possible methods. 5-point scale varying from ++ to - -.

	Driving Simulator	**Virtual Reality**	**360° Videos**	**360° Photos**	**2D Computer Study**
Requirement 1	++	++	++	++	++
Requirement 2	+	++	++	+ / -	-
Requirement 3	- -	- -	-	-	+/-
Requirement 4	++	++	++	++	++

4.2. Design Test Scenarios and Hypotheses

After the method was chosen, the scenarios that would be shown to the participants had to be designed. This section describes the design process to develop these scenarios. Again, the goal of the experiment was to find at what safety margins human occupants of both HDVs and CAVs felt safe during a weaving traffic situation, while considering the HDV-CAV, CAV-HDV, and CAV-CAV interaction scenarios.

4.2.1. Variation of Test Scenarios

Chapter 3 presented the formulas to calculate safety margins around the entire vehicle. However, according to time restrictions, not every margin at every location around the vehicle could be tested. Multiple situations of two vehicles interacting could be thought of to show to the participant, and to measure the feeling of safety of the participant. Beside variation in the interaction scenarios, variation could also be made between the following aspects:

- Crossing direction: The crossing vehicle can enter the intersection from the right or left side, considering the perspective of the subject vehicle;
- Crossing order: The crossing vehicle crosses in front or behind the subject vehicle;
- Perspective: The crossing situation could be experienced from the perspective of the subject vehicle or the crossing vehicle.

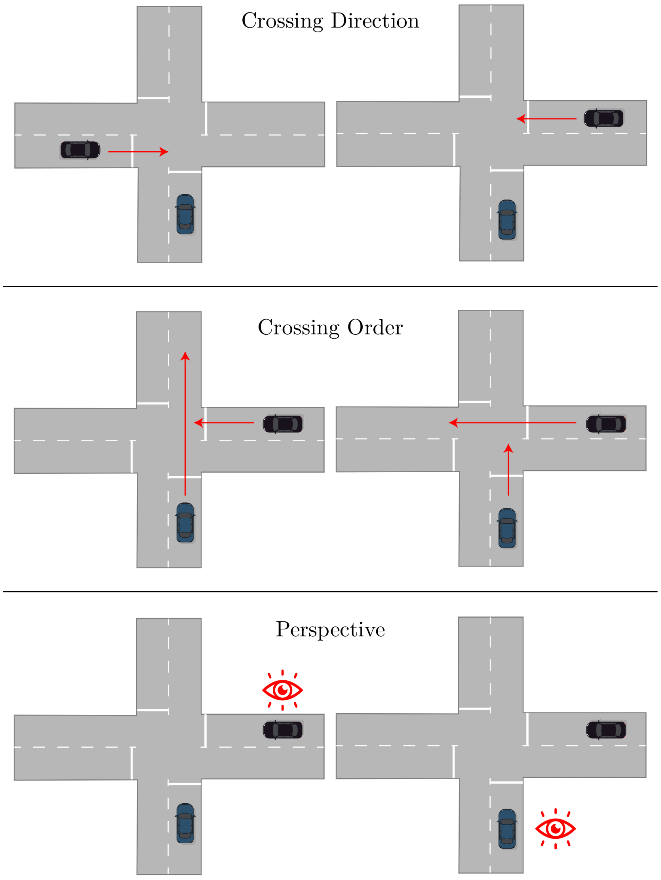


Figure 4.1: Main variations for test scenarios

Figure 4.1 illustrates these variation possibilities. In total, 2 crossing directions × 2 crossing orders × 2 perspectives × 3 interaction scenarios = 24 scenarios were feasible. When accounting for the overlap in these factors creating multiples of the same traffic situation (when considering all three of the factors binary the [1,1,1] situation could be the same as the [0,0,0] situation) 12 would be left, which even excluded the variation in the location of the safety margin (around the vehicle) and the number of different safety margin values that could be tested. When considering these variations as well, up to 300 scenarios could be considered. Since this number of possible test scenarios would require too much time to test, a selection was made.

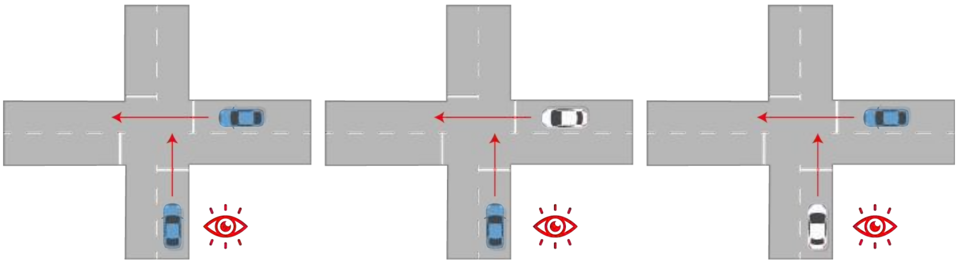
The first choice made was between testing the impact of different crossing directions, and testing the impact of the two crossing orders. Therefore, five people were asked to judge two traffic scenarios: (1) a vehicle crossing ahead of them, (2) a vehicle crossing behind them. It became clear that it was easier to judge a traffic situation where the crossing vehicle was crossing in front of their vehicle. The two main reasons for this were the visibility angle of the HMD: to see a vehicle next to oneself required less natural neck-turning movements. The other reason was that people were less focused on the traffic situation when they crossed first, because they assumed they had priority.

Hence, the decision was made that virtual reality was a less suitable method to test the variation in crossing order. Furthermore, testing for a difference in crossing direction was expected to be possible when using virtual reality. Because of this choice, it was also not desired to test for variation in perspective, because that would have resulted in traffic situations where the crossing vehicle crossed at the back of the subject vehicle, which thus was concluded not to be sufficient to test with VR.

According to the above stated arguments, in total six scenarios were created: 3 interaction scenarios × 2 crossing directions. An overview of the scenarios is given in Table 4.2. Figure 4.2 illustrates all vehicle interaction scenarios that were tested during the experiment.

Table 4.2: Test scenarios summarized

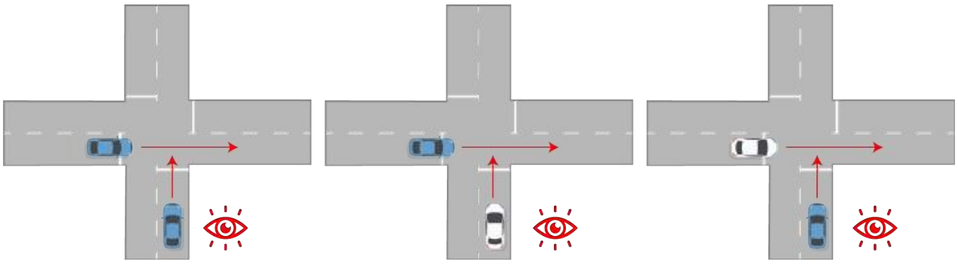
Scenario #	*Interaction Scenario*	*Vehicle Perspective*	*Crossing vehicle approaching from left / right*
1	CAV-CAV	CAV	Right
2	CAV-HDV	CAV	Right
3	HDV-CAV	HDV	Right
4	CAV-CAV	CAV	Left
5	CAV-HDV	HDV	Left
6	HDV-CAV	CAV	Left



Scenario 1
CAV-CAV

Scenario 2
CAV-HDV

Scenario 3
HDV-CAV



Scenario 4
CAV-CAV

Scenario 5
HDV-CAV

Scenario 6
CAV-HDV

Figure 4.2: Test scenarios of the experiment; perspective indicates by bold letters and red eye. CAV indicated in blue, HDV indicated in white.

4.2.2. Approach to determine perceived safety

The experiment had to show what time gap was accepted (was perceived as safe) by the participants in front of their vehicle. The time gap was defined as the time between the crossing (and conflicting) vehicle leaving and the subject vehicle entering their conflict area.

Participants were shown 5 different time gaps for each of the six scenarios, for which they had to indicate their feeling of safety. An advanced method to measure the feeling of safety is to measure at what moment in time at a crossing situation the participant would brake, and how intensive the brake was. However, no sufficient equipment was available to measure this braking moment. Therefore, an alternative method was chosen. The choices for the 5 time gaps were based on values found in the literature. The smallest time gap equaled a value of 0.5 seconds. This value was based on the 0.3 seconds which is now possible with truck platooning (Janssen et al., 2015) and then extended to 0.5 seconds because of the more erratic nature of the simulated situation when compared to a truck platooning situation. The largest time gap was based on the study of Siebert and Wallis (2019), and equaled a value of 4.0 seconds. Furthermore, according to the literature, other suggestions for suitable time gaps laid approximately between 1.0 and 2.0 / 2.5 seconds. Therefore, the other time gaps were divided over these values to test more or less equally between 0.5 and 4.0 seconds, which resulted in the following time gaps: 0.5, 1.0, 1.5, 2.0, and 4.0. Since not much research was found that supported required time gaps between 2.0 and 4.0 seconds, it was chosen to not measure time gaps between these values. Furthermore, not more than 5 time gaps per interaction scenario were tested due to time constraints. To keep the participants focused and motivated during the experiment, a duration of a maximum of 30 minutes was desired, of which a maximum of 15 to 20 minutes were reserved for the actual virtual reality test. Otherwise, it was expected that the participants could start to suffer from motion sickness (Dużmańska et al., 2018).

Due to the lack of material to measure the moment of braking, each participant was instructed to indicate their feeling of safety using a 4-point Likert-type scale. For each situation (6 scenarios × 5 time gaps) an oral indication had to be given using the following scale: 1) Very safe 2) Pretty safe 3) A little unsafe 4) Very unsafe. Hence, their perceived safety was measured on an ordinal scale. By applying this scale, a situation was always judged as either safe or unsafe. This scale was based on the research of Evans et al. (2006). Moreover, when a participant felt the intention to brake or intervene, they could push the brake pedal when driving an HDV, or mention it when being in a CAV. However, it turned out that the participant was not always focused on braking. Moreover, some participants only wanted to release their gas pedal in some situations, which led to unclear notation. Therefore, it was assumed that this data was not significant and was subsequently not included in the data analysis in Chapter 5.

Concluding, each participant would be shown 30 vehicle interaction situations (or: 30 videos): 5 time gaps × 3 interaction scenarios × 2 crossing directions. Section 4.3 explains the applied methodology during the experiment.

4.2.3. Expectations

The literature suggested multiple parameter values to be used to calculate the required safety margins around a vehicle. These are summarized in Table 6.2.

The goal of the experiment was to determine the preferred time gap between a conflicting vehicle leaving and the subject vehicle entering their conflict area, for all interaction scenarios that include a CAV. This preferred time gap is comparable to the gap acceptance values found in the literature. To explain the difference, the gap acceptance G was described from the perspective of the vehicle that encroached another vehicle. However, this experiment in fact tests whether the gap acceptance of the encroaching vehicle is also accepted as a safe time gap by the encroached vehicle.

The outcome of the experiment was compared to an expected outcome. The expected outcome was based on the maximum values found for the gap acceptance G of vehicle A and the preferred time headway h of vehicle B (See Table 6.2). So, this experiment tests whether the value for G of vehicle A (blue vehicle) also fits for vehicle B (white vehicle), or whether another time gap would fit better for vehicle B, perhaps influenced by its value for h. Below the expected outcome is described per interaction scenario tested. Figure 4.3 illustrates G and h.
The final expectations for the outcome of the experiment, as based on literature study then follows:

- When a CAV intersects the planned trajectory of an HDV, the human driver of the HDV prefers a time gap between 2.0 and 2.3 seconds.

- When an HDV intersects the planned trajectory of a CAV, the human occupant of the CAV prefers a time gap between 2.3 and 4.0 seconds.

- When a CAV intersects the planned trajectory of a CAV, the human occupant of the CAV prefers a time gap between 2.0 and 4.0 seconds.

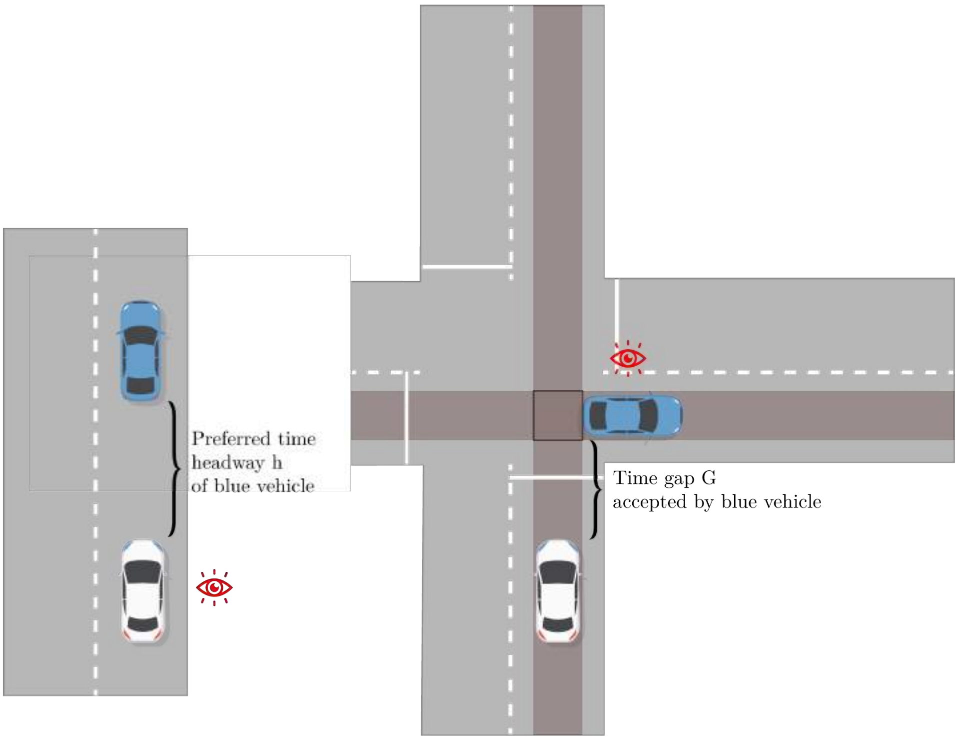


Figure 4.3: Values of preferred time headway *h* and gap acceptance *G* found in the literature were combined to generate an expected outcome of the human experiment.

4.3. Methodology

This section is divided into two parts. First the way in which the model was set up in order to test all 30 vehicle interactions was explained. Thereafter, the experiment procedure was elaborated upon.

4.3.1. Model

The virtual environment was modelled using the gaming software *Unity* version 2019.1.1f1. Two input fields were programmed that were connected to the starting time of the two crossing vehicles. Both vehicles drove with a speed of 50 km/h. The vehicles were comparable to a passenger car with the following dimensions: length 4.63 meter and width 1.87. This size is comparable to a Ford Focus or Renault Megane. In total, three vehicle types were programmed: (1) a (human-driven) car with hands on the steering wheel; (2) a (self-driving) car including a passenger; (3) and a (self-driving) car without having hands on the steering wheel. The perspectives of vehicle (1) and (3) were used to let the participants experience the traffic situation from. Vehicle (1) and (2) were used as crossing vehicles.

Furthermore, the starting positions from the vehicles differed exactly one vehicle length. Thus, when both cars would start driving at the same time, the first vehicle would have just left their conflict area, when the second vehicle enters the conflict area. In that case, the time gap tested would equal 0 seconds. To change the value of the safety margin, the subject vehicle was given a postponed starting time. The difference in starting times equaled the time gap, i.e. the safety margin that was tested.

The virtual environment could be experienced via a *HTC Vive 1.5 virtual reality head-mounted display*. This HMD has a field of view of 110 degrees. That value is approximately 70 degrees less than the human horizontal field of view (Mazuryk & Gervautz, 1996). The participants could rotate their head to observe the total environment. The HMD was connected to the computer on which Unity was running, which made it possible to determine what was shown on the HMD.

Figure 4.4 shows a crossing situation at four different moments in time. The left-side figures show the situation from the perspective of a human driver, while the right-side figures represent the top view from the crossing situation. The buttons on which the starting times of both vehicles were set can be seen in the left-side pictures as well. Moreover, the blue car represents the CAV and the orange car the HDV.

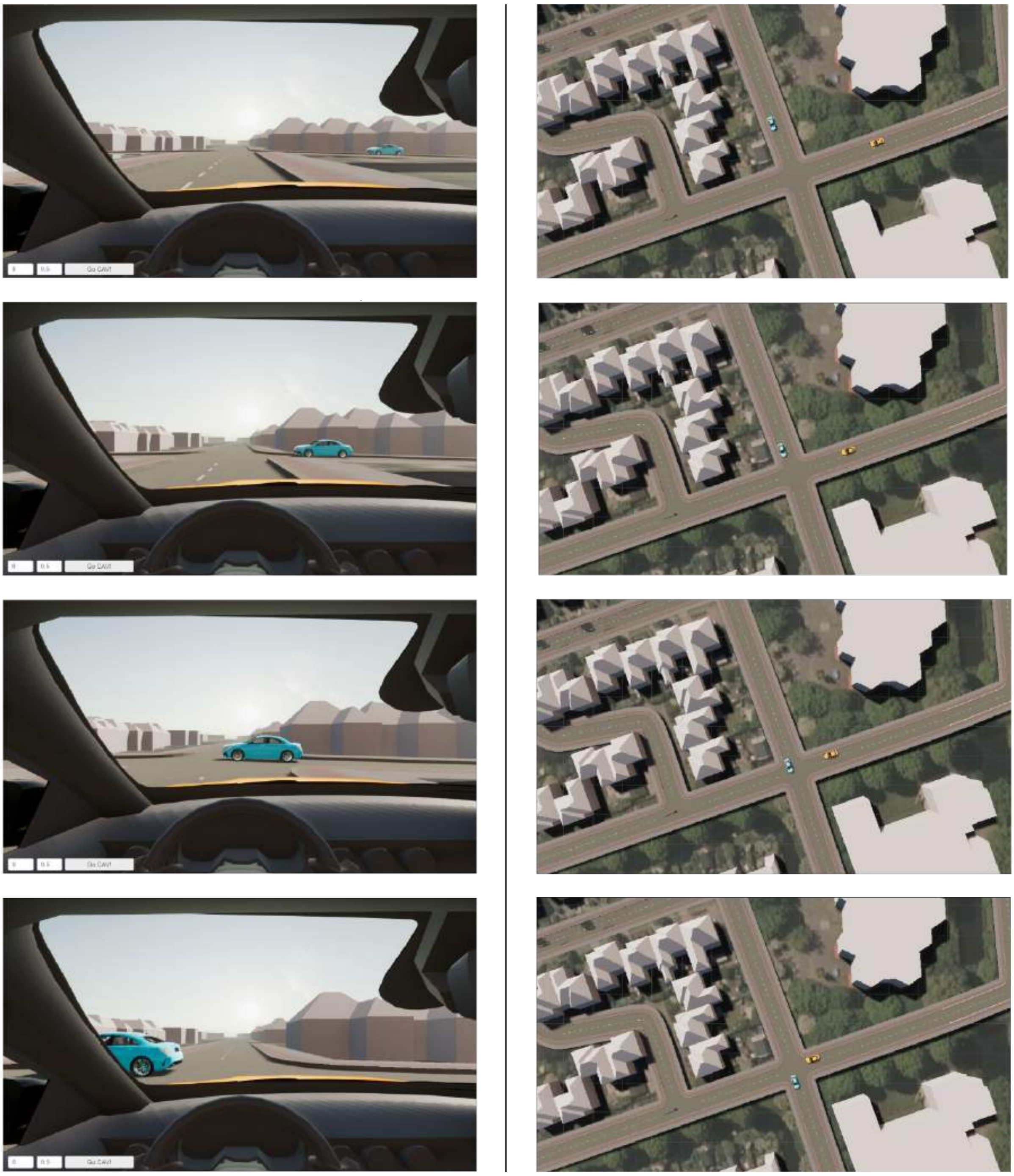


Figure 4.4: Crossing situation shown from human driver's (orange vehicle's) perspective (left) and top view (right)

4.3.2. Set up of Experiment

The set up of the experiment was divided into two parts: (1) recruitment for participants and (2) executing the VR experiment. During these two phases data was collected that was later analysed (see Chapter 5).

The experiment was promoted among students at the University and among employees at Sweco. Potential participants were found via posters, e-mails or via a personal invitation. The participants themselves could book a time slot via *Calendly* to execute the experiment. Calendly took care that the meeting was immediately scheduled in the participants' as well as the experimenters' online personal agenda. A few days before the experiment would take place, a reminder was sent to the participant including a request to fill out a first questionnaire. The goal of this questionnaire was to gather information on demographics and familiarity with the studied subject: general questions were asked about age, gender, study/work field, driving experience and driving style, and about their experience with automated driving.

The experiments were conducted at the office of Sweco in Utrecht or at Delft University of Technology. At Sweco a private room was available. At the University mostly a private room was available, otherwise a shared but quiet room was used to conduct the experiment.

Figure 4.5 - A shows the Head-Mounted Display that was used for this experiment. Figure 4.5 - B shows a participant that was conducting an experiment at Sweco. As can be seen, the participant held his hands on a steering wheel. A steering wheel and a gas and brake pedal were added to the test set up in order to increase the experience of really being in a vehicle. However, it is important to note that these additions could not be used to influence the scenario shown in the virtual environment.

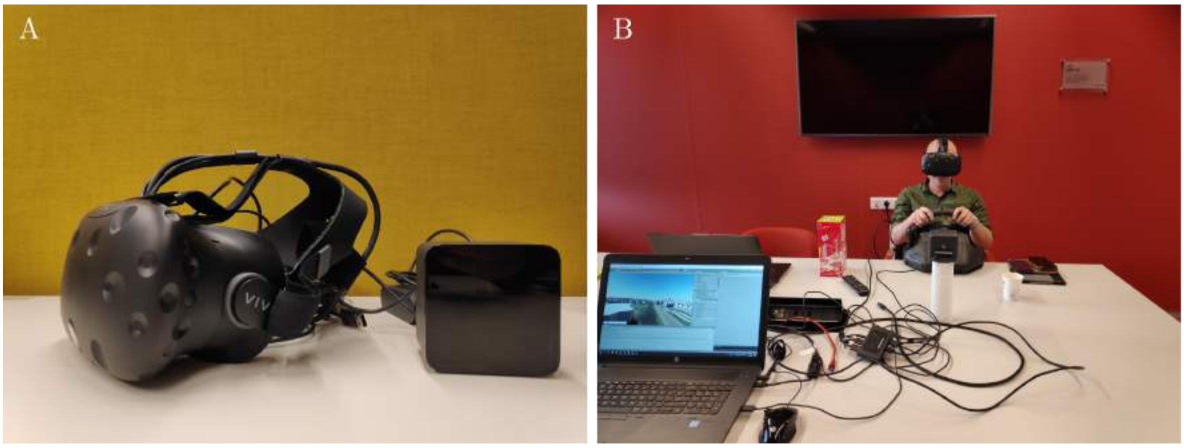


Figure 4.5: A) HTC Vive Head-Mounted Display (2PU6100) and HTC Vive Base Station 1.0 (2PR8100); B) Participant conducting experiment at Sweco and Model visible on researcher's laptop.

Before a participant started the VR experiment, first an instruction about the experiment had to be read. This instruction can be found in Appendix B. Thereafter, the participant had to take place behind the steering wheel and had to put on the HMD. First, two example situations were shown to the participant in order to get familiar with the virtual environment. From pilot tests it became clear that sometimes the participant did not know where to look, was not focused the first few seconds, and / or did not know where to focus on. The following two examples were shown:

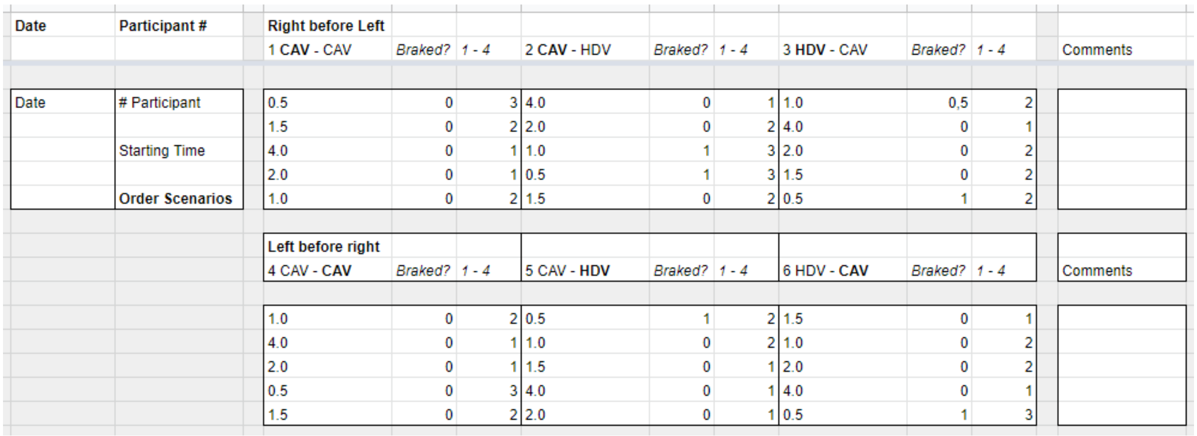
- Example 1: A crossing HDV was approaching from the right. The participant was sitting in a CAV and could not use the steering wheel and pedals. A time gap of 0 seconds was applied;
- Example 2: A crossing CAV was approaching from the left. The participant was sitting in an HDV and could use the steering wheel and pedals. A time gap of 5 seconds was applied.

With these two examples the participant experienced sitting in both vehicle types and saw both vehicle types approaching. Here, they also saw the difference between a vehicle approaching from the right and one approaching from the left. By showing a 0 second time gap and a 5 second time gap, the participants were expected to unconsciously be better able to use the 4-point scale. Moreover, it was again explained to the participants that they had to rate these traffic situations (or: videos) for the real experiment on a scale 1 to 4. Besides, the participants were asked if the scenarios were clear.

When the participants had no further comments or questions, the real experiment could start. Each participant got shown all 30 traffic situations, however, both the scenarios and the time gaps were shown in a random order. An important note here is that it was unfavorable to switch between two scenarios. Namely, when starting a new scenario, the participant was shown a 'waiting room'. To avoid this room to be shown too many times during one session (and thus to avoid distractions), all five time gaps of one scenario were showed sequentially. Furthermore, three requirements for the randomness were described as follows: (1) Avoid the participants being able to predict from which side of the intersection the crossing vehicle would approach. Therefore, the scenarios were not shown in an order where first all right approaching vehicles were shown, after which all left approaching vehicles were shown (or vice versa). (2) Avoid the participants being able to predict what time gap would be shown next. Therefore, the time gaps were not shown in an ascending or descending order. (3) To keep the order in which the six scenarios were shown to the participant as random as possible, no order was allowed to be used for more than two times.

After one video, the participant indicated the feeling of safety orally. Also the urge to intervene in a self-driving car or the urge to brake in a human-driven care were registered by the researcher. Halfway through the experiment, the participant was asked whether they suffered from motion sickness and if they perhaps needed a break. This was rarely the case.

All data that was collected during the experiment was listed in an Excel file. An example of this file is shown in Figure 4.6. The three interaction scenarios were distinguished per crossing direction. For each of the six scenarios a random order of the five time gaps was listed. Next to each time gap it was noted if the participant had used the brake or felt the urge to intervene, also, the score the participant gave to that specific traffic situation was recorded. Furthermore, space was left to note possible comments of the participant. Also the date, participant number, and starting time were noted per participant. In the second column the random order was noted in which the six traffic scenarios were shown to the participant.



Date	**Participant #**	**Right before Left**									
		1 **CAV** - CAV	*Braked?*	*1 - 4*	2 **CAV** - HDV	*Braked?*	*1 - 4*	3 **HDV** - CAV	*Braked?*	*1 - 4*	Comments
Date	# Participant	0.5	0	3	4.0	0	1	1.0	0,5	2	
		1.5	0	2	2.0	0	2	4.0	0	1	
	Starting Time	4.0	0	1	1.0	1	3	2.0	0	2	
		2.0	0	1	0.5	1	3	1.5	0	2	
	Order Scenarios	1.0	0	2	1.5	0	2	0.5	1	2	
		Left before right									
		4 CAV - **CAV**	*Braked?*	*1 - 4*	5 CAV - **HDV**	*Braked?*	*1 - 4*	6 HDV - **CAV**	*Braked?*	*1 - 4*	Comments
		1.0	0	2	0.5	1	2	1.5	0	1	
		4.0	0	1	1.0	0	2	1.0	0	2	
		2.0	0	1	1.5	0	1	2.0	0	2	
		0.5	0	3	4.0	0	1	4.0	0	1	
		1.5	0	2	2.0	0	1	0.5	1	3	

Figure 4.6: Example Data Collection File Excel

After all videos were shown to the participant, they were asked to fill out a second questionnaire. The second questionnaire was about their experience of the experiment: about the level of reality, empathy, and motion sickness. Both questionnaires can be found in Appendix C.

Figure 4.7 illustrates the complete methodology as described previously. Eventually, 3 data files were obtained for data analysis. These files are presented in Appendix D.

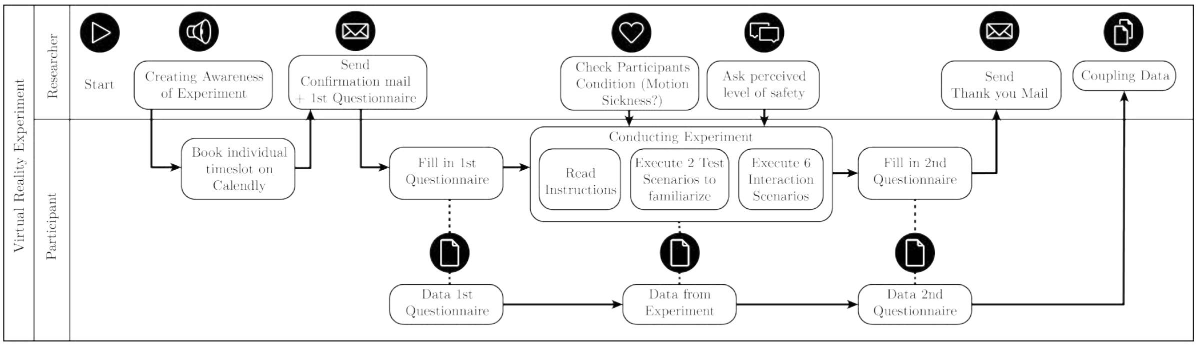


Figure 4.7: Process Virtual Reality Experiment

5

Results of Virtual Reality Experiment

This chapter first presents a descriptive analysis of the results. Thereafter, the results were statistically analysed, and the answer to the second research question was given.

5.1. Descriptive Analysis

The experiment was executed among 82 participants: 53 male and 29 female participants aged between 17 and 62 years old ($\mu = 32.5$; $\sigma = 11.3$). Moreover, 42 people had work or study experience within the field of (smart) mobility, whereas 40 people had not. Furthermore, 34 participants had experience with vehicles of automation level 1, and 8 people had experience with level 2. Besides, 13 participants had joined a ride within a self-driving vehicle, in which they could not intervene, before. No distinction was made between nationality as long as the driver had driving experience within the Netherlands. In total, 80 participants had the Dutch nationality, whereas 2 participants had a different nationality: 1 Polish and 1 Indian person conducted the experiment. Figure 5.1 illustrates the frequency of age per gender. The average age among male participants is 35.7 years, whereas the female participants are on average 26.7 years old. In December 2017, only 12.2 % of the drivers were between 26 and 35 years old. 14.2 % was between 36 and 45 years old. The largest age group was represented by persons with an age between 46 and 55 with a percentage of 19.7 % (Oostvogels, 2018). The average age of this experiment must thus be considered to be different from the real population of car users. Moreover, due to the fact that the female participants were younger than the male participants, and because of the unequal distribution of female and male participants, the data set is not suitable to independently assess effects of gender and age on the perceived safety. Effects of gender could be tested using only younger participants, and effects of age could be tested within male participants only. The conclusions drawn in the next section therefore only fit the sample, and must be interpreted carefully considering the effects on the whole population.

Based on the data obtained from the second questionnaire, some other diagrams that describe the participants were presented in Appendix E. It shows that almost half of the participants have experience with automated driving, either with level 1 or level 2. This is important to take into account during the interpretation of the results. Furthermore, half of the participants has been in possession of a driving license for longer than 10 years. However, for another 25% this period is only less than a year. When the participants had to indicate their driving style on a 5-point scale, none of them indicated it as aggressive. 12% indicated their driving style one point below aggressive. Most people gave a score of 2 or 3. This perhaps could be of influence on the accepted safety margins. Furthermore, of all 82 participants, 43 participants drive only 4 hours or less per week, which is below the Dutch average. In 2018, The Netherlands counted 8,373,244 passenger cars (CBS, 2019a).

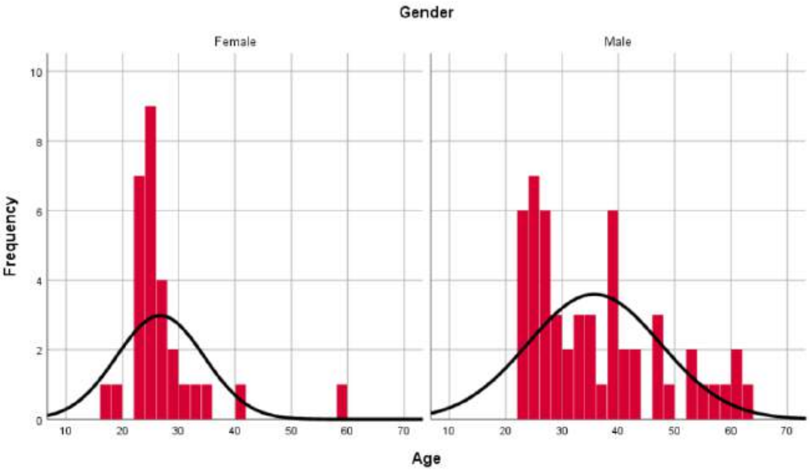


Figure 5.1: Distribution Age and Gender

In total, 104,735,900,000 kilometres were driven by Dutch passenger cars within the Netherlands in 2018 (CBS, 2019b). So, each passenger car drove 12,508 kilometres per year = 241 kilometres per week. When assuming an average speed of 36.6 km/h when being in the car, an average number of driving hours is 6.55 hours per week (Blankesteijn, 1994). Finally, more than three quarters of the participants had no experience with virtual reality studies before. However, it turned out that the participants could empathize with the environment quite well, and that motion sickness occurred very rarely (See Appendix E.2).

5.2. Statistical Analyses

This section answers sub-question 2.2. The section describes the statistical analyses that were executed with the collected data. Here, various hypotheses were tested. The purpose of testing these hypotheses was to describe the effects of the time gaps shown, the crossing direction of the crossing vehicle, and the three interaction scenarios that were shown, on the scores given by the participants (or: the perceived safety of the participants). Once these (potential) effects were described, the data was presented such that the acceptance rate per time gap was shown. Moreover, it could be described under what circumstances the participants felt more (or less) safe. However, eventually it appeared that none of the above variables had a significant effect on the perceived safety. Therefore, the acceptance rate value applied to all traffic situations that were shown to the participants.

Before explaining the effects of the time gaps, crossing directions, and interaction scenarios on the scores given in detail, first the hypotheses and the used correlation coefficients are introduced. Thereafter, the effects are explained one by one.

5.2.1. Introduction Correlation Coefficients and Hypotheses

The software *IBM SPSS Statistics version 25* (in short: SPSS) was used to research the existence of the above mentioned effects on the perceived safety of the participants. Only non-parametric tests were applied, since the obtained data was not normally distributed. Table 5.1 shows which correlation coefficients could possibly explain associations between the variables. Besides, the table explains to what type of data the correlation coefficients are suitable to apply. Table 5.2 illustrates which coefficient was applied to each variable to investigate its effect on the perceived safety. Moreover, the hypotheses tested were described. During the statistical analyses, the variables were categorised as follows:

1. Time gap: 1) 0.5 sec; 2) 1.0 sec; 3) 1.5 sec; 4) 2.0 sec; 5) 4.0 sec;
2. Crossing direction: 1) Left-before-right; 2) Right-before-Left;
3. Interaction scenarios: 1) **CAV**-CAV; 2) **CAV**-HDV; 3) **HDV**-CAV;
4. Scores: 1) Very safe; 2) Quite safe; 3) A little unsafe; 4) Very unsafe.

Table 5.1: Overview of possible Correlation Coefficients

Correlation Coefficient	**Required data type for both variables**	**Characteristics of the test**
Spearman's Rank-Order	Ordinal data, Interval data, or Ratio data	1) Indicates strength and direction of association found. 2) Suitable for large sample sizes
Kendall's tau-b	Ordinal data with more than two categories	1) Indicates strength and direction of association found. 2) Suitable for small sample sizes
Chi-Square Test of Association: Phi	Categorical data with only 2 categories	1) Tests for a significant association between two variables. 2) Only indicates strength of association found. 3) Applies to 2x2 tables only (i.e. both variables may not have more than 2 categories)
Chi-Square Test of Association: Cramer's V	Categorical data (i.e. Nominal and Ordinal data)	1) Tests for a significant association between two variables. 2) Only indicates strength of association found. 3) Only works for two nominal variables or one nominal and one ordinal variable. 4) Applies for tables larger than 2x2 (i.e. at least one of the variables must have more than two categories).

Table 5.2: Applied correlation coefficients per effect researched. *The scores given indicate ordinal data with 4 categories.

Effect of ...	**Data type**	**Suitable correlation coefficient***	**Null-hypothesis**
Time gap	Ordinal data (>2 categories)	Spearman's Rank-Order	The scores given are not associated with the time gaps shown.
Crossing Direction	Nominal data (2 categories)	Cramer's V	The scores given are not associated with the crossing direction.
Interaction Scenario	Nominal data (>2 categories)	Cramer's V	The scores given are not associated with the interaction scenario shown.

5.2.2. Expectations from the Collected Data

The collected data is illustrated in Figure 5.2. The figure presents the percentage of the scores given to a time gap for each interaction scenario, and for each crossing direction. After observing these graphs, expectations were formulated about the effects of the time gap, crossing direction, and interaction scenario on the scores given. The following subsections explain whether these expectations were valid, and therefore answers sub-questions 2.2 and 2.3. Below the expectations are described.

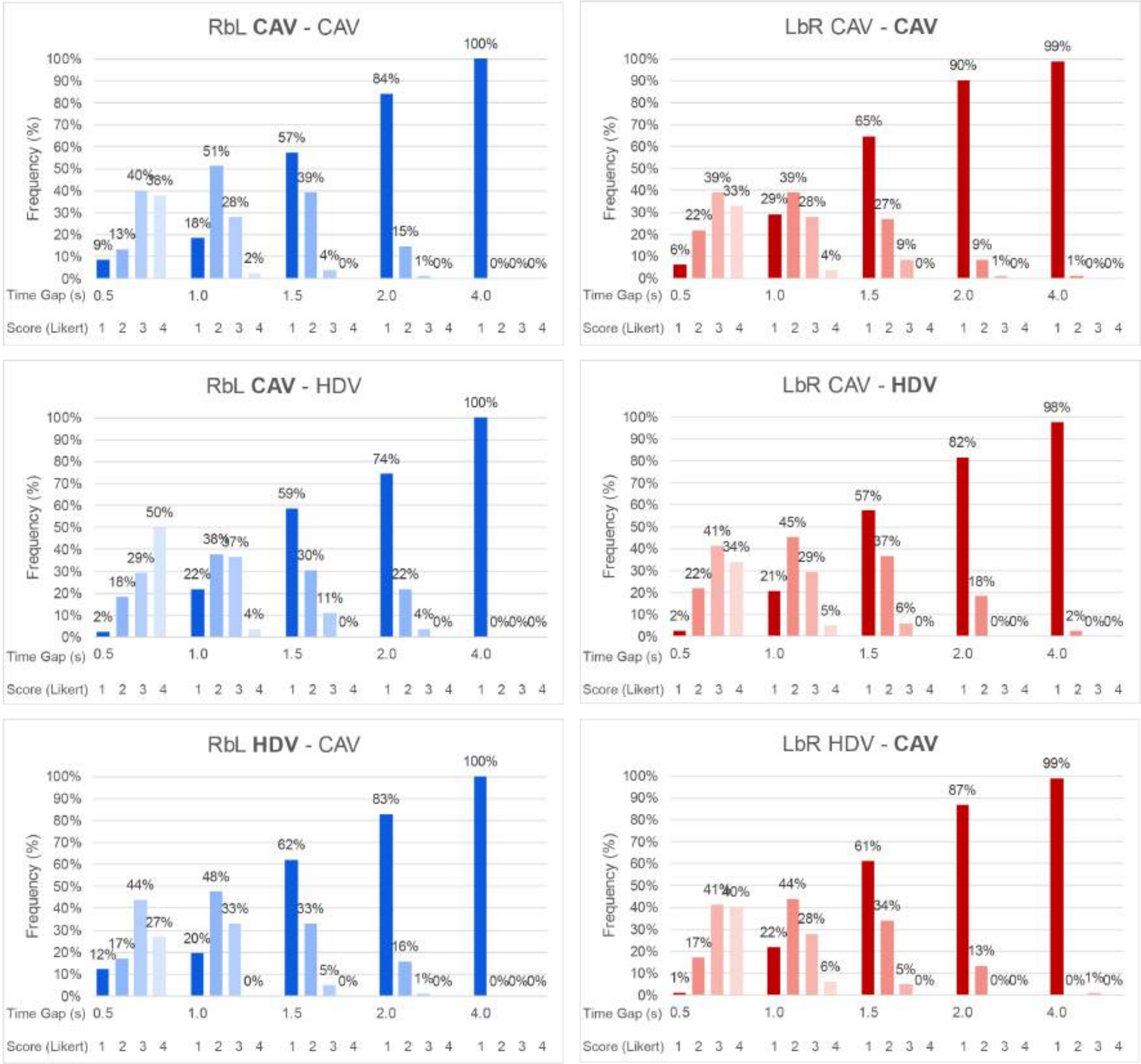


Figure 5.2: Feeling of safety Likert scores (lower x-axis) given per time gap (upper x-axis) presented per combination of an interaction scenario and crossing situation. [LbR = Left-before-Right; RbL = Right-before-Left]

1. An association between the scores and the four time gaps was expected due to the increasing trend for score *1) Very safe* with increasing time gaps. Moreover, the decreasing trends in *3) A little unsafe* and *4) Very unsafe* with increasing time gaps confirmed the expectation for a correlation. Besides, score *2) Pretty safe* first increased, and later decreased. Thus, from 1.5 second time gap on, the Likert scores 2, 3, and 4 all decreased in frequency, whereas 1) increased. Therefore, a negative correlation between the scores and time gaps was expected: Larger time gaps result in a lower Likert scores, and thus a higher level of perceived safety.

2. When comparing the interaction scenarios with the crossing order, no striking differences seemed to exist. All bars distinguished per time gap, score, and interaction scenario, imply to have nearly the same frequency. Therefore, no association was expected to exist between the scores given and the crossing direction.

3. All graphs look quite similar. Only a few differences seem to exist. Considering the RbL **CAV**-HDV scenario, a large majority of the participants felt *very unsafe* at the 0.5 s time gap, while at all other interaction scenarios most people felt *a little unsafe*. Besides, it seemed that on average, the participants felt most unsafe during the **CAV**-HDV interaction scenario, compared to the other two scenarios. However, these differences found are not remarkably large, and are not really striking at first sight. Therefore, it was expected that no association would exist between the interaction scenarios and the given scores.

5.2.3. Effects of Time Gap on Scores given

An important first step is to check whether the collected data was valid and could make sense to draw conclusions from. Namely, when an association would exist between the scores given by each participant and the time gap shown to the participant, it could be assumed that the data received from the experiment was not based on chance. A negative correlation was expected to exist between the scores and the time gaps for each of the six situations.

As was indicated in Table 5.1, a sufficient statistical measure to find the strength and direction of an association that possibly exist between two variables that were measured on an ordinal scale, is the *Spearman rank-order correlation coefficient* (i.e. Spearman's correlation coefficient). This measure has two assumptions that must fit the collected data in order to be allowed to be applied:

1. The variables must be ordinal (e.g. Likert scale) or scale (interval or ratio) data. This assumption is true for this experiment, since both variables represent ordinal data.

2. One variable must be monotonically related with the other (i.e. as variable X increases, variable Y should either never decrease or never increase). Normally, scatter plots prove this assumption. However, since both the scores and time gaps are discrete variables, a colour scale was used to clarify the frequency of the scores given per time gap. Figure F.1 in Appendix F illustrates these adjusted scatter plots including this colour scale and including the number of occurrences. According to this figure, it became clear that the data was indeed monotonic.

Since the two assumptions were fulfilled by the data, the Spearman's correlation coefficient was found appropriate to apply. Together with a statistical test, a null-hypothesis is given that must be rejected when the P-value is less than the significance level set. The smaller the P-value, the smaller the probability that the null-hypothesis is correct, and thus the stronger the evidence that the null-hypothesis must be rejected.

When the P-value is less than 0.05, the null-hypothesis was rejected correctly with 95% certainty. When the P-value is lower than a significance level of 0.01, this percentage would be 99%. The null-hypothesis and the alternative hypothesis applied are presented as follows:

- H_0: The scores given are not associated with the time gaps shown.

- H_1: The scores given are associated with the time gaps shown.

The Spearman's correlation coefficient ranges between -1 and +1, which indicates respectively perfect negative correlation and perfect positive correlation. These values will only appear when comparing a variable with itself. To find the correlation between the time gaps shown and the scores given, the Spearman's Correlation test was executed seven times: one time per interaction scenario, varying on crossing direction, and one time on the whole data set. The six traffic situations were tested for association in case the interaction scenarios and / or the crossing direction would appear to be statistically independent from each other.

The outcome of the statistical measures are shown in Appendix F, Tables F.1 and F.2. Table 5.3 shows an overview of the Spearman's correlation coefficients corresponding to the seven tests. As can be seen, the correlation coefficients found all equaled a value between -0.733 and -0.779. Correlation values between -0.7 and -1.0 indicate a strong and negative correlation (Ratner, 2009). Furthermore, all seven P-values were lower than the significance level of 0.01, hence it could be concluded that the negative correlations observed between the time gaps shown and the scores given for each situation, were statistically significant at a 99% significance level. Therefore, the null-hypothesis was rejected: the scores given thus strongly associate with the time gaps, and the data collected was thus assumed not to be random.

Table 5.3: Spearman's Correlation Coefficients: indicate significant negative associations between time gap and scores at 0.01 significance level.

	All Data	**CAV-CAV**		**CAV-HDV**		**HDV-CAV**	
	-	*RbL*	*LbR*	*RbL*	*LbR*	*RbL*	*LbR*
Spearman's Correlation Coefficient	-0.750	-0.756	-0.733	-0.752	-0.779	-0.723	-0.760
P-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

5.2.4. Effect of Crossing Direction on Scores given

This subsection answers sub-question 2.2: *To what extent varies the preferred safety distance of a human driver with the direction from which a crossing vehicle is approaching the same intersection?*

In Accordance with Figure 5.2, no significant difference between the given scores at the LbR and RbL situation was expected. Figure F.2 in Appendix F, shows three graphs that illustrate the frequency of the given scores per interaction scenario and per time gap, while clearly distinguishing the crossing direction. This figure more clearly shows the expected existence of only marginal differences between the RbL and LbR situation for each score given at each time gap. Only for a few situations might the difference be significant.

To research whether the scores given at the LbR and RbL situation were statistically significantly different from each other, multiple Chi-Squared tests for Association were executed. As was already described, these tests are used to discover whether a relationship between two categorical variables exist. The Cramer's V value should be used to interpret the correlation rather than the Phi value, since the scores given contain 4 categories.

As was explained in Table 5.1, a Chi-square test of Association has two assumptions which the data must adhere to, otherwise no reliable conclusions could be drawn from the test results. The data obtained fit these assumptions, which are described as follows:

- The two variables should be measured at an ordinal or nominal level (i.e. categorical data).
- The two variables should consist of two or more attribute levels (e.g. 2 groups: male / female; 3 groups: Belgian, Dutch, German, etc.)

The null-hypothesis and the alternative hypothesis applied were the following:

- H_0: The scores given are not associated with the crossing direction.
- H_1: The scores given are associated with the crossing direction.

The first Chi-Square test was executed to find an association between all scores (ordinal data, 4 categories) and whether the score was given during an RbL or LbR situation (nominal data, 2 categories). Thus, no distinction was made between the interaction scenarios here. Thereafter, 15 more Chi-Square tests were executed to test for effects of the crossing direction, specified to one time gap within a specific interaction scenario. These tests were useful in case the interaction scenarios would appear to lead to statistically different results. These tests would moreover show whether the crossing direction would influence the feeling of safety at certain time gaps.

The results of all 16 Chi-Square tests that were applied appeared to be insignificant. The Chi-Squared test that was applied to the whole data set resulted in a P-value (Pearson Chi-Square) of 0.952, which is much higher than the significance level of 0.05. Therefore, the null-hypothesis could not be rejected. Namely, the P-value indicates that when the null-hypothesis would be rejected, the chance is 95.2% that this would be wrong.

Neither did any of the 15 other Chi-Square tests result in a significant correlation. Actually, in 11 of the 15 cases, the output value was invalid, because of an excessively high percentage of the cells having an expected count less than 5. Table 5.4 presents all P-values found, and indicates the invalid P-values with an *. Therefore, according to these 15 Chi-Square tests the null-hypothesis could not be rejected either. Hence, the results presented in this subsection indicate that the crossing direction does not affect the scores given by the participants. Therefore, the scores given to the LbR and RbL traffic situations were combined to only three data sets: one per interaction scenario, as illustrated in Figure F.12, in Appendix F. Moreover, Tables F.3 to F.11 show the output from the 16 Chi-Square tests generated using SPSS.

Table 5.4: P-values resulted from 16 Chi-Square tests for Association. * Invalid P-values

		All Interaction Scenarios combined
P-value	*All time gaps combined*	0.952

		CAV-CAV	**CAV-HDV**	**HDV-CAV**
P-value	*0.5 s*	0.510	0.398*	0.085
	1.0 s	0.305*	0.615*	0.235*
	1.5 s	0.149	0.344	0.806*
	2.0 s	0.475*	0.066*	0.563*
	4.0 s	0.316*	0.316*	0.155*

5.2.5. Effect of Interaction Scenarios on Scores given

Now that it was clear that the crossing direction had no influence over the scores given, it was investigated whether or not the interaction scenario that was shown to the participant made a difference regarding the scores that were given. To determine whether the three different interaction scenarios resulted in significantly different results (scores), a similar statistical test was applied as was described to be able to determine the influence of the crossing direction. Namely, again nominal data (Interaction Scenario) was compared with ordinal data (Scores). In total four Chi-Square tests for Association were executed in order to determine whether a relation between the interaction scenarios and the scores given existed. The first Chi-Square test was applied over the whole data set: all scores of all interaction scenarios were compared for independent results. The other three Chi-Square tests only compared the data sets of two interaction scenarios. These last three tests were executed to cover for the possibility where two interaction scenarios generate very similar scores, hence the first chi-square test would have resulted in no correlation between all three interaction scenarios, while there perhaps was between only two scenarios.

The following hypotheses were used:

- H_0: The scores given are not associated with the interaction scenario shown.
- H_1: The scores given are associated with the interaction scenario shown.

The output of the Chi-Square tests is shown in Appendix F, F.5. As can be seen here, no significance was found and the null-hypothesis could thus not be rejected. Hence, it can be concluded that the participants did not give significantly different scores per interaction scenario. Since the interaction scenarios are not independent, all scores were combined to one data set for the following results.

5.2.6. Perceived Safe Time gaps

Eventually, the goal is to get an indication of roughly what safety margin people feel safe at in the future hybrid traffic situation. Table 5.5 provides an overview of the frequency of each score that was given to a time gap. Note that no further distinction was made between the interaction scenarios, nor between the crossing directions, since those scores were not statistically different from each other. Moreover, note that the table defines *Safe* by the scores 1 and 2, whereas *Unsafe* was defined by the scores 3 and 4. Furthermore, Figure 5.3 illustrates the data of Table 5.5 in a bar graph.

Table 5.5: Frequency scores given to a certain gap, all interaction scenarios combined.

	Score								**Safe**	**Unsafe**
Gap	1		2		3		4			
0.5	27	5%	90	18%	193	39%	182	37%	24%	76%
1.0	108	22%	217	44%	150	30%	17	3%	66%	34%
1.5	296	60%	164	33%	32	7%	0	0%	93%	7%
2.0	410	83%	76	15%	6	1%	0	0%	99%	1%
4.0	488	99%	3	1%	1	0%	0	0%	100%	0%

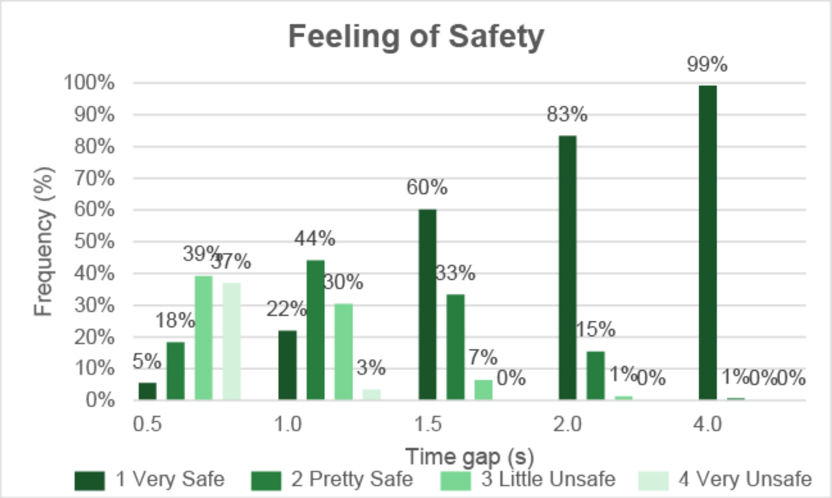


Figure 5.3: Frequency Scores per Time gap - All Interaction Scenarios Combined

When plotting the percentages that represented a safe feeling at the participants against the corresponding time gaps it seemed that a certain relationship exist between these two variables. Figure 5.4 illustrates this relation that followed from the data. Smooth lines were drawn between the data points in order to get an indication of what a model could look like that fit the data.

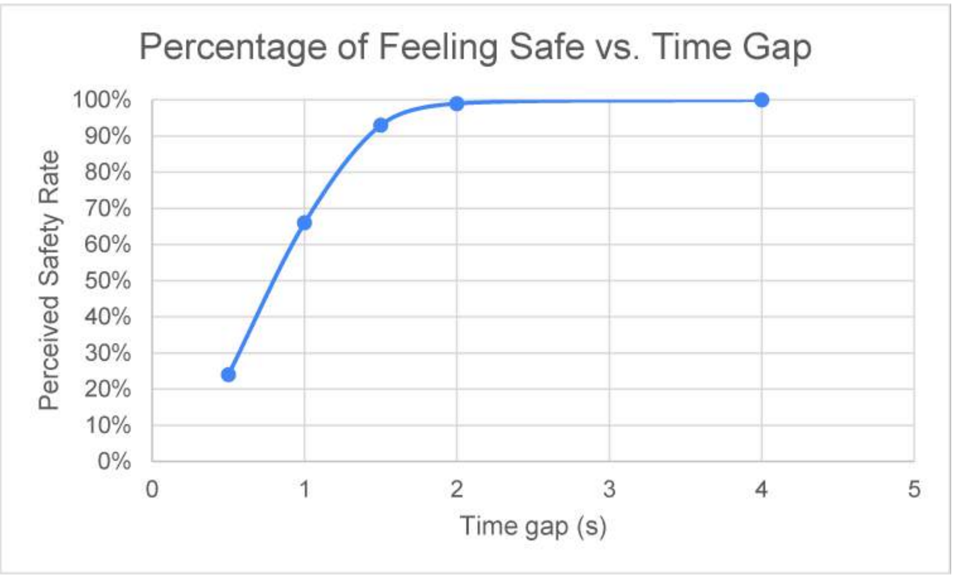


Figure 5.4: Possible relationship between the time gap and the percentage of people that will feel safe. Note: this graph only applies for the assumed traffic situation as was described in this research with a speed limit of 50 km/h.

From both the table and the figure it can be seen that 76% of the participants felt unsafe at the 0.5 second time gap. However, as can be seen in Figure 5.4 too, a big leap of 42% is seen between the 0.5 and 1.0 second time gap. Hence, already from the time gap of 1.0 second onward, the the majority of the participants feels safe (66%). From the 1.5 second time gap, already 93% of the participants feels safe, of which 64% feels 'very safe' rather than 'pretty safe' (36%). When the time gap of 2.0 seconds is shown, it can be concluded that every participant, except for 6 participants who felt 'a little unsafe', felt safe. Applying a time gap of 4.0 seconds resulted in an acceptance rate of 100%: every participant felt safe except for 1 person. To conclude, the majority of the participants would feel safe when using a time gap of 1.0 second. However, the question arises what the minimum desired acceptance rate is to assume when applying the time gap as a perceived safety margin. When an acceptance rate of 66% would be desired, the 1.0 second time gap would be sufficient to implement. However, during the starting phase of self-driving vehicles, perhaps a higher acceptance rate is desired to gain trust from the car occupants. In that case, a time gap value around 1.5 seconds might be more suitable. Finally, the expectations presented in Subsection 4.2.3, describe higher perceived safety margins than would be required according to the data from the human experiment. When applying the expected time gaps, it is probable that every road user will feel safe.

Influence of independent variables on the scores

Eventually, questions may arise whether the preferred time gap value is associated with any human characteristic that was collected via the questionnaires. Although this question is not the scope of this study, some statistical tests were executed to find a correlation between an independent variable (i.e. characteristics of the participants) and the dependent variable (i.e. the scores given). The correlations that followed could help interpreting the results found. In total, three significant, but weak, correlations were found between the scores (dependent variable) and an independent variable. The first correlation found was between gender and score. This correlation indicated that the female participants felt unsafe more often compared to the male participants. However, as explained before, it cannot be concluded that this correlation would be true for the whole population, due to the unequal gender distribution of the sample. The two other correlations were assumed to be valid to apply on the total population, and are described as follows:

- With 95% certainty, a weak correlation exist between the affinity with smart mobility and the scores given by the participant. No direction of the association could be given, since a Chi-Square test was applied.
- With 95% certainty, a positive and weak correlation exist between the driving style of the participant and the scores given by that participant. This implies that participants with a more aggressive driving style may be inclined to give higher scores (and thus feel unsafe more often than cautious drivers). This relation was found using the Spearman's correlation coefficient.

Especially the correlation between driving style and score is remarkable, since the literature describes that aggressive drivers are inclined to drive closer to their surrounding traffic. This may insinuate that the aggressive drivers also feel comfortable with this driving style. However, the correlation found contradicts this expectation.

Besides, more statistical analyses were executed related to the correlations among independent variables themselves. These correlations could perhaps clarify or influence the associations described above. However, no associations appeared to exist between Affinity and Driving Style and any other independent variable. Therefore, the independent variables described above are assumed to be directly correlated with the scores given. According to these correlations, a cautious statement that could be made is that when promoting a cautious driving style, more drivers would accept shorter time gaps, which could increase the throughput at the intersection.

Appendix G shows the significant correlation values found between two independent variables and between one independent variable and the dependent variable. Moreover, some extra explanation was provided about the correlations that were found, but that were less relevant to include here.

6

Conclusion

In total seven sub-questions were formulated to be answered. The first four sub-questions helped to answer the first research question (see Section 6.1). The last three sub-questions made it possible to answer the second research question (see Section 6.2). At the end of each section, the corresponding research question is answered.

6.1. Part I: Mathematical Formulation Safety Margins

1.1. *What is the relationship between an individual Space-Time reservation, actual safety margins, and perceived safety margins?*

The goal of this question was to provide clarity about the concepts that were introduced in this thesis. Their relationship is explained below.

- **individual Space-Time reservation:** A spatial area on the road that is reserved for only one CAV during a specific moment in time. The entire vehicle must occupy the reserved space at the indicated time in order to safely cross the intersection. Each CAV that wants to cross an intersection receives a series of these reservations that must be tracked by the vehicle. It is preferable to assign the CAV a trajectory including iSpaT reservations for every 0.1 second, as this frequency equals the frequency at which a vehicle can broadcast its own location. Consequently, checking whether the CAV is tracking the trajectory correctly is easy for the traffic controller.

The size of the location that must be reserved for a CAV depends on both technical and non-technical factors. These factors can influence the actual safety or the perceived safety of the vehicle and its occupants. To guarantee the safety of all car users, the impact of these factors is described as either *actual safety margins* or *perceived safety margins* around a vehicle. As a result of these margins around the vehicle, the vehicle size virtually grows; this virtual size is used by the traffic controller to plan all trajectories. The safety margins can be distinguished as follows:

- **Actual Safety Margins:** The impact of factors that influence the reliability of the current position of a CAV and the reliability of the CAV being able to track its assigned trajectory, is translated to actual safety margins around a vehicle. Thus, when a vehicle communicates its current position and vehicle dimensions to the traffic controller, the traffic control system virtually adds all required actual safety margins around this communicated vehicle location to demarcate the area on the road within which the vehicle is certainly located. This area is called the *Potential Vehicle Location* (PVL).

- **Perceived Safety Margins:** Where the actual safety margins help demarcating the area within which the vehicle is certainly located, the perceived safety margins create an area around the PVL that must be free of other traffic to ensure that the car users feel safe within their car. This area is called the *Preferred Clearance Zone* (PCZ).

To conclude, the traffic control system receives (among others) the location and vehicle dimensions from all CAVs that want to cross an intersection. The traffic control system plans trajectories for all CAVs considering the PVL and the PCZ of the vehicle. The traffic control system assigns iSpaT reservations having a reserved spatial area equal to only the vehicle size. The vehicle must track the trajectory as precise as possible. The traffic controller thus covered for inaccuracies in positioning and tracking.

1.2. *Which factors result in safety margins around a vehicle required to plan individual Space-Time reservations, considering both HDVs and CAVs?*

Tables 3.1 and 3.2 summarize all factors that together determined the size of the PVL and PCZ, thus summarizing the factors that all resulted in either an actual or perceived safety margin around the vehicle. The technical factors in Table 3.1 represented the factors that were related to inaccuracies of CAVs and the traffic control system. The non-technical factors (Table 3.2), on the other hand, are often human factors of which the perceived safety could depend on the environmental and road conditions of the traffic situation. Furthermore, the tables distinguish whether the factors found applied for HDVs interacting with CAVs, or for CAVs interacting with either an HDV or CAV. Sometimes a factor applied for both vehicle types.

The following technical factors were identified: *positioning inaccuracy, velocity inaccuracy, communication delay at V2I- and V2V-communication, computation time of the traffic model, subject time of the automated vehicle, actuator accuracy, reaction time of the CAV, inaccuracies at time synchronisation between CAVs and infrastructure,* and *driving experience of CAV.*

The following non-technical factors were found: *preferred driver space, reaction time of the driver, preferred time headway, time gap accepted by car driver or car occupant, driving experience (either in a CAV or HDV), trust in the vehicle, traffic density, weather conditions, mood of the driver, preferred driving style,* and *current visibility.*

1.3. *According to the impact of each factor on the safety of a vehicle, what size is required for all actual and perceived safety margins to establish safe Space-Time reservations?*

The impact of each identified factor on the required safety margin size was explained either quantitatively or qualitatively. The qualitative relations that depended on environmental and traffic conditions or that depended on human characteristics are presented in Table 6.1. These factors were not further considered while expressing the required size of the safety margins on each side of the vehicle. In order to include the qualitative relationships as quantitative parameters, first more research is required. Factors that did not depend on specific scenarios were included in the basic formulas for the safety margin size presented in Chapter 3.

Chapter 3 describes various formulas that were established to express the required size of a safety margin around a vehicle. Some of the variables in these formulas were expected to have different values when comparing the four interaction scenarios. Suggestions for these variables were given according to the literature study. Table 6.2 summarizes the quantitative values that were suggested based on the literature. Only the value for T was not based on the literature, but on the current modelling time of Smart Traffic. As can be seen, a suggestion was not provided for all variables mentioned in Chapter 3. Namely, as was described before, more research is required to define the structure and corresponding parameter values of the safety margins required due to trajectory tracking inaccuracies. Moreover, no suggestion was found for α due to an insufficient amount of time. Therefore, by using this table, it is not yet possible to calculate the exact dimensions of all safety margins. Note that the values of G were based on the literature rather than on the results of the experiment. Also note that the values presented in the table are suggestions, hence with more research the suggestions perhaps could change their value.

Table 6.1: Qualitative explanation of expected relationships between scenario-dependent factors and the size of a safety margin.

Scenario-dependent Factor	**Technical / Non-Technical**	**Vehicle type**	**Relationship with Size of Space-Time Reservation**
Driving Experience of CAV	Technical	CAV	The more driving hours a (C)AV made, the smaller the necessary safety margins are expected to be.
Driving Experience of human driver	Non-Technical	HDV	Bad driving experiences leads to larger safety margins.
Driving Experience of human occupant	Non-Technical	CAV	Good driving experiences in (C)AV, leads to smaller safety margins.
Trust	Non-Technical	HDV	Human drivers prefer a similar driving style for the (C)AV compared to their own driving style.
Trust	Non-Technical	CAV	More trust in the (C)AV leads to smaller safety margins.
Traffic Flow	Non-Technical	HDV	A more dense traffic flow, leads to smaller safety margins.
Weather Conditions	Non-Technical	HDV	Bad weather conditions, leads to larger safety margins.
Weather Conditions	Non-Technical	CAV	Only the condition of the road surface could influence the required safety margins: the worse these conditions, the larger the margins.
Mood	Non-Technical	HDV	The more aggressive the driver, the smaller the safety margins can be.
Preferred Driving Style	Non-Technical	CAV	Often people prefer their own driving style for the (C)AV.
Visibility	Non-Technical	HDV	Less visibility results in larger safety margins.

Table 6.2: Assumed values for safety margins based on literature research [N/A: Not Applicable; TBD: To Be Determined]

Safety Margin	***Variable***	**HDV-HDV**	**HDV-CAV**	**CAV-HDV**	**CAV-CAV**
M_p	p_{long}	2.95 m	2.95 m	0.02 - 0.10 m	0.02 - 0.10 m
	p_{lat}	1.15 m	1.15 m	0.02 - 0.10 m	0.02 - 0.10 m
M_{vel}	w^V	0.04 - 0.10	0.04 - 0.10	-0.10 <w <+0.10	-0.10 <w <+0.10
	T	1 to 3 sec	1 to 3 sec	1 to 3 sec	1 to 3 sec
M_h	h_{front}	1.5 sec	2.0 sec	2.0 - 4.0 sec	0.3 - 4.0 sec
	h_{back}	1.0 sec	1.5 sec	1.5 - 4.0 sec	0.3 - 4.0 sec
M_{ds}	s_{long}	8.7 m	8.7 m	8.7 m	8.7 m
	s_{lat}	8.7 m	8.7 m	8.7 m	8.7 m
M_{gap}	G	1.8 s	2.3 s	2.3 s	2.05 s

1.4. *To what extent could the required safety margins of two vehicles overlap while still ensuring the actual and perceived safety of all human occupants?*

A distinction was made between the actual safety margins that formed the PVL, and the perceived safety margins that determined the PCZ. The PVL describes the location where the vehicle itself could be located, whereas the PCZ describes the preferred space around the vehicle that has to be free of other traffic. The question was whether is was allowed that a PVL and a PCZ could use the same space on the road. The answer was found by reasoning:

- When 2 PVLs would use the same road space at the same time, it is highly likely that a collision would occur. This must be avoided, so no overlap is allowed between PVLs;

- When 1 PVL and 1 PCZ of different vehicles would use the same road space at the same time, it is highly likely that the PCZ would not be free of other traffic. Therefore, the car user could feel unsafe, which is desired to be avoided. So, overlap between a PVL and a PCZ of different vehicles must not be allowed;

- When 2 PCZs would use the same road space at the same time, both PCZs would still be free of other traffic. No feeling of unsafety would occur among the car users, hence overlap between PCZs is allowed and even favorable in the context of efficient use of road space.

6.1.1. Research Question 1

The first research question was described as follows:

While considering the hybrid traffic period, what mathematical formulation that expresses the impact of technical and non-technical factors, describes the required size of safety margins around a vehicle?

In total, two formulations were presented to answer this first research question: one representing the longitudinal margins around a vehicle, and one representing the lateral margins. Both formulas can be used for all four interaction scenarios. To describe the safety margins on the longitudinal sides of the vehicle, the positioning inaccuracy, the trajectory tracking inaccuracies, the preferred driver space, and the preferred time headway were taken into account. Besides, to describe the safety margins on the lateral sides of the vehicle, again the positioning inaccuracy, the trajectory tracking inaccuracies, and the preferred driver space were considered. However, instead of the preferred time headway, the accepted time gap was taken into account here. Note that not for all safety margins a concrete value could be determined yet. M_{tt} and M_{ts} require further research to be expressed quantitatively, or sufficient inaccuracy values to be described for. Since the actual safety margins must all be summed to define the PVL, and only the maximum value of the perceived safety margins is needed to describe the PCZ, the mathematical formulations were described as presented below.

$$\mathrm{M}_{long}^{is} = \mathrm{M}_{p}^{is} + \mathrm{M}_{tt}^{is} + \mathrm{M}_{ts}^{is} + \max\left(\mathrm{M}_{ds}^{is}, \mathrm{M}_{h}^{is}\right) \qquad \forall i \in I, \forall s \in S \tag{6.1}$$

$$\mathrm{M}_{lat}^{is} = \mathrm{M}_{p}^{is} + \mathrm{M}_{tt}^{is} + \max\left(\mathrm{M}_{ds}^{is}, \mathrm{M}_{gap}^{is}\right) \qquad \forall i \in I, \forall s \in S \tag{6.2}$$

I = {HDV-HDV, HDV-CAV, CAV-HDV, CAV-CAV}
S = {FRONT, BACK, LEFT, RIGHT}

6.2. Part II: Accuracy Formulation Safety Margins in Front of a Vehicle

During the second part of the research, the goal was to find the perceived safety margin in front of a vehicle by executing a human experiment. Afterwards, these values were compared to the values found in Part I. Below sub-questions 2.1, 2.2 and 2.3 are answered. Eventually, the second research question was answered.

2.1. *What would be a suitable set up for an experiment to find a person's preferred safety distance in front of a vehicle, considering the hybrid traffic interaction scenarios?*

The first step for creating a suitable set up for the experiment, was finding a suitable method. To be able to choose a method, several methods were tested on four requirements as described in Section 4.1. The most important requirement was that the test environment had to feel as realistic as possible. After comparing the methods, two appeared to be the most suitable to use: a 360-degree video study and a virtual reality study, both experienced via a Head-Mounted Display. The 360° video study was expected to be more realistic, and to take less preparation time than the virtual reality study. However, it became clear that a 360° video study was not possible, as it was impossible to simultaneously film and drive safely from the driver's seat. Therefore, the choice was made to apply a virtual reality study.

After the method was determined, a decision had to be made regarding which traffic interactions were presented to the participant. Namely, many traffic situations were interesting to test the perceived safety of a participant. After a small pilot study, VR was determined to be most suitable for the situation where a vehicle was crossing in front of the subject vehicle. Variation was created by letting the crossing vehicle approach either from the right or the left side of the intersection. This variation later helped to be able to check for a difference in the perceived safety levels due to the crossing direction.

To check for the preferred safety margins in front of the vehicle, a participant got shown 30 videos of different vehicle interaction situations. For each video they had to indicate their feeling of safety. Since no instruments were available to measure if or when a participant would have used brakes or intervened during a situation, an alternative method was applied to get an indication of the perceived safety: five different time gaps (or safety margins in front of the vehicle) were tested for each combination of an interaction scenario and a crossing direction. In total 30 videos were shown to a participant (3 interaction scenarios × 2 crossing directions × 5 time gaps). All 30 videos were shown in a random order to the participant to eliminate biases due to assignment of test scenarios. Due to software limitations, no variation could be made between the (6) combinations of an interaction scenario and a crossing order. Within such a combination, the order of the time gaps shown was possible to vary. Moreover, the order in which the 6 combinations of an interaction scenario and a crossing order were shown were varied. Therefore, none of the participants saw the 30 videos in exactly the same order. After each video the participant had to indicate their feeling of safety orally using a 4-point Likert-type scale. The advantage of a 4-point scale was that there was no option to choose a neutral option, so the situation was always judged as either safe or unsafe.

The five time gaps were based on the perceived safety margin values found in the literature. However, the smallest time gap was based on the value that is currently possible with truck platooning. It was expected that a time gap difference of at least 0.5 seconds enables a participant to (without knowing) experience the situations differently. This resulted in the following time gaps: 0.5, 1.0, 1.5, 2.0, and 4.0 seconds.

Before the 30 videos were shown to the participants, first two test scenarios were shown in order to make the participant familiar with the virtual environment, and in order to make them feel comfortable with rating a video. The first example showed a time gap of 0 seconds and the second example showed a time gap of 5 seconds. None of the 30 videos would thus show time gaps higher or lower than these values.

Finally, to increase the feeling of being in the virtual environment, a steering wheel and gas and brake pedals were added to the test set up. However, it is important to note here that these materials did not react to the participant's actions.

2.2. *To what extent varies the preferred safety distance of a human driver with the direction from which a crossing vehicle is approaching the same intersection?*

A Chi-Square test was applied in order to check for a significant association between the crossing direction and the scores given. The Chi-Square test showed a P-value of 0.952. This value was compared to the significance value of 0.05. Since 0.952 > 0.05, the null-hypothesis that assumed no association between the crossing direction and scores given, could not be rejected. Therefore, it cannot be concluded that an association exist between the participants' perceived safety and the direction from which the crossing vehicle was approaching the intersection.

2.3. *To what extent varies the preferred safety distance of a human driver with different vehicle interaction scenarios that can occur during the hybrid traffic period?*

After applying four Chi-Square tests, one on the whole data set, and one per interaction scenario, it could not be concluded that a significant relationship would exist between the scores given and the interaction scenarios that were shown. This suggested that no real difference was experienced between the three different interaction scenarios by the participants, and thus it did not make a difference whether the participant was driving an HDV or sitting in a CAV. Neither did the vehicle type of the crossing vehicle matter. However, according to the results of the second questionnaire, the participants did indicate that they could empathize well with their roles as human driver and passenger of a CAV, as well as with the crossing vehicle being an HDV or CAV. As an affirmative question, the participants were also asked to what extent they experienced sitting in an HDV differently from sitting in an CAV. The majority indicated that they actually experienced this difference. Together with the results that the participants were focused, did not experience motion sickness, and felt being present in the VR environment, it was concluded that indeed no difference was experienced between the three interaction scenarios, and that all scores (thus the complete data set) could be combined to find the preferred safety margin in front of their vehicle.

6.2.1. Research Question 2

The second research question was described as follows:

According to a human experiment, what is the value of the perceived safety margin that is required in front of a vehicle, considering the different interaction scenarios that appear during the hybrid traffic period, and how does this value relate to the values found in the literature?

According to the answers to sub-questions 2.1 to 2.3, it became clear that the answer to the second research question could be applied to both an HDV or a CAV, independent of the vehicle type of the crossing vehicle, and independent of the crossing direction of the crossing vehicle.

Table 5.5 shows the percentages of participants feeling safe and unsafe at a specific time gap. Besides, Figure 5.4 shows a relationship between the time gap and the acceptance rate that fits this data. The figure shows that 93% of the participants feels safe at a 1.5 second time gap. However, concluding one value that could represent the required safety margin in front of the vehicle that would apply for the feeling of safety of all road users, is very complicated. Namely, the safety margin to adopt in front of a vehicle will depend on the desired acceptance rate. Figure 5.4 indicates the percentage of people that will feel safe at intermediate values for time gaps tested. For example, a time gap of 0.8 seconds, may result in an acceptance rate of 50%.

To answer the second part of this research question: how the observed safety margin values relate to the values expected according to the literature, a reflection was provided on the expectations that were generated in Subsection 4.2.3. They are repeated below:

- When a CAV intersects the planned trajectory of an HDV, the human driver of the HDV prefers a time gap between 2.0 and 2.3 seconds.
- When an HDV intersects the planned trajectory of a CAV, the human occupant of the CAV prefers a time gap between 2.3 and 4.0 seconds.
- When a CAV intersects the planned trajectory of a CAV, the human occupant of the CAV prefers a time gap between 2.0 and 4.0 seconds.

First, it can be noticed that these expectations made a distinction between the three interaction scenarios. However, according to the results, no statistically significant difference was found between the scores given at each of these scenarios. Nevertheless, each expectation was individually compared to the data that resulted from combining all interaction scenarios and crossing directions. It became clear that for each time gap expected, a perceived safety rate higher than 99% followed: a time gap of 2.0 seconds was accepted by 99% of the participants. Therefore, it was concluded that all expectations would result in a positively perceived safety feeling for all car users. However, applying time gaps higher than 2.0 seconds would lead to a negative influence on the throughput at the intersection while the perceived safety feeling would not (further) increase.

Therefore, the values expected based on the literature 1) can be combined to one value, and 2) should not be higher than 2.0 seconds. Since the literature described that distances between automated vehicles and non-automated vehicles could decrease with driving experience and trust (Dixit et al., 2016; Pereira et al., 2015; Gouy et al., 2014), it is expected that 2.0 seconds might be a good perceived safety margin during the starting phase of iSpaT reservations. However, it must be noted that this value is thus expected to decrease as the hybrid period continues.

7

Discussion and Future Research

This chapter describes the main discussion points that followed from both part I and II of this research. For each part, the results were discussed, as well as the methodology that was applied. Furthermore, advice for future research was provided after a point of discussion. At the end of a section, the points for further research are summarized.

7.1. Part I: Mathematical Formulation Safety Margins

Part I is described by Chapter 2 and 3. Chapter 2 focused on defining all factors that resulted in actual and perceived safety margins. Suggestions for these sizes were provided too. The discussion points were mainly related to the research process and completeness of the factors. Chapter 3 used the literature study to formulate the mathematical formulas that could describe the safety margins around a vehicle. In some cases suggestions were made about the impact on the size of the safety margins. The main discussion points were related to the precision of the suggestions and the applicability of the formulas to other traffic situations.

7.1.1. Discussion on Results

- The first important point of discussion regards the fact that this research does not describe a safety margin for the uncertainty of the exact location of the vehicle when receiving the (first) iSpaT message. The time between the CAV sending a registration message to the traffic control system and the CAV receiving the iSpaT message depends on the computation time of the traffic model, and on the timing of the receipt of the registration message between two calculation iterations. In Chapter 2 a computation time between 1 and 3 s was assumed. If the registration message is received directly after a calculation step, this registration will not be included in another round of calculation for another 1 to 3 s. This can result in the CAV possibly having to wait for 6 seconds before receiving its reservations. When assuming the speed of the CAV to be 50 km/h, the CAV would have driven more than 80 meters during these 6 s. However, when the vehicle would brake or accelerate, this distance could change, hence it is hard for the traffic control system to determine the location and time of the first (or the first couple of) iSpaT reservations. Huge safety margins would be necessary when applying the method as described in this thesis. Therefore, future research concerning this large uncertainty in vehicle positioning would be useful.

- Formulas were presented for HDVs as well, despite the assumption that these vehicles will not drive according to iSpaT messages. However, the information obtained from these formulas could still be valuable for the quality of the predictive power of Smart Traffic. Currently, no behavioural aspects of HDVs are involved in Smart Traffic (i.e. only the capability of an HDV to reach the green light is calculated). An outcome could be that HDVs may prefer different time headway values during peak hours compared to off-peak hours. This perhaps could improve the predictive power of Smart Traffic.

- The concept of iSpaT reservations was based on the fact that all automated vehicles were self-driving and could communicate with each other and with the infrastructure. Moreover, the CAVs were all assumed to be able to track the assigned trajectory of the traffic controller. However, in the future hybrid traffic situation, vehicles of other automation levels will also drive on the road. It is crucial that the vehicles that will drive according to iSpaT messages must be able to communicate with the traffic control system, and preferably with surrounding traffic as well. Therefore, vehicles with an automation level below level 4 are expected not be able to drive according to iSpaT messages. As soon as a vehicle is unable to drive according to iSpaT messages it is advised to not even inform the vehicle with these messages. Perhaps that would lead to unexpected driving behaviour or distracted drivers.

- Since Smart Traffic is a traffic control system that works at signalized intersections, the question arises whether iSpaT reservations could also be applied at unsignalized intersections. This question would be very interesting for further research. The expectation according to this thesis is that it may not be impossible, however, the question is to what extent the value of the safety margins needs to change. Namely, even more uncertainty about the driving behaviour of HDVs occurs. The traffic lights gave certainty about the planned route of the HDV and when they would start crossing the intersection. At unsignalized intersections, much more uncertainty will occur. Moreover, the question arises how efficient the throughput can be when CAVs would require (very) large safety margins, and if CAVs even get the opportunity to cross (will HDVs overtake them if they keep large safety margins?). Because of these reasons, at the current design state of iSpaT reservations, it is not expected that Smart Traffic will work at unsignalized intersections as long as HDVs will drive on the road as well. Note, when all vehicles on the public roads would be connected and automated, maybe no traffic signals or iSpaT messages would be necessary at all, since the CAVs would communicate via V2V-communication when to cross the intersection. The role of iSpaT reservations during a fully automated traffic situation is also interesting for further research.

- The safety margins were described to be located in front of, at the back of, and on both sides of the vehicle. Moreover, it was assumed that the largest safety margins at each side of the vehicle were connected to each other in order to create a safety space around the entire vehicle. However, no mathematical description was provided about this assumption. Eventually, this description is required for further developing Smart Traffic. Moreover, future research could deepen insights into these 'corner' margins: what is the best method to deal with safety margins at these corners? Is the applied method in this thesis sufficient, for example in terms of computation time of the traffic model or regarding an efficient throughput at the intersection?

- As soon as iSpaT messages could be sent to CAVs, the goal is to let CAVs weave through each other and through HDVs over the intersection. Ideally, at a 100% penetration rate, no vehicle queues would occur anymore. That would be beneficial regarding fuel emissions and the mood of the drivers (never waiting in front of an intersection to cross it). However, it is important to also consider slow traffic: cyclists and pedestrians possibly also need to cross the intersection. Future research can focus on the optimization between the waiting times for slow traffic and the vehicle queue length. This thesis did not consider the presence of slow traffic.

- Besides the factors that were found that were included in the safety margin formulas, factors were found which influence the required safety margins that could only be described by an expected qualitative relationship (see Table 3.3). However, these factors may also be important to include in the formulas. Further research should focus on generating reliable parameter values that can describe the impact of these factors on the size of the safety margins. Furthermore, the impact of these scenario-dependent factors was expected to only influence the size of the preferred clearance zone. Therefore, no safety issues occur by not implementing these factors in the described formulas. Effects of not having these factors included are, worst case, that passengers still do not feel safe with the estimated preferred clearance zone, and that the time slots will not be distributed optimally. For example, if it would be the case that passengers would prefer smaller time gaps during peak hours, but wider gaps during off-peak hours, with the current set up of the safety margin formulas, these desires would not be taken into account. As soon as the driver's characteristics and environmental conditions could be taken into account, the traffic control system could plan better fitting and more efficient trajectories.

- It was assumed that the Preferred Clearnace Zone (PCZ) cannot overlap with the Potential Vehicle Location (PVL). However, the size of the PVL was based on the fact that all actual safety margins should be maximally accounted for (i.e. all factors showed their maximum impact). The question arises with what probability this maximum deviation will occur. Possibly, if this probability is very low, then it could perhaps be favorable to let these two areas overlap to a certain extent. Still no collisions would occur, the only risk is that people might feel unsafe. Further research should show what this probability is and what the gain can reached in terms of a higher vehicle throughput at the intersection.

- This research also provided some suggestions that could be used for some variables of the formulas. The assumption that all HDVs will be connected to the 5G network is an important one to mention here, since this cannot by guaranteed by this thesis. However, it was expected since 5G is expected to be enrolled in the Netherlands in 2023 (Nando Kasteleijn, 2020). Moreover, it was not expected that Smart Traffic can assign iSpaT messages by that time. When not all HDVs would be connected to the 5G network by the time that Smart Traffic could assign iSpaT reservations, another actual safety margin would be required for HDVs. Of course, when another vehicle positioning system would be used in the future, this safety margin also has to be changed.

- Smart Traffic can be applied to any signalized intersection in the Netherlands, and does not require changes to traffic lights. Smart Traffic is a software tool which predicts traffic flows. When improving Smart Traffic with the iSpaT concept, Smart Traffic could still be applied to every signalized intersection, also abroad. However, possible changes must be made in the law or other infrastructural elements: what will happen if CAVs run through a red light?

- The literature study focused on passenger cars. However, other vehicle types, like autonomous trucks, should also be able to receive iSpaT messages. Future research is necessary in order to conclude to what extent both the actual and perceived safety margins vary for other vehicle types. Presumably no real difference would exist in the equations for the safety margins, however, differences can exist in the parameter values. Moreover, perhaps some safety margins will disappear or will need to be added.

- Emergency situations were not the scope of this research. This research assumed that during emergency situations, the CAVs can behave as regular passenger cars. However, it is important to analyse how the system of iSpaT reservations can be restarted after an emergency situation.

7.1.2. Reflection on Methodology

A literature research was applied in order to find all factors that possibly influenced the size of the required safety margins around the vehicle. The discussion points below are related to this research process.

- Before the literature study was executed it was determined what specific traffic scenarios were desired to analyse. However, finding enough literature that described the distances held between vehicles for the different crossing situations at (unsignalized) intersections in an urban area proved to be more difficult than expected. Therefore, also literature was analysed that described traffic situations outside the urban area. The vehicle distances that followed from these studies were considered to be less reliable and might be less applicable for the safety margins around vehicles at urban intersections. However, these articles were still very valuable in finding potential factors that could influence the size of the safety margins. The effect of the factors that followed from these studies were often described qualitatively (e.g. mood or weather conditions). Vehicle distances found in these studies were used to compare and validate the vehicle distances found in studies that did consider the urban environment.

- It was hard to find factors that specifically asked for a safety margin in front of the vehicle while another vehicle was crossing from the left or right side. Namely, gap acceptance describes what time gap is minimally required to cross or insert in front of another vehicle. The case described here, considers what time gap is minimally required to enter the conflict area after the crossing vehicle had left the conflict area. Moreover, both vehicles should be at full speed during this situation. Namely, this vehicle interaction would be typical for weaving vehicles, which is not happening currently on public roads. Therefore, combinations were made of values found for a vehicle's gap acceptance, encroachment time, and vehicle following distances (time headway). These combinations were later tested in the experiment of part II.

- This research only executed a literature study to find all factors that influenced the size of the safety margins. As many factors as possible were distilled from various literature studies. However, the question remains how one can be certain that all factors were found. The reasons to end the literature study included a combination of not finding any new factors and the time planning. It is expected that the literature study describes the most important factors. However, it cannot be guaranteed that new factors will not arise during further literature research.

7.1.3. Further Research - Part I

Regarding the discussion points described for the first part of this research, the following directions are interesting for further research:

- Research about the large uncertainty in vehicle positioning between the moment the CAV registers itself at the intersection and the moment it receives its iSpaT message. During this period the positioning inaccuracy can become excessively large, hence safety margins would be an inefficient solution regarding the throughput at the intersection.

- The question arises whether iSpaT reservations can be assigned to CAVs at unsignalized intersections. While there are arguments for not expecting this, further research could focus on the possibilities of iSpaT messages during the hybrid traffic period at unsignalized intersections.

- When all vehicles on the road are fully automated and connected, perhaps iSpaT messages are not necessary anymore. However, maybe they are still needed to let slow traffic safely pass the intersection. Future research could shed light on this.
- Each side of the PVL must be covered with a PCZ, also the corners. This research connects the maximum safety margin values at each side of the vehicle, forming one large rectangle. However, is this method sufficient and the most efficient method to create a PCZ around the complete PVL?
- Further research can focus on correct parameter values to implement the scenario-dependent factors in the formulas to calculate the required size of the safety margins around the vehicle. This thesis only provides a qualitative explanation of their impact on the size of the margins.
- The PVL is based on the assumption that all factors can show their maximum impact on the required safety margins simultaneously. However, it is valuable to research the probability of all factors simultaneously deviating to their maximum.
- The thesis only focused on passenger cars. However, more vehicle types drive on the road: trucks or motorcycles for example. A question that could be investigated is how the actual and perceived safety margins will change, disappear, or will be extra needed, for these vehicle types.

7.2. Part II: Accuracy Formulation Safety Margins in Front of a Vehicle

In the second part of this discussion, the results of the experiments are discussed and limitations are explained. Moreover, again a reflection on the applied methodology is given, which is interesting since the set up of the methodology is a sub-question of this research.

7.2.1. Discussion on Results

- The first point of discussion considers the sample of participants that executed the experiment. Although attempts have been made to make the sample as diverse as possible, the sample does not seem to perfectly describe the total population. This could have led to results that were not applicable to the total population, and possibly explains the outcome of the experiment that found smaller perceived safety margins than were expected. As was explained before, the number of male and female participants in the sample was not equally distributed. Moreover, the female participants were younger than the male participants. Therefore, the data set was not suitable to independently assess effects of gender. Effects of gender could be tested using only younger participants (i.e. only compare the young male participants with the young female participants). Moreover, despite of the fact that no correlation was found between gender and age, possibly effects of age would be more reliable when testing for correlations within the male participants only. However, this was not done for this experiment, since in that case the results following from certain comparisons would only apply for a small part of the total population (of car users). Namely, according to Kampert and Molnár-in 't Veld (n.d.) persons between 30 and 65 years old make the most driving hours, while the possible comparisons would have been made among the younger drivers (or only male drivers). Finally, about half of the participants had affinity with smart mobility or automated vehicles, which may be a higher percentage than in the population. Hence, the correlation found between *Affinity* and *Score* would perhaps not exist. According to Molnar et al. (2018) no association would exist between people with affinity for technology and the trust people have in automated vehicles. Therefore, this association too perhaps does not exist in the population.

- The preferred time gaps that followed from the results of the experiment were lower than was expected as a result of the literature. Perhaps the unequal distribution of gender and age caused this difference, or the high number of smart mobility experts in the sample. However, another reason could be the quality of the available studies and thus the quality of the expectations. As explained in the previous section, no studies described in the literature covered the exact same crossing situation as was tested in the experiment. During the experiment both vehicles were driving their maximum speed and were driving towards their conflict area. The literature found only described studies where vehicles were following each other, where one of the two vehicles was not at speed, or where the two vehicles were approaching the intersection from opposite directions, which probably ensured the vehicles to better estimate each other's behaviour. Moreover, the time gaps tested were experienced from a car perspective that was not found in the literature. The expectations were based on similar crossing situations, but which were explained from a different perspective, and based on studies considering a correct perspective, but studying a deviating traffic situation (i.e. car following).

- A further point of discussion followed from the statistical analyses that were applied. It became clear that the three interaction scenarios that were tested, did not result in output that was significantly different from each other. This is remarkable because of the results of the second questionnaire (Appendix E.2). These results suggested that the participants could empathize with both roles of a human driver and an occupant of a CAV. Moreover, they show that the participants could also empathize with the crossing vehicle being an HDV or CAV. Even the presence and absence of the steering wheel and pedals were rated to be of added value for empathizing with these roles. Therefore the question rises whether the test set up was sufficient in order to measure the correlation between different situations and different results, or that the set up was correct, but that people really did not experience difference regarding their feeling of safety. A master thesis of Visée (2019) concluded that people often do not prefer different driving styles for automated vehicles compared to human-driven vehicles. The literature study presented in Chapter 2 also concluded that people prefer their own driving style for automated vehicles. Therefore, it could make sense that people experience the three interaction scenarios differently, but that they just do not prefer different safety gaps for the different scenarios.

  One possibility to make sure that indeed no different time gaps were required for the different interaction scenarios, is to conduct a second experiment that would include three comparable test groups. Each group should be exposed to only one interaction scenario, but test for the same time gaps. If their results would still not differ, it would be likely that the interaction scenarios really do not make a difference. The reason this was not done for the experiment of this research, was that the set up with three different groups would require many more participants to draw statistically significant conclusions. This would have cost too much time for this research.

- The following discussion point is related to Figure 5.4. That figure showed the percentages per time gap at which people felt safe in the car. Between these data points, a line was drawn in order to show a relationship that fits the data. However, this line only represents an estimation, and cannot be interpreted as fundamentally true. Though, it does seem plausible that a time gap of 2.0 seconds or higher would always be accepted as a safe time gap. This contradicts with the results of Siebert and Wallis (2019) that found that only 70% of its participants felt safe in a CAV, within an urban environment, where the CAVs drove 4.0 seconds apart from each other. Moreover, according to Figure 5.4, it seems likely to conclude that time gaps higher than the maximal time gap tested in this experiment (4.0 sec), will always be experienced as safe in reality. However, it is much harder to describe such an expectation for the time gaps lower than the smallest time gap tested (0.5 seconds). It is highly likely that the smaller the time gap the lower the acceptance rate will be. However, further research would be necessary in order to find how the curve will look like between 0 and 0.5 seconds.

- Another relevant discussion point about Figure 5.4 is how the trend would change over the years. When trust in automated driving would indeed increase with driving experience, this line will possibly change over time showing a higher acceptance rate at smaller time gaps. Moreover, the question arises how reliable this graph still is when implementing iSpaT messages. Namely, by the time iSpaT messages will be implemented, it is likely that automated driving is more common on public roads. Therefore, it is expected that experience with automated driving among the population will be higher than it currently is. Hence, the trend shown in this figure possibly does not represent the desired time gap in 5 or 10 years. How this trend will evolve over the years where automated driving will be more and more common is interesting for further research.

- The final discussion point related to the results is the question what safety margin should be adopted when iSpaT messages could be assigned as soon as self-driving vehicles drive in public in urban areas.

  When considering the preferred clearance zone in front of the vehicle, it might be wise to start with a safety margin value of at least 1.5 seconds. This gap is expected to be accepted by 93% of the drivers, which represents a large majority, and equals the average of the following distances from various studies discussed in Chapter 2 (Michael et al., 2000; Duan et al., 2013; Sayer et al., 2003). Moreover, after 1.5 seconds it seemed that the effect of a larger time gap does not really affect the perceived safety feeling anymore. Furthermore, it was expected that trust in automated vehicles increases with driving experience in automated vehicles, and that human-driven vehicles intend to copy driving behaviour of automated vehicles (Gouy et al., 2014). Therefore, the expectation is that when the 1.5 second time gap is applied for a while, the safety margin could further decrease to values of 1.0 second or lower. However, regular checks to see if drivers still feel comfortable and safe with the smaller margins is desired.

  A second option is to let the passengers of the CAV indicate or install their personal preferred safety margins to the car. It was assumed that the CAV communicates its capabilities (like max. speed and acceleration) to the traffic controller, so maybe it will also be possible for the CAV to communicate the preferred safety margins of its passengers. This second option is interesting for further research.

7.2.2. Reflection on Methodology

This subsection reflects on the methodology of the experiment that was executed in the second part. No complete research approach was found in the literature to adopt for this experiment: the methodology was partly based on different literature studies and partly based on expert advice. Therefore, the following discussion points are important to take into account in possible follow-up studies. The reflection is structured in the form of three topics.

Simulation Environment

The first couple of discussion points are about the VR environment itself.

- The participants experienced the VR environment via a HMD with a field of view of 110 degrees. People with two good eyes have a horizontal field of view of 180 degrees. According to the Commission Directive 2009/112/EC, the field of view must be at least 120 degrees to be allowed to drive. During the experiment the participants had to rotate their head to oversee the traffic situation more than needed in a real car. Not all participants were actively moving their head to oversee the complete situation. Therefore, these participants might have seen the crossing vehicle later than possible. This could have led to startle responses and thus to a lower perceived feeling of safety. However, it is unclear how many participants negatively experienced the smaller field of view of the HMD. For follow-up studies, this would be a relevant question to add to the second questionnaire.

- The simulated environment was modelled using the game-design software *Unity*. Running this program requires much computer power. Therefore, it could happen that the environment trembled or shook during the experiment. This could have been experienced as disturbing or potentially made the environment feel a bit less realistic. Moreover, it could possibly also cause motion sickness, although this was rarely the case. The second questionnaire had to indicate how focused the participants were and how realistic the environment was experienced. According to these results, the majority of the participants felt focused and experienced the VR environment as realistic. Therefore, the shaky environment is not expected to have further impact on the results. However, for further research that would use this VR environment, it might be comfortable for the participants to have a less shaky environment. A computer with higher computational power would solve the problem.

- Since the concept of iSpaT messages was conceived for signalized intersections only, it had perhaps been better to also implement traffic lights in the simulated environment. However, when designing the environment, it was chosen to only focus on the time gap between the vehicles, and to not distract the participants with other elements in the environment. Therefore, the result was a sober environment with only two vehicles, an intersection, and some grey blocks indicating buildings.

- Moreover, no sound effects were available. If these were available, it may have led to an even better focus on the experiment, and perhaps to an even better empathy with the environment. However, asking the participant for their feeling of safety would have been more complicated with the presence of sound effects. Besides, due to the sober environment, urban noises might have been experienced somewhat awkward. When urban noises are desired in a follow-up experiment, more city elements and another way of indicating the feeling of safety are recommended.

- The environment where the crossing vehicle approached from the right side was not completely similar to the situation where the vehicle was crossing from the left side. In the two situations different elements (temporarily) limited the view on the crossing vehicle of the participant. It was ensured that buildings only temporarily blocked the view of the driver (similar to what could happen on a real intersection). However, an important difference to mention here is the visibility limitation due to the left A-pillar of the subject vehicle. This pillar blocked a larger part of the view for a longer period during the situations where the crossing vehicle approached from the left side, compared to the opposite direction. Therefore, sometimes the crossing vehicle was hidden behind the A-pillar, which resulted in a sudden appearance of the crossing vehicle, close to the conflict area. These disturbances were experienced during the 0.5 and 1.0 second time gap. This problem could have been reduced by choosing a car with smaller A-pillars. The worse visibility during these two time gaps when the vehicle was approaching from the left, might have influenced the results. Possibly the results following from the left-before-right (LbR) situation were judged as more unsafe, due to the late appearance. Therefore, the conclusion that no difference would be experienced between both crossing situation might be untrue.

To further discuss the reliability of the conclusion that no difference was experienced between the two crossing directions, the time during which the participants could anticipate the traffic situation was analysed. The anticipation time is defined as the time between the moment the vehicle became visible for the participant and the time it had left the conflict area. Note that both vehicles drove with the same speed and crossed perpendicularly. Table 7.1 summarizes these anticipation times per time gap, per interaction scenario, per crossing direction. Besides, Table 7.2 shows the differences in anticipation time per time gap per interaction scenario. Negative values indicate a lower anticipation time at the Left-before-Right (LbR) situation, whereas positive values indicate a lower anticipation time at the Right-before-Left (RbL) situations. As can be seen, 1 second is the smallest anticipation time, and occurs during 4 of the 30 traffic scenarios. The highest anticipation time is 2.5 seconds, which appears 8 times. A striking difference is seen when comparing the anticipation times during the 1.0 s time gap of the LbR situation and the RbL situation. A difference of 1.5 seconds is noticed at the CAV-CAV and CAV-HDV situation, and a 1.0 second difference at the HDV-CAV situation. Other differences in anticipation time were not higher than 0.5 seconds. Except for 3 situations, in which a difference in anticipation time actually existed. However, it is questionable whether the given scores would be significantly different when each of the 30 traffic situation had had the same anticipation time, or at least the same anticipation time during one time gap. Low anticipation times possibly caused higher scores (more unsafe), hence the LbR situation might have resulted in lower scores when the anticipation time would have been equal to the RbL situation. When this expectation would be true, the question is whether these higher scores would be significantly different from the current scores. Further research would be necessary to answer this question. Thus, an improvement would be suggested in the model by equalizing the anticipation times for all 30 scenarios.

Table 7.1: Anticipation time in seconds for all 30 traffic scenarios

	Anticipation Time [s]					
	Left before Right			*Right before Left*		
Time gap	**CAV-CAV**	**CAV-HDV**	**HDV-CAV**	**CAV-CAV**	**CAV-HDV**	**HDV-CAV**
0.5	2.5	2.5	3	2.5	2.5	2.5
1.0	1.0	1.0	1.5	2.5	2.5	2.5
1.5	1.5	1.5	2.0	2.0	2.0	2.0
2.0	1.0	1.0	2.0	1.5	1.5	1.5
4.0	2.0	2.0	2.0	1.5	1.5	1.5

Table 7.2: Difference in anticipation time by comparing LbR and RbL situations

Difference in Anticipation Time [s] (LbR - RbL)			
Time gap	**CAV-CAV**	**CAV-HDV**	**HDV-CAV**
0.5	0	0	0.5
1.0	-1.5	-1.5	-1.0
1.5	-0.5	-0.5	0
2.0	-0.5	-0.5	-0.5
4.0	0.5	0.5	0.5

Experimental Setup

The following discussion points and limitations are related to the set up of the experiment.

- The steering wheel and pedals did not work. Although this was on purpose, some participants mentioned that they preferred to have it working. Apart from the fact that it was beyond the available skills to create an interface between the software and the wheel and pedals, by giving the participants the power to change the speed and direction of the car, the test set up would have changed. In that case, it would not be certain anymore that the five desired time gaps were all tested. It was therefore not recommended to create this interface.

- The experiment was conducted at three different locations. Most of the experiments were conducted in a private room at Sweco. Other experiments were conducted at Delft University of Technology, of which some were conducted in a private room and others in a (quiet) shared room. It would have been more favourable to have conducted all experiments at the same location, as that would have eliminated possible influences (e.g. temperature, chair and table height, white noise) from the test environment on the experimental results. However, this research did not account for these possible influences, because no striking events or influences occurred at each of the three test locations. It is advised for follow-up studies to execute all experiments in the same room if possible.

- To prevent the participants from being able to predict what time gap would be shown next, the five time gaps were shown in a random order per traffic situation. Unfortunately, it was not possible to show all 30 videos in a random order, because in order to change from traffic situation (total 6: 3 interaction scenarios x 2 crossing directions), the participant got shown a 'waiting room', which resembled a night's sky. To minimize the need to show this 'waiting room' to the participant, and to prevent them from possibly getting distracted from their focus on the VR environment, the traffic situations were changed as rarely as possible. Of course, the 6 traffic situations themselves were shown in a random order. To prevent predictability of what is shown next as much as possible, no orders were used where first three right-before-left situations were shown, after which the three left-before-right situations were presented (or vice versa). Considering the predictability of the study, for follow-up studies is would be valuable to be able to randomize between all 30 situations.

- Although it was attempted to prevent predictability during the experiment as much as possible, often participants started to recognize that there would never be more than two vehicles in the crossing situation, and that after one night sky, the vehicles would always enter the intersection from the same direction (learning effect). Therefore, the participants might judge time gaps shown later in the experiment differently than those that were shown earlier in the experiment. Possibly later in the experiment, the participants would accept smaller gaps, if they started to recognize the situation, and thus could better anticipate on what was going to happen. In order to tackle this, no order of the six traffic situations was shown more than 2 times: 11 orders were shown two times, the remaining 60 orders were unique. However, these 11 double orders were still unique in the fact that the time gaps were shown randomly. Moreover, each of the six traffic situations was shown equally often as first, second, and third, etc. to the participants. Examples of effects that were eliminated by the randomness: less focus at the end of the experiment, and learning effects towards the end.

Other limitations

Finally, three other limitations that were related to the experiment are described below.

- The experiment only tested crossing situations where the crossing vehicle crossed in front of the subject vehicle. However, other crossing situations are also important to describe all perceived safety margins. Perhaps other methods than virtual reality would be more suitable.
- If iSpaT messages become reality, a weaving pattern of vehicles could become reality on intersections. More vehicles may influence the perceived safety margins. Therefore, a follow-up research should also test for platoons of vehicles.
- Another future research could focus on the effect of slow traffic (bicycles and pedestrians) with the arrival of iSpaT messages. Namely, if traffic lights would become unnecessary for CAVs, when can pedestrians and cyclists cross an intersection? For example, do they also get an iSpaT message? Or how will their traffic lights cooperate with iSpaT messages?

7.2.3. Further Research - Part II

To summarize, further research is interesting within the following fields:

- The trend shown in Figure 5.4 represents the acceptance rate that followed from the experiment. However, it could be interesting to see how this trend will change over the years when automated driving becomes more and more common. The expectation is that with more experience and trust in automated vehicles, higher acceptance rates can evolve at lower time gaps. Executing experiments with participants having more experience with highly automated vehicles can be a method for further research. Perhaps, also time gaps could be tested between 0 and 0.5 seconds.
- Since the sample is not completely representative of the population, more experiments are interesting to execute with older participants, participants with less knowledge of smart mobility, female participants, and participants with a lower level of education. These participants could make the sample more representative of the population.
- Instead of applying the same perceived safety margins to all vehicles, maintaining unique perceived safety margins to each vehicle would be ideal. Future research can focus on whether and how the perceived safety margins could be known to the vehicle. Examples of questions that might be answered here are: would you buy a vehicle with perceived safety margins set by the car manufacturer, or could you change the margins per ride, per driver, per day, per journey, or per road type?
- To make sure that really no difference was experienced in the perceived safety of both crossing directions, the virtual environment should be redesigned in a way that for both crossing situations the participants would have to wait the same times before the crossing vehicle appears.
- Further research is required to describe the perceived safety margins around the other sides of the vehicle. This experiment only considered the preferred time gap in front of the vehicle during a 90-degree crossing situation.
- In the future, more than two vehicles will be on the crossing area of the intersection. Therefore, it is interesting to execute experiments where multiple vehicles cross the intersection, either in platoon formation or as individual cars.
- Finally, adding slow traffic to this experiment would be interesting as well. How will slow traffic influence the perceived safety of the car occupants?

References

ANWB. (2015). *Verschil snelheidsaanduiding navigatieapparatuur en dashboard.* Retrieved 2019-11-04, from https://www.anwb.nl/experts/auto/92/verschil-snelheidsaanduiding-navigatieapparatuur-en-dashboard

Ashalatha, R., & Chandra, S. (2011). Critical gap through clearing behavior of drivers at unsignalised intersections. *KSCE Journal of Civil Engineering*, *15*(8), 1427–1434.

Bellem, H., Thiel, B., Schrauf, M., & Krems, J. F. (2018). Comfort in automated driving: An analysis of preferences for different automated driving styles and their dependence on personality traits. *Transportation research part F: traffic psychology and behaviour*, *55*, 90–100.

Blankesteijn, H. (1994, Feb). Geld is tijd. *nrc.nl*. Retrieved from https://www.nrc.nl/nieuws/1994/02/03/geld-is-tijd-7212423-a290307

Blissing, B., & Bruzelius, F. (2018). Exploring the suitability of virtual reality for driving simulation. In *Driving simulation conference 2018* (pp. 163–166).

Boelhouwer, A., van Dijk, J., & Martens, M. H. (2019). Turmoil behind the automated wheel. In *International conference on human-computer interaction* (pp. 3–25).

Broughton, K. L., Switzer, F., & Scott, D. (2007). Car following decisions under three visibility conditions and two speeds tested with a driving simulator. *Accident Analysis & Prevention*, *39*(1), 106–116.

Burns, C. G., Oliveira, L., Hung, V., Thomas, P., & Birrell, S. (2019). Pedestrian attitudes to shared-space interactions with autonomous vehicles–a virtual reality study. In *International conference on applied human factors and ergonomics* (pp. 307–316).

CBS. (2019a). *Motorvoertuigenpark; inwoners, type, regio, 1 januari.* Retrieved 2020-01-06, from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7374hvv/table?fromstatweb

CBS. (2019b). *Verkeersprestaties motorvoertuigen; kilometers, voertuigsoort, grondgebied.* Retrieved 2020-01-06, from https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80302ned/table?ts=1578323426200

Chai, L., Cai, B., ShangGuan, W., & Wang, J. (2017). Connected and autonomous vehicles coordinating method at intersection utilizing preassigned slots. In *2017 ieee 20th international conference on intelligent transportation systems (itsc)* (pp. 1–6).

Chai, L., Cai, B., ShangGuan, W., Wang, J., & Wang, H. (2018). Connected and autonomous vehicles coordinating approach at intersection based on space–time slot. *Transportmetrica A: Transport Science*, *14*(10), 929–951.

Choi, J. K., & Ji, Y. G. (2015). Investigating the importance of trust on adopting an autonomous vehicle. *International Journal of Human-Computer Interaction*, *31*(10), 692–702.

Chovan, J. D., Tijerina, L., Everson, J., Pierowicz, J., & Hendricks, D. (1994). *Examination of intersection, left turn across path crashes and potential ivhs countermeasures* (Tech. Rep.).

Cody, D., Nowakowski, C., & Bougler, B. (2007). Observation of gap acceptance during intersection approach.

Crawford, A. (1963). The overtaking driver. *Ergonomics*, *6*(2), 153–170.

del Peral-Rosado, J., Granados, G., Raulefs, R., Leitinger, E., Grebien, S., Wilding, T., ... others (2018). Whitepaper on new localization methods for 5g wireless systems and the internet-of-things.

del Peral-Rosado, J., Saloranta, J., Destino, G., López-Salcedo, J., & Seco-Granados, G. (2018). Methodology for simulating 5g and gnss high-accuracy positioning. *Sensors*, *18*(10), 3220.

Dixit, V. V., Chand, S., & Nair, D. J. (2016). Autonomous vehicles: disengagements, accidents and reaction times. *PLoS one*, *11*(12), e0168054.

Dresner, K., & Stone, P. (2004). Multiagent traffic management: A reservation-based intersection control mechanism. In *Proceedings of the third international joint conference on autonomous agents and multiagent systems-volume 2* (pp. 530–537).

Dresner, K., & Stone, P. (2006). Human-usable and emergency vehicle-aware control policies for autonomous intersection management. In *Fourth international workshop on agents in traffic and transportation (att), hakodate, japan.*

Dresner, K., & Stone, P. (2008). A multiagent approach to autonomous intersection management. *Journal of artificial intelligence research*, *31*, 591–656.

Duan, J., Li, Z., & Salvendy, G. (2013). Risk illusions in car following: Is a smaller headway always perceived as more dangerous? *Safety science*, *53*, 25–33.

Dużmańska, N., Strojny, P., & Strojny, A. (2018). Can simulator sickness be avoided? a review on temporal aspects of simulator sickness. *Frontiers in psychology*, *9*, 2132.

Elbanhawi, M., Simic, M., & Jazar, R. (2015). In the passenger seat: investigating ride comfort measures in autonomous cars. *IEEE Intelligent Transportation Systems Magazine*, *7*(3), 4–17.

Evans, S. M., Berry, J. G., Smith, B. J., & Esterman, A. J. (2006). Consumer perceptions of safety in hospitals. *BMC Public Health*, *6*(1), 41.

Ferreira, M., Fernandes, R., Conceição, H., Viriyasitavat, W., & Tonguz, O. K. (2010). Self-organized traffic control. In *Proceedings of the seventh acm international workshop on vehicular internetworking* (pp. 85–90).

Fraedrich, E., Beiker, S., & Lenz, B. (2015). Transition pathways to fully automated driving and its implications for the sociotechnical system of automobility. *European Journal of Futures Research*, *3*(1), 11.

Frison, A.-K., Wintersberger, P., Liu, T., & Riener, A. (2019). Why do you like to drive automated?: a context-dependent analysis of highly automated driving to elaborate requirements for intelligent user interfaces. In *Proceedings of the 24th international conference on intelligent user interfaces* (pp. 528–537).

Frison, A.-K., Wintersberger, P., & Riener, A. (2019). Resurrecting the ghost in the shell: a need-centered development approach for optimizing user experience in highly automated vehicles. *Transportation research part F: traffic psychology and behaviour*, *65*, 439–456.

Galileo. (2018). *The path to high gnss accuracy.* Retrieved 2019-11-01, from `https://galileognss.eu/the-path-to-high-gnss-accuracy/`

Gibbs, S. (2017). Google sibling waymo launches fully autonomous ride-hailing service. *The Guardian*, *7*.

Gouy, M., Wiedemann, K., Stevens, A., Brunett, G., & Reed, N. (2014). Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control? *Transportation research part F: traffic psychology and behaviour*, *27*, 264–273.

Griesche, S., Nicolay, E., Assmann, D., Dotzauer, M., & Käthner, D. (2016). Should my car drive as i do? what kind of driving style do drivers prefer for the design of automated driving functions. In *Proc. 17th braunschweiger symp. automatisierungssysteme assistenzsysteme eingebettete syst. transportmittel (aaet)* (pp. 185–204).

Guler, S. I., Menendez, M., & Meier, L. (2014). Using connected vehicle technology to improve the efficiency of intersections. *Transportation Research Part C: Emerging Technologies*, *46*, 121–131.

Hamed, M., Easa, S., & Batayneh, R. (1997). Disaggregate gap-acceptance model for unsignalized t-intersections. *Journal of transportation engineering*, *123*(1), 36–42.

Hasan, K. F., Wang, C., Feng, Y., & Tian, Y.-C. (2018). Time synchronization in vehicular ad-hoc networks: A survey on theory and practice. *Vehicular communications*, *14*, 39–51.

Hegeman, G., Hoogendoorn, S., & Brookhuis, K. (2004). Observations overtaking manoeuvres on bi-directional roads. *Advanced OR and AI Methods in Transportation*, *1*, 505–510.

Hennessy, D. A., Howard, S., & Carr, E. (2011). Driver space preference: differences across age, gender and traffic conditions. *Traffic Psychology: an International Perspective. Nova Science Publishers, New York*, 233–249.

Janssen, R., Zwijnenberg, H., Blankers, I., & de Kruijff, J. (2015). Truck platooning. *Driving The Future of Transportation, TNO.*

Kampert, N. J. v. d. S. M., A., & Molnár-in 't Veld, H. (n.d.). *Nederlanders en hun auto.* Retrieved from https://www.cbs.nl/nl-nl/achtergrond/2017/08/nederlanders-en-hun-auto (Accessed: 01-31-2020)

Kaysi, I. A., & Abbany, A. S. (2007). Modeling aggressive driver behavior at unsignalized intersections. *Accident Analysis & Prevention*, *39*(4), 671–678.

Lee, J., & Park, B. (2012). Development and evaluation of a cooperative vehicle intersection control algorithm under the connected vehicles environment. *IEEE Transactions on Intelligent Transportation Systems*, *13*(1), 81–90.

Mackay, A., Fortes, I., Santos, C., Machado, D., Barbosa, P., Boas, V. V., ... Sousa, E. (2019). The impact of autonomous vehicles' active feedback on trust. In *International conference on applied human factors and ergonomics* (pp. 342–352).

Mahmud, S. S., Ferreira, L., Hoque, M. S., & Tavassoli, A. (2018). Overtaking behaviour on rural highways under an heterogeneous traffic environment: Evidence from a developing country. In *Australasian transport research forum (atrf), 40th, 2018, darwin, northern territory, australia.*

Mao, X., Wada, M., & Hashimoto, H. (2003). Nonlinear gps models for position estimate using low-cost gps receiver. In *Proceedings of the 2003 ieee international conference on intelligent transportation systems* (Vol. 1, pp. 637–642).

Marsh, P., & Collett, P. (1987). The car as a weapon. *Et cetera*, *44*(2), 146.

Mazuryk, T., & Gervautz, M. (1996). Virtual reality-history, applications, technology and future.

Michael, P. G., Leeming, F. C., & Dwyer, W. O. (2000). Headway on urban streets: observational data and an intervention to decrease tailgating. *Transportation research part F: traffic psychology and behaviour*, *3*(2), 55–64.

Molnar, L. J., Ryan, L. H., Pradhan, A. K., Eby, D. W., Louis, R. M. S., & Zakrajsek, J. S. (2018). Understanding trust and acceptance of automated vehicles: An exploratory simulator study of transfer of control between automated and manual driving. *Transportation research part F: traffic psychology and behaviour*, *58*, 319–328.

Nando Kasteleijn. (2020). *5g komt dit jaar naar nederland, maar kent langzame start.* Retrieved 2020-01-21, from https://nos.nl/artikel/2316992-5g-komt-dit-jaar-naar-nederland-maar-kent-langzame-start.html

Nie, L., Guan, J., Lu, C., Zheng, H., & Yin, Z. (2018). Longitudinal speed control of autonomous vehicle based on a self-adaptive pid of radial basis function neural network. *IET Intelligent Transport Systems*, *12*(6), 485–494.

Oostvogels, B. (2018). *Zo oud is de gemiddelde automobilist in nederland.* Retrieved 2019-01-07, from https://autorai.nl/zo-oud-is-de-gemiddelde-automobilist-in-nederland/

Openbaar Ministerie. (2018). *snelheid, reactie en remweg.* Retrieved 2019-10-18, from https://www.om.nl/onderwerpen/verkeer/handhaving-verkeer/snelheid/snelheid-reactie/

Park, K. (2018, May). *How 5g reduces data transmission latency.* Retrieved 2019-29-10, from https://www.edn.com/electronics-blogs/5g-waves/4460644/How-5G-reduces-data-transmission-latency-

Pereira, M., Beggiato, M., & Petzoldt, T. (2015). Use of adaptive cruise control functions on motorways and urban roads: Changes over time in an on-road study. *Applied ergonomics*, *50*, 105–112.

Péter, G., Kiss, B., & Tihanyi, V. (2019). Vision and odometry based autonomous vehicle lane changing. *ICT Express*.

Ratner, B. (2009). The correlation coefficient: Its values range between+ 1/- 1, or do they? *Journal of targeting, measurement and analysis for marketing*, *17*(2), 139–142.

Rossner, P., & Bullinger, A. C. (2019). How do you want to be driven? investigation of different highly-automated driving styles on a highway scenario. In *International conference on applied human factors and ergonomics* (pp. 36–43).

Sayer, J. R., Mefford, M. L., & Huang, R. W. (2003). The effects of lead-vehicle size on driver following behavior: Is ignorance truly bliss? , 221–225.

Sharon, G., & Stone, P. (2017). A protocol for mixed autonomous and human-operated vehicles at intersections. In *International conference on autonomous agents and multiagent systems* (pp. 151–167).

Shengbo, Q., Keliang, D., & Qingli, L. (2003). An effective gps/dr device and algorithm used in vehicle positioning system. In *Proceedings of the 2003 ieee international conference on intelligent transportation systems* (Vol. 1, pp. 632–636).

Shinar, D., & Schechtman, E. (2002). Headway feedback improves intervehicular distance: A field study. *Human Factors*, *44*(3), 474–481.

Siebert, F. W., Oehl, M., Bersch, F., & Pfister, H.-R. (2017). The exact determination of subjective risk and comfort thresholds in car following. *Transportation research part F: traffic psychology and behaviour*, *46*, 1–13.

Siebert, F. W., Oehl, M., & Pfister, H.-R. (2014). The influence of time headway on subjective driver states in adaptive cruise control. *Transportation research part F: traffic psychology and behaviour*, *25*, 65–73.

Siebert, F. W., & Wallis, F. L. (2019). How speed and visibility influence preferred headway distances in highly automated driving. *Transportation research part F: traffic psychology and behaviour*, *64*, 485–494.

Smith, K., Bjelkemyr, A., Bärgman, J., Johansson, B., & Lindman, M. (2009). *Ivss intersection accidents: Analysis and prevention, final report – volume 1 (main report).*

Suzuki, K., & Yamada, K. (2011). Method for evaluating effectiveness of information presentation in terms of collision avoidance. *International Journal of Intelligent Transportation Systems Research*, *9*(1), 37–46.

Sweco. (2018). *Smart mobility voor een leefbare stad en minder co2-uitstoot.*

Sweco Nederland. (2018). Use case : Traffic orchestration on a hybrid intersection.

SWOV. (2012). Headway times and road safety.

Taieb-Maimon, M., & Shinar, D. (2001). Minimum and comfortable driving headways: Reality versus perception. *Human factors*, *43*(1), 159–172.

Talebpour, A., & Mahmassani, H. S. (2016). Influence of connected and autonomous vehicles on traffic flow stability and throughput. *Transportation Research Part C: Emerging Technologies*, *71*, 143–163.

Tang, T.-Q., He, J., Yang, S.-C., & Shang, H.-Y. (2014). A car-following model accounting for the driver's attribution. *Physica A: Statistical Mechanics and its Applications*, *413*, 583–591.

Tao, M. (2018). *5g promotes the intelligence connected vehicles.* Retrieved 2019-11-02, from `https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20180709/Documents/S3-P4-5G.pdf`

Tejado, I., Milanés, V., Villagrá, J., Godoy, J., HosseinNia, H., & Vinagre, B. M. (2011). Low speed control of an autonomous vehicle by using a fractional pi controller. *IFAC Proceedings Volumes*, *44*(1), 15025–15030.

Tennant, C., Howard, S., Franks, B., Bauer, M., & Stares, S. (2016). *Autonomous vehicles-negotiating* *a place on the road: A study on how drivers feel about interacting with autonomous vehicles on the road (executive summary). retrieved july, 16, 2017.*

Tennessee Coalition for the Safety of Senior Drivers. (2018). Tennessee comprehensive driver license manual.

Ueno, H. (1991). Analysis of accidents in right turns using a fuzzy logic simulation model. *The 13th ESV Proceedings, 1991.*

Verhoeven, J. W., Pieterse, M. E., & Pruyn, A. T. (2006). Effects of interior color on health care consumers: A 360 degree photo simulation experiment. *ACR North American Advances.*

Visée, A. (2019). *Should autonomous vehicles behave?* The Netherlands.

Vogel, K. (2003). A comparison of headway and time to collision as safety indicators. *Accident analysis & prevention*, *35*(3), 427–433.

Waldrop, M. M. (2015). Autonomous vehicles: No drivers required. *Nature News*, *518*(7537), 20.

Wang, J. H. (2009). *Studying the vehicle headway issue and its impact on the slow-down effect* (Unpublished doctoral dissertation). University of Rhode Island.

Wasielewski, P. (1979). Car-following headways on freeways interpreted by the semi-poisson headway distribution model. *Transportation Science*, *13*(1), 36–55.

WeWantAnyCar. (2016). *Car speedo: How fast are you really going?* Retrieved 2019-11-02, from `https://www.wewantanycar.com/news/car-speedo-how-fast-are-you-going/`

Willekens, M., & Stolz, C. (2018). Kruispunttopologie voor ivri's: de stand van zaken. *nm magazine*, *2018*(3).

Yang, K., Guler, S. I., & Menendez, M. (2016). Isolated intersection control for various levels of vehicle technology: Conventional, connected, and automated vehicles. *Transportation Research Part C: Emerging Technologies*, *72*, 109–129.

Yang, Q., & Sun, J. (2007). A location method for autonomous vehicle based on integrated gps/ins. In *2007 ieee international conference on vehicular electronics and safety* (pp. 1–4).

Zhang, Q., Ge, Y., Qu, W., Hennessy, D. A., & Zhang, K. (2019). Effects of anger and collision history on driver space preference. *Transportation research part F: traffic psychology and behaviour*, *63*, 108–117.

Zhou, H., Ivan, J. N., Gårder, P. E., & Ravishanker, N. (2017). Gap acceptance for left turns from the major road at unsignalized intersections. *Transport*, *32*(3), 252–261.

A

Scientific Paper

SAFETY MARGIN DEVELOPMENT FOR A SPACE-TIME RESERVATION TRAFFIC CONTROL SYSTEM

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Abstract: With the arrival of Connected and Automated Vehicles (CAVs) concepts for traffic control systems emerge that let CAVs weave over the crossing area of an intersection. However, in the current literature, the safety of these vehicles is generally an assumption rather than a certainty. Moreover, the time period where CAVs and Human-Driven Vehicles (HDVs) share the road (i.e. hybrid traffic period) is often not considered by the design of these concepts. This paper describes technical and non-technical factors that influence the actual and perceived safety of passengers of HDVs and CAVs during the vehicle interactions that occur in the hybrid traffic period. The impact of the indicated factors on the actual or perceived safety of a vehicle is analyzed and described in terms of required safety margins around a vehicle. The size of the safety margins described depend on the positioning inaccuracy of the vehicle, its trajectory tracking inaccuracy, a time synchronisation inaccuracy, and on the preferred time headway, preferred driver space, and accepted time gap of the car occupants.

Due to a lack of available data that could be used to compare the expected size of the safety margins around the vehicle with, this research presents a methodology to generate own data that could be used for this comparison. A virtual reality experiment was executed among 82 participants, which resulted in a 93% acceptance rate at a time gap of 1.5 seconds between one vehicle leaving and another vehicle entering their conflict area. It appeared that neither the crossing direction (left, right) nor the vehicle composition (HDV, CAV) of a vehicle interaction scenario influenced the perceived safety margins in front of the vehicle. The experiment found lower perceived safety margins in front of the vehicle than was expected according to the literature study. This may be the result of the sample not completely being comparable to the total drivers population. 2.0 seconds was accepted by 99% of the participants. The question arises what acceptance rate is desired to determine the minimum time gap that can be used as a perceived safety margin by future traffic control systems. The accepted time gap is expected to decrease as soon as more drivers get experienced with CAVs.

Keywords: *Actual Safety, Perceived Safety, Safety Margins, individual Space-Time Reservation, Hybrid Traffic Control System, Connected and Automated Vehicles, Virtual Reality Experiment*

1 Introduction

Traffic light control systems are widely used to monitor and control the traffic flow at intersections, mostly in urban areas. They aim to realize an efficient but safe traffic flow on the transportation routes. With the expected arrival of connected and automated vehicles (CAVs), new traffic control concepts emerge with the goal to increase both the safety and efficiency at intersections. According to Ferreira et al. (2010), possibly (physical) traffic lights will become unnecessary if all vehicles could communicate via Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication. The two most seen concepts for automated traffic control systems described in the literature were either based on (1) a first-come-first-serve (FCFS) principle, or (2) minimizing the total vehicle delay. Both concepts consider a traffic situation with a 100% penetration rate of CAVs, where these vehicles will weave over the intersection without causing any collision. Concept (1), as explained by Dresner and Stone (2004, 2008), assigns a trajectory plan to each vehicle, based on their expected arrival time at the crossing area. Studies that applied concept (2), either assigned an acceleration profile (Lee & Park, 2012) or a speed profile (Chai et al., 2017, 2018) to the approaching vehicles, to optimize all departure times.

Some research focused on potential traffic control systems for the hybrid traffic period where CAVs and human-driven vehicles (HDVs) share the road. None of the systems mentioned was implemented yet, however, their development is important, since the evolution of highly automated vehicles is going fast (Waldrop, 2015; Gibbs, 2017).

The studies of Dresner and Stone (2006) and Sharon and Stone (2017) describe a control system where HDVs still use physical traffic lights. Here, CAVs would not be allowed to cross any route that could be driven by an HDV having a green light. The studies of Guler et al. (2014) and K. Yang et al. (2016) describe the concept to predict the behaviour of HDVs based on the travel information that CAV could provide via V2I-communication.

Sweco, an engineering consultancy company, also has ambitions to control traffic during the hybrid traffic period. Currently, Sweco owns a traffic contol system that improves the efficiency at intersections and which is actually being used in various Dutch cities: *Smart Traffic*. Smart Traffic improves the throughput at intersections by increasing the reliability of SPaT (Signal Phase and Timing) messages. Certain messages describe the current phase at a signalized intersection, together with the residual time of the phase, for each lane of the intersection. Via in-car applications, drivers can receive this information while driving. However, generally these SPaT messages are only reliable the last few seconds before the vehicle has arrived at the traffic lights. Namely, regularly the phases of traffic lights are scheduled based on real-time traffic data, which for example can cause last minute green light extension. Smart Traffic plans the phases on the traffic lights based on a traffic forecast, rather than on the real time traffic information. In other words, Smart Traffic predicts what the traffic situation will be in, approximately, 10 seconds ahead. This means that the time-to-red or time-to-green will not change the last 10 seconds before the vehicle has arrived at the traffic lights, which ensures highly reliable SPaT messages. Human drivers can easily adapt their driving behaviour on this information.

Sweco already has a conceptual idea about how Smart Traffic can be able to control a combination of CAVs and HDVs: while HDVs will still receive SPaT messages, *individual Space-Time* (iSpaT) messages will be send to CAVs. An iSpaT message informs the CAV with a series of iSpaT reservations. One reservation explains at what location the CAV needs to be at what specific moment in time. only one vehicle at a time (either an HDV or CAV) is allowed to be at a certain location at a certain time. Hence, a unique trajectory of multiple locations over time is assigned to a CAV that must be tracked to cross the intersection and to not cause any collision. The messages will only be send to CAVs, because HDVs are expected to not be able to follow the trajectory accurately without creating unsafe traffic situations.

Research Gap

The fact that none of the concepts to simultaneously control CAVs and HDVs is implemented yet may have two reasons. First, the technology of CAVs is not yet fully developed. The second, and more important reason to consider, is that current literature often assumes the vehicles to be actually safe, for example by assuming perfect knowledge of the vehicle locations. However, their assumptions do often not apply in practice, which gives rise to uncertainties and inaccuracies in the traffic control designs. For a reliable traffic control system that will let vehicles weave across an intersection, either in the hybrid or fully automated traffic period, assumptions about the safety of a vehicle must become certainties about the safety of a vehicle.

A distinction can be made between the *actual safety* and the *perceived safety* of a vehicle and its passengers. When the vehicle is actual safe, collision avoidance is guaranteed. The perceived safety describes the feeling of being safe in a vehicle. Both types of safety are important to guarantee before the automated intersection control can be realised. Various factors are expected to influence the actual and perceived safety, however which factors exactly and to what extent is yet unknown. The research gap that is distilled is presented as follows: it is unknown yet to what extent the actual and perceived safety of all vehicles in the hybrid traffic period will be influenced when vehicles will weave over the intersection. Besides, it is unknown how this influence will affect current concepts of hybrid traffic control systems.

Scope and Research Questions

This paper describes the factors that influence the actual and perceived safety of both HDVs and CAVs, when considering a hybrid traffic control system that let these vehicles weave over an intersection. The impact of these factors on the safety of these vehicle types is described in terms of actual and perceived *safety margins* around a vehicle. These margins let the vehicle virtually grow, and this virtual size can be used by the traffic control system to plan all trajectories for all vehicles. When the virtual sizes will not overlap, the actual and perceived safety can be guaranteed on the road too. The size of all actual safety margins must be combined to one space in which the corresponding vehicle is located. This space is called the *Potential Vehicle Location (PVL)*. The perceived safety margins must let the car passengers feel safe within their car, and are therefore (virtually) added to the PVL. The largest perceived safety margin required at each side of a vehicle together form the zone that must be free of other traffic: the *Preferred Clearance Zone*. This zone added to the PVL. Figure A.1 illustrates a vehicle within the PVL and having the PCZ around it. Note that the figure only illustrates an impression of the location of the PVL and PCZ compared to the vehicle. The shape and symmetry of the PVL and PCZ suggested by this figure may be not true or different.

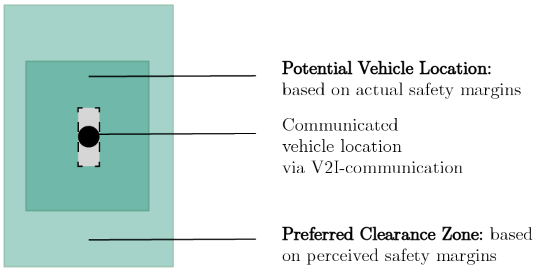


Figure A.1: Actual and perceived safety margins illustrated around a vehicle

In total, four *interaction scenarios* can occur during the hybrid traffic period, which are itemized below. For all four scenarios the actual and perceived safety margins are determined.

- **CAV** - CAV: Interaction between two CAVs, experienced from a **CAV**.
- **CAV** - HDV: Interaction between one CAV and one HDV, experienced from an **CAV**.
- **HDV** - CAV: Interaction between one CAV and one HDV, experienced from an **HDV**.
- **HDV** - HDV: Interaction between two HDVs, experienced from an **HDV**.

Interaction scenarios including a CAV will be new on the road, hence limited literature was available regarding vehicle interactions including CAVs. Therefore, a human experiment was executed to obtain data about the perceived safety feeling of car occupants during the first three interaction scenarios mentioned. This data could be compared to expectations based on the literature study. Due to time restrictions, only the preferred safety margins in front of a CAV were tested and compared.

This paper is split into two parts, and therefore answers two research questions. They are described as follows:

[1] While considering the hybrid traffic period, what mathematical formulation that expresses the impact of technical and non-technical factors, describes the required size of safety margins around a vehicle?

[2] According to a human experiment, what is the value of the perceived safety margin that is required in front of a vehicle, considering the different interaction scenarios that appear during the hybrid traffic period, and how does this value relate to the values found in the literature?

To answer the first research question a literature study was applied. The influence of both technical and non-technical factors on the required size of the safety margins was explained. The second research question was answered based on the results of a virtual reality human experiment.

2 Literature Study

The idea of a safety buffer around a vehicle is not new in the literature. Dresner and Stone (2008) introduced the concept of static buffers, time buffers, and hybrid buffers. They mentioned the need for a hybrid buffer, which dimensions can change by speed differences or changes over time. However, this research does not explain what factors determine the dimensions of these buffers. Besides, Chai et al. (2017, 2018) mentioned the need for a minimum safe distance between two following vehicles in order to avoid rear-end collisions. These studies assumed a minimum distance of one vehicle length, however, the validity of the safety that these margins would guarantee was not specified. The literature study distinguished non-technical factors and technical factors that contributed to the determination of the size of a space-time reservation. It was explained how these factors may influence the safety margins and suggestions were made for the minimum size of the safety margins around CAVs and HDVs during the hybrid traffic scenario.

Non-Technical Factors

The margins required by non-technical factors often covered the perceived safety of the car passengers. Moreover, safety margins were required as a result of environmental circumstances, or were needed during emergency or unexpected situations. While this study did not focus on the latter situation, these factors were described in order to provide a complete overview of all non-technical factors. The research presented in this subsection considered the interaction between two HDVs. Later, the results of these interactions could be used to determine the expected interactions on between two CAVs or one CAV and a HDV.

A distinction was made between factors that require a safety margin on the longitudinal sides of the vehicle, and on the lateral sides. The lateral safety margins were established for the case when the CAV was driving on the conflict area. Otherwise, it was assumed that the CAV was able to stay within its lane and would not require further lateral safety margins.

Longitudinal Safety Margins

The search for factors that influenced the longitudinal margins was covered by studies that observed vehicle following behaviour and overtaking manoeuvres. Moreover, studies were found that described the need for a certain *preferred driver space* (Hennessy et al., 2011; Zhang et al., 2019). This was defined as a personal space extending from the driver to surround the vehicle in traffic (Marsh & Collett, 1987). The studies concluded that there is a need for a fixed distance around the vehicle that is free of other traffic. The study of Tang et al. (2014) also mentioned the concept of a basic need of a fixed space free of other traffic on the longitudinal sides of a car, and assumed a value of 8.7 meters at a speed of 55 km/h. Despite the fact that more research would be valuable in order to suggest a value with more reliability, this value was assumed as a starting value for a minimum free space in front and at the back of a vehicle during car following situations. Moreover, this value might also be assumed in lateral direction when a conflicting vehicle is approaching the vehicle on its right or left side.

Furthermore, research was executed related to the *time headway* (THW) taken during car following behaviour and before and after an overtaking situation. Taieb-Maimon and Shinar (2001) studied the influence of speed and gender on the vehicle following behaviour. They concluded with an average THW value between 0.94 and 1.00 sec, where speed did not influence the THW value, but female drivers drove according to a smaller THW. The THW value found by Shinar and Schechtman (2002) matched the values of Taieb-Maimon and Shinar (2001) with an average THW value found around 1.0 second. This study distinguished the influence of speed, gender, age, and the time of day. No relationship between THW and age or gender was found. Besides, it was found that drivers kept larger THW values during night. Moreover, also the speed had a significant effect on the THW value: drivers were slightly more likely to maintain shorter THW values at higher speeds. Higher THW values were found by Michael et al. (2000), Duan et al. (2013), and Sayer et al. (2003). According to their findings, the average THW value laid around 1.4 and 1.6 seconds. Factors that were considered here were speed, size of the leading vehicle, and presence of surrounding traffic. The studies contradict each other regarding the effect of the vehicle size. Duan et al. (2013) suggest larger THW values when following larger vehicles, whereas Sayer et al. (2003) stated the opposite. Therefore, no conclusion was made regarding the size of the leading vehicle. Again, no significant association was found between speed and the THW taken. A final research that considered vehicle following situations was presented by Broughton et al. (2007), that focused on the difference in THW values during different speeds and different weather conditions. In this study, higher speeds resulted in larger THW values. Moreover, during foggy weather conditions, the THW increased at high speeds, but decreased at lower speeds.

Besides, Hegeman et al. (2004), Crawford (1963), and Mahmud et al. (2018) investigated the THW values in front of a vehicle before an overtake, and at the back of a vehicle after the overtaking manoeuvre. Again the results of the studies contradict. Mahmud et al. (2018) concludes that the distance between two vehicles is larger before the overtaking manoeuvre than afterwards, whereas Hegeman et al. (2004) observed the opposite. Besides, Crawford (1963) concluded for a fixed headway distance of ~12 meter in front of a car before overtaking. According to these studies, it was concluded that the preferred THW in front of a vehicle could differ from the preferred THW at the back of the vehicle. However, to what extent they would differ was not concluded.

Next to perceived safe THW values, also THW values exist that guarantee the actual safety of the passengers. These THW values are based on a driver's reaction time. In the Netherlands, this value is known as the *2-second rule* (SWOV, 2012; Tennessee Coalition for the Safety of Senior Drivers, 2018) and claims a THW of 2 seconds to be the minimum safe distance between two vehicles. However, in Germany this value is set to 1.8 seconds (Vogel, 2003).

Lateral Safety Margins

Accepted time gaps were considered to determine the preferred lateral margins during weaving traffic conditions. These time gaps are defined as the preferred time between one vehicle leaving a certain area and the subject vehicle entering that same area (or vice versa). Research focused on the gap acceptance and encroachment time of vehicles being either on speed or not. No clear difference was found between the preferred margins on the right side of the vehicle versus the left side of the vehicle. The gap acceptance values found were more complicated to base a value for the preferred lateral safety margin on, since the intersection geometry played a major role in the value found for the gap acceptance. When 2 lanes had to be entirely crossed, Ashalatha and Chandra (2011) found significant critical gaps varying between 4.30 and 5.25 seconds (avg. 5.01 sec). Note that the vehicles were approaching from a minor road and had no speed when starting crossing the lanes of the major road. The study found that a higher number of lanes to cross, resulted in a higher gap acceptance value. However, no quantitative relation was described. Other research considered a two lane intersection where vehicles had to make a right or left turn (depending on the driving side situation). Suzuki and Yamada (2011) tested fixed time gaps via a driving simulator experiment. It found that 5.76 seconds was accepted by almost 60% of the participants. 4.32 seconds was accepted by only 20%. Ashalatha and Chandra (2011)'s research observed real traffic situations and found a gap acceptance value of 3.68 seconds for a similar case. This is a remarkable difference, which may be related to the nationality of the drivers. The study of Ashalatha and Chandra (2011) was executed in India, whereas the study of Suzuki and Yamada (2011) was executed in North America. So, two new potential factors were considered here: country and intersection geometry.

More relevant were the studies presented by Cody et al. (2007), Chovan et al. (1994), and Ueno (1991). They observed real traffic situations as shown in Figure A.2, where the SV (Subject Vehicle) crosses in front of the POV (Possible Oncoming Vehicle), while both vehicles were on speed. Ueno (1991) found that a time gap below 3 seconds would always let the SV stop. When the vehicle would have continued driving at 50 km/h, the TTC between the SV and POV would be approximately 0.6 seconds. A TTC value of 5.6 seconds would always let the SVs cross in front of the POV. Cody et al. (2007) found an average TTC value by substracting the clearance time of the gap acceptance value. This resulted in an acceptance TTC value of 1.84 seconds. A similar study was executed by Smith et al. (2009), which found a TTC value of 2.32 seconds for the same traffic situation.

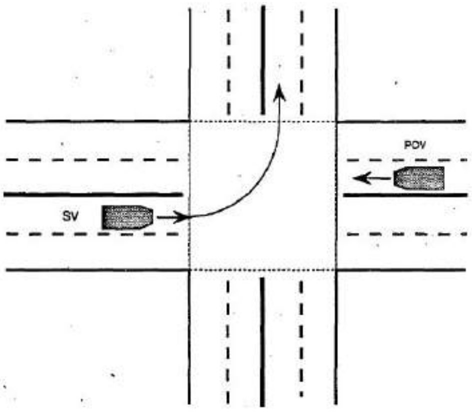


Figure A.2: Left turn scenario considered by Ueno (1991); Chovan et al. (1994), where SV = Subject Vehicle and POV = Possible Oncoming Vehicle

Furthermore, some literature described that *physical factors* could determine the preferred distance between vehicles, either lateral or longitudinal. Michael et al. (2000) described the aggressive driving style, which included keeping smaller distances towards other vehicles. Also Hegeman et al. (2004) mention the existence of dangerous driving behaviour, which might be related to the mood of drivers. Moreover, Zhang et al. (2019) researched the effects of emotional status and driving experience on the driving behaviour. It concluded that induced anger and previous collision history can increase the preference for space among drivers. Finally, Zhou et al. (2017) and Hamed et al. (1997) mentioned the importance of socioeconomic characteristics that could influence the difference in gap acceptance, like gender, age, and trip purpose. However, no quantitative explanation was provided related to these factors and the preferred distances to other vehicles.

Technical Factors

A basic traffic control system performs three steps: (1) detecting vehicles, (2) modelling their trajectory, and (3) sending instructions to a vehicle to follow the modelled path. These steps are repeated each time interval. However, per step, inaccuracies can occur that affect the safety of the vehicle.

Measurement Inaccuracies

Considering the first step, the *positioning inaccuracy* and *velocity inaccuracy* were distinguished. The positioning inaccuracy will depend on the positioning system used by the vehicle and the traffic control system. Global Positioning System (GPS) could cause location errors up to a value of 30 meters (Galileo, 2018). However, to decrease the positioning inaccuracy of an (automated) vehicle, it is desired to apply more than one positioning system. For example, Q. Yang and Sun (2007) could reduce the location error to a maximum value of 0.30 meter. With the arrival of the 5G network even lower location errors are expected, varying between 0.02 and 0.10 meter (del Peral-Rosado, Saloranta, et al., 2018). Considering The Netherlands, the arrival of 5G is expected in 2023 (Nando Kasteleijn, 2020). Whereas GPS is often not reliable in dense urban areas, 5G is reliable in harsh urban environments (Shengbo et al., 2003; Mao et al., 2003; del Peral-Rosado, Saloranta, et al., 2018). This research assumed that as soon as Smart Traffic is further developed and is able to assign iSpaT reservations, all HDVs and CAVs will be connected to the 5G network. Therefore, positioning inaccuracies are expected lay between 0.02 and 0.10 meter for both HDVs and CAVs in the future hybrid traffic period.

When considering the velocity inaccuracy, for both vehicle types it was expected that the measured velocity not always equals the actual velocity (WeWantAnyCar, 2016; Nie et al., 2018). The difference here was that the measured speed of an HDV is never higher than the actual speed, whereas this could be the case for CAVs. For HDVs a velocity deviation between 4% and 10% is common. No concrete value was found for CAVs that represent the level of velocity inaccuracy. Therefore, this percentage was assumed to lay between either -4% and -10% or +4% and +10%. However, further research would be necessary to confirm or reject this assumption.

Model Inaccuracies

Model inaccuracies represented the *latency of communication* between two CAVs or between one CAV and the infrastructure, and represented the computation time of the traffic model. Both inaccuracies were expected to be only relevant during emergency situations. Considering the future situation where CAVs receive a space-time reservation from the traffic controller (Sweco Nederland, 2018), there are two moments of communication: when the automated vehicle communicates its location and other parameters to the traffic controller; and when the traffic controller communicates the space-time reservation to the automated vehicle. For both moments a certain delay will exist between the moment of sending and receiving the message. The value of the delay shall depend on the network type used. As explained before, currently the 5G network is being developed. A requirement of this network is to minimize the value of latency to 1 millisecond (ms) (Park, 2018). Currently, the 4G network is used for V2I communication with a communication delay around 20 ms (Tao, 2018). The delay in communication is especially important to consider during emergency situation. Namely, if an automated vehicle is driving according to its space-time reservation, but suddenly it needs to brake or divert, it is not driving according to the space-time reservation anymore. This could have an influence on the possibilities for other traffic to stay within their reservation. In order to lead the other traffic safely through the intersection, fast communication between the vehicles and infrastructure is essential.

Moreover, the *traffic model* also needs a certain *computation time* in order to determine the space-time reservations for each vehicle. This is defined as the time between receiving a vehicle location and sending an iSpaT message to these vehicles. Of course, there is no value yet available for this case, since there is no suitable traffic control system yet developed. However, the current traffic control system applied by Sweco, where highly reliable time-to-red and time-to-green times are calculated, currently has set the maximum computation time between 2 and 3 seconds. As soon as a vehicle is registered it will be included in the following forecast cycle. In worst case, a vehicle is registered just at the beginning of a new cycle. In that case, the computation time is twice the cycle time. Best case has a computation time equal to the cycle time.

Vehicle Inaccuracies

The final technical factors found were related to inaccuracies of the CAVs. When a vehicle is planning to make a right or left turn, it is important to consider that not every vehicle will use the same space in order to make that turn. The curve of the turn can differ per vehicle according to the size of the vehicle, the speed of the vehicle, the maximum acceleration, and deceleration. Moreover, vehicles will always swing out, meaning that the width of the curved path driven by the vehicle is wider than the width of the vehicle itself. This effect has a positive relationship with the size of the vehicle causing larger vehicles to swing out more and thus requiring even more extra space at the crossing area than smaller vehicles. Furthermore, their speed was expected to be lower while making a turn, which results in a longer period of making the turn. By assuming that a vehicle is able to stay within its lane, this inaccuracy should not require any safety margins. Finally, steering errors will also require a safety margin around the entire vehicle. Steering errors can be the result of technical errors in the vehicle or can occur due to external influences, for example due to heavy wind.

Another factor that was distinguished is the *reaction time* of a CAV, according to (del Peral-Rosado, Granados, et al., 2018), a reaction time of 0.1 second could be established. This time is important to consider during emergency situations if the CAV is driving without having a reservation. The reaction time can be influenced by its environment and the penetration rate of connected vehicles (Talebpour & Mahmassani, 2016). According to Park (2018), within the 5G network, the reaction time between connected and automated vehicles will be minimized. To make reliable conclusions about the total reaction time of a human driver, more literature research would be necessary.

Finally, an important factor distinguished is the difference in *time synchronisation* of the internal clocks of two CAVs or a CAV and the infrastructure. Since the traffic control system will inform the CAV where it needs to be at what specific moment in time, it is desired that all internal clocks are aligned. However, in case two internal clocks will not be aligned, which is highly likely, safety margins will be required to cover for the vehicle being earlier or later at the assigned location than was expected or intended by the traffic controller. Already several advanced synchronisation techniques have been developed that reduce any possible offset as much as possible (Hasan et al., 2018).

Expectations for Hybrid Traffic Situation

The literature discussed considered the interaction between two HDVs. However, during the hybrid traffic situation, also interaction between HDVs and CAVs and between two CAVs will occur. Trust is the major factor that influences the user acceptance regarding CAVs (Choi & Ji, 2015). Besides trust, also the driving experience was expected to influence the preferred safety margins.

According to Frison, Wintersberger, and Riener (2019), the feeling of being out of control ensures less trust with automated driving. Moreover, the participants of this study declared that they assessed their own driving performance to be better than the performance of an automated vehicle. Besides, when the traffic density increased, people felt less comfortable in the vehicle. Also (Frison, Wintersberger, Liu, & Riener, 2019) concluded that trust issues emerged in more complex environments. Therefore, at urban intersections it was expected that people become distrustful to the automated vehicle and prefer larger safety margins compared to the margins adhered during their own driving style. Besides, the study of Siebert and Wallis (2019), concluded that a comfortable THW in highly automated driving decreases with speed increase. According to their results, a comfortable THW in the urban environment (50 km/h) may lay between 1.5 and 4.0 seconds considering clear weather conditions. A value of 1.5 seconds was accepted by 50% of the participants of the experiment, whereas more than 70% of the participants accepted the margin of 4.0 seconds.

Moreover, an earlier study presented in Siebert et al. (2014, 2017) focused on the preferred THW towards any kind of vehicle by an occupant of a semi-automated vehicle. Factors as comfort and risk were evaluated during different car-following scenarios. It appeared to be that the transition from 2.0 seconds to 1.5 seconds equaled the transition from a pleasant to an unpleasant feeling for the occupant at a speed of 50 km/h. No real danger was experienced at THW values between 4.0 and 2.5 seconds,which is in contrast with the highly automated vehicle situation.

A study of Tennant et al. (2016), focused on the interaction between HDVs and CAVs from the perspective of HDVs. the found that human drivers think that automated vehicles can drive more safe than human drivers, however, the human driver also felt uncomfortable in boarding or driving alongside an automated vehicle. On the contrary, the study also found that human drivers become more comfortable the longer they are exposed to automated driving. Also Dixit et al. (2016) and Pereira et al. (2015) expected an increase in trust when CAVs make more driving hours. Moreover, they found that smaller safety margins became preferred with the increase of automated driving experience. The study of Gouy et al. (2014) showed that human drivers adjust their behaviour according to the behaviour of other traffic. They found that human drivers also decreased their THW value when the THW of a platoon of trucks driving next to them, drove with a small THW. A THW of 0.3 seconds is already available between trucks driving in a platoon (Janssen et al., 2015). It is expected that this short THW value may be applied to HDVs too.

According to the previously discussed literature, it is expected that with the arrival of semi-automated vehicles, where the human driver can still control the vehicle, no significant changes will occur in the preferred THW compared to the current traffic situation. However, with the arrival of highly and automated vehicles, where the human driver looses its ability to take over control, an increase in safety margins is expected. Perhaps this increase can take values up to 4.0 seconds (Siebert & Wallis, 2019). As soon as human drivers or occupants of (semi-) automated vehicles get more experience with automated driving, the required safety margins will possibly decrease.

3 Determination Safety Margins

According to the literature study, various factors were distilled that may influence the size of the safety margins around a vehicle. However, according to the literature found, it was not possible to determine a quantitative relationship with a required safety margin size for all factors. Further research was considered to be necessary in order to determine these relationships. Table A.1 summarizes the qualitative relationships assumed between the factors and the size of the safety margins. The factors considered in this table only represent the factors that were dependent on environmental or vehicle conditions (i.e. they were scenario-dependent).

The remaining factors were assumed to not vary significantly with environmental or traffic conditions. Neither would they only be necessary during emergency situations. Therefore, for six factors a quantitative description is presented that describe their required safety margins around a vehicle. Table A.2 illustrates where around the vehicle the safety margin is required.

Table A.2: Overview of location around vehicle where each safety margin value is required

	Front	**Back**	**Left**	**Right**
M_p	x	x	x	x
M_{tt}	x	x		
M_{ts}	x	x		
M_h	x	x		
M_{ds}	x	x	x	x
M_{gap}			x	x

Safety Margins per Factor

Below the relation between each factor and the safety margin size is quantitatively explained. The factors result in actual safety margins or perceived safety margins. Inaccuracies are defined as a maximum deviation that can occur. Hence, all factors describe a worst case scenario.

Table A.1: Qualitative explanation of expected relationships between scenario-dependent factors and the size of a safety margin.

Scenario-dependent factor	**Vehicle perspective**	**Actual / Perceived safety**	**Relationship with safety margin size**
Driving Experience of CAV	CAV	Actual	The more driving hours a (C)AV makes, the more its perception and prediction of other traffic behaviour improves, and the smaller the necessary safety margins are expected to be.
Driving Experience of human driver	HDV	Perceived	More bad driving experiences leads to larger safety margins.
Driving Experience of human occupant	CAV	Perceived	More good driving experiences in (C)AV, leads to smaller safety margins.
Trust	HDV	Perceived	The higher the feeling of being out of control in traffic (themselves or conflicting vehicles), the larger safety margins are required.
Trust	CAV	Perceived	More trust in the (C)AV leads to smaller safety margins.
Traffic Density	HDV	Perceived	A more dense traffic stream, leads to smaller safety margins.
Weather Conditions	HDV	Both	Bad weather conditions lead to larger safety margins.
Weather Conditions	CAV	Both	Bad weather conditions lead to larger safety margins. However, a decrease in visibility might not play a role anymore.
Mood	HDV	Perceived	The more aggressive the driver, the smaller the safety margins can be.
Preferred Driving Style	CAV	Perceived	Often people prefer their own driving style for the (C)AV (i.e. acceleration profile, max. speed, etc). Another style may lead to larger margins.
Visibility	HDV	Perceived	Less visibility results in larger safety margins.

Actual Safety - Positioning Inaccuracy

The position of CAVs are assumed to be communicated via the 5G network. HDVs are assumed to have an electronic device inside that is connected to the 5G network. However, since it is unknown where exactly in the HDV that device is located, a higher positioning inaccuracy accounts for HDVs, which size depends on the vehicle dimensions. For CAVs a positioning inaccuracy of maximum 0.10 m can be assumed around the entire vehicle, whereas for HDVs this inaccuracy could increase to a value of 1.15 m lateral, and 2.95 m longitudinal. Equation A.1 represents the safety margin required to cover for the positioning inaccuracy.

$$\mathrm{M}_p^{Vs} = p^{Vs} \tag{A.1}$$

Where:

M_p^{Vs}	=	Safety margin required by positioning inaccuracy of vehicle $V \in \{HDV, CAV\}$	[m]
p^{Vs}	=	Positioning inaccuracy of vehicle V at vehicle side $S \in \{front, back, left, right\}$	[m]

Actual Safety - Trajectory Tracking

When a vehicle gets assigned a personal trajectory that must be followed, multiple inaccuracies can occur while the vehicle is tracking its trajectory. Therefore, it is expected that the vehicle can enter the assigned position earlier or later than was assigned. A safety margin M_{tt}^V must cover for the trajectory tracking inaccuracy of vehicle V. Examples of factors that can influence this inaccuracy are the total weight of the vehicle and the quality of the road surface. Namely, these factors influence the acceleration and deceleration profile of the vehicle, and possibly depend on the reaction time of the vehicle. Certain factors require further research. Two factors that were found in the literature influencing the trajectory tracking accuracy are related to the actual velocity of the vehicle. 1) Inaccuracies due to a difference in the actual vehicle speed and measured vehicle speed M_{vel}^V: the actual speed of an HDV will always be lower than the measured speed, with a maximum speed difference of 10% of the measured speed. On the contrary, the actual speed of CAVs could be either higher or lower than the measured speed.

2) A CAV determines its preferred driving speed. Each subject time the CAV will check its measured speed with its intended speed. Speed variations that occur during one subject time must be covered by safety margins in front and at the back of the CAV M_{st}^{v}.

Actual Safety - Time Synchronisation

The internal clock of the traffic control system and the CAVs are desired to be aligned. However, perfect alignment is unlikely or expensive to guarantee (Hasan et al., 2018). The problem that results from misalignment between the internal clocks, is that the CAV can be at a another location than was expected by the traffic control system at a certain moment in time. Or, vice versa, the vehicle will be at a certain location at another moment in time than was expected by the traffic control system. Despite of existing methods to synchronise the internal clocks as good as possible, still deviations exist between the clocks. Safety margins M_{ts}^{V} are required in front and at the back of a vehicle to cover for the maximum clock offset that is expected to exist between a CAV and the traffic control system. To express the clock offset in terms of a certain distance, the maximum clock offset (time synchronisation inaccuracy) between the CAV and traffic control system is multiplied by the average speed of the vehicle over one space-time reservation. Equation A.2 presents the safety margin required to cover for the clock offset.

$$M_{ts}^{V} = \alpha \cdot \bar{u}^{V} \tag{A.2}$$

M_{ts}^{V}	=	Safety margin to cover for inaccuracies in time synchronisation between the traffic controller and vehicle V;	[m]
α	=	Maximum inaccuracy that can occur after time synchronisation;	[s]
$\bar{u}^{V}$	=	Average speed of vehicle V over one space-time reservation;	[m/s]

Perceived Safety - Preferred Time Headway

As was concluded in the literature study, both in front and behind the vehicle a certain time headway (THW) exist that felt comfortable to the driver, the preferred time headway. However, it did not became clear whether or to what extent these values differed from each other. Therefore, no distinction was made between the THW in front or at the back of the vehicle. Moreover, the preferred THW was measured from the rear-end (i.e. rear bumper) of the preceding vehicle to the front-end (i.e. front bumper) of the following vehicle.

Equation A.3 applies for the THW in front and at the back of a vehicle. It was assumed that the vehicles could drive with a constant speed en would not need to brake or overtake due to a slower driving preceding vehicle.

$$\mathrm{M}_{h}^{Vs} = h^{Vs} \cdot \bar{u}^{V} \tag{A.3}$$

Where:

M_{h}^{Vs}	=	Safety margin required to cover for the preferred time headway of a car user of vehicle V at vehicle side s	[m]
h^{Vs}	=	Preferred time headway h of car user in vehicle V at vehicle side s	[s]
$\bar{u}^{V}$	=	Average actual speed of vehicle V over one space-time reservation (0.1 s)	[m/s]

Perceived Safety - Preferred Driver Space

Equation A.4 shows the determination of the safety margins according to the preferred driver space around the vehicle. This value is a minimum fixed value around the vehicle and may differ per interaction scenario and per side of the vehicle.

$$\mathrm{M}_{ds}^{V} = s^{V} \tag{A.4}$$

Where:

M_{ds}^{V}	=	Safety margin required to cover for the preferred driver space;	[m]
d^{V}	=	Preferred driver space d around vehicle V.	[m]

Perceived Safety - Accepted Time Gap

The safety margins required on both sides of the vehicle when the vehicle is at the conflict area, could be calculated using Equation A.5. Here, the average speed of the oncoming vehicle is considered rather than the speed of the subject vehicle. Namely, the speed of oncoming vehicles determine the time gap, because due to that speed, the time gap increases or decreases in size. Equation A.5 describes the safety margin required as a result of the preferred time gap between the subject vehicle and a conflicting vehicle. To express the time value in terms of a certain distance, again the standard formulation $s = v \cdot t$ was applied.

$$\mathrm{M}_{gap}^{V} = G^{V} \cdot \bar{u}^{O} \tag{A.5}$$

Where:

M_{gap}^{V}	=	Safety margin required to cover for the accepted time gap of car user of vehicle V;	[m]
$\bar{u}^{O}$	=	Average speed of oncoming vehicle O;	[m/s]
G^{V}	=	Accepted time gap of vehicle V	[s]

Overlap

Each vehicle, either an HDV or a CAV, is included in the traffic model to plan the trajectories for the CAVs and the traffic light phases for the HDVs. Each vehicle has a virtual PVL and PCZ around it. The question whether and to what extent the PVL and PCZ of different vehicles can use the same space on the road at the same time, is explained by reasoning:

- When 2 PVLs would use the same road space at the same time, it is highly likely that a collision would occur. This must be avoided, so no overlap is allowed between PVLs;
- When 1 PVL and 1 PCZ of different vehicles would use the same road space at the same time, it is highly likely that the PCZ would not be free of other traffic. Therefore, the car user could feel unsafe, which is desired to be avoided. So, overlap between a PVL and a PCZ of different vehicles must not be allowed;
- When 2 PCZs would use the same road space at the same time, both PCZs would still be free of other traffic. No feeling of unsafety would occur among the car users, hence overlap between PCZs is allowed and even favorable in the context of efficient use of road space.

As was explained before, the PVL of a vehicle is found by the sum of all actual safety margins, and the size of the PCZ is determined based on the maximum values of the perceived safety margins at each side of the vehicle. These definitions were applied to answer the first research question in the next section.

Mathematical Formulation

Eventually, the first research question was answered. Equations A.6 and A.7 present the required safety space at both the longitudinal and lateral side of the vehicle, considering each interaction scenario and each side of the vehicle. However, it may be clear that not for all safety margins the required size can be calculated yet. Especially M_{tt} requires further research to be quantitatively explained by technical and non-technical factors. Besides, more research is needed towards the relationship between the clock offset and the required safety margins. Parameter values that were already found in the literature that help to determine most safety margins are illustrated in Table 6.2. Finally, safety margins are also generated for HDVs, but as was explained before, these are not communicated to the vehicles, since the traffic safety can become in danger when human drivers will try to follow strict trajectories.

$$\mathrm{M}_{long}^{is} = \mathrm{M}_{p}^{is} + \mathrm{M}_{tt}^{is} + \mathrm{M}_{ts}^{is} + \max\left(\mathrm{M}_{ds}^{is}, \mathrm{M}_{h}^{is}\right) \tag{A.6}$$

$$\forall i \in I, \forall s \in S$$

$$\mathrm{M}_{lat}^{is} = \mathrm{M}_{p}^{is} + \mathrm{M}_{tt}^{is} + \max\left(\mathrm{M}_{ds}^{is}, \mathrm{M}_{gap}^{is}\right) \tag{A.7}$$

$$\forall i \in I, \forall s \in S$$

I = {HDV-HDV, HDV-CAV, CAV-HDV, CAV-CAV}
S = {FRONT, BACK, LEFT, RIGHT}

Table A.3: Assumed values for safety margins based on literature research

Safety Margin	***Variable***	**HDV-HDV**	**HDV-CAV**	**CAV-HDV**	**CAV-CAV**
M_p	p_{long}	2.95 m	2.95 m	0.02 - 0.10 m	0.02 - 0.10 m
	p_{lat}	1.15 m	1.15 m	0.02 - 0.10 m	0.02 - 0.10 m
M_{vel}	w^V	0.04 - 0.10	0.04 - 0.10	-0.10 <w <+0.10	-0.10 <w <+0.10
	T	1 to 3 sec	1 to 3 sec	1 to 3 sec	1 to 3 sec
M_h	h_{front}	1.5 sec	2.0 sec	2.0 - 4.0 sec	0.3 - 4.0 sec
	h_{back}	1.0 sec	1.5 sec	1.5 - 4.0 sec	0.3 - 4.0 sec
M_{ds}	d_{long}	8.7 m	8.7 m	8.7 m	8.7 m
	d_{lat}	8.7 m	8.7 m	8.7 m	8.7 m
M_{gap}	G	1.8 s	2.3 s	2.3 s	2.05 s

4 Human Experiment

For the second part of this research, a human experiment was executed in order to generate data that could be compared to the expected accepted time gap that followed from the literature study. These expected accepted time gaps are presented on page 114. During this experiment only the expected safety margin values for the HDV-CAV, CAV-HDV, and CAV-CAV *interaction scenarios* were considered, since these scenarios would be new on the road and their values therefore required the most assumptions. Due to time restrictions, only the maximum perceived safety margin in front of the vehicle was tested. Further research is necessary to test the perceived safety margins on the other sides of the vehicle.

Requirements and Suitable Method

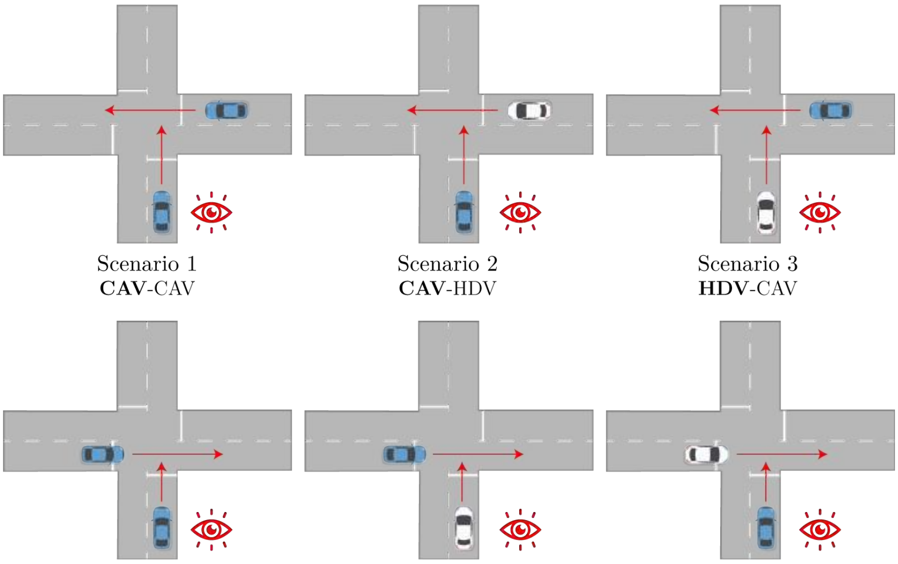
As part of this research, a suitable method had to be found to establish an experiment suitable for finding the preferred safety margins in front of both CAVs and HDVs during the various interaction scenarios. Four requirements were established for finding a suitable method:

1. The test environment must be safe for all persons involved;
2. The test environment must feel as realistic as possible to gather responses that are comparable to responses in a real life situation;
3. The total duration of the experiment, including its preparation, cannot take longer than 2 months;
4. There is no budget for the experiment.

In total, five methods were compared to these requirements: a driving simulator study, a virtual reality study, a 360-degree video study, a 360-degree photo study, and a 2D computer study. Eventually, it was decided to execute a Virtual Reality (VR) study, because this method (1) was safe to apply, (2) ensured a sufficient realistic environment, (3) would take a realistic amount of time to prepare and execute the experiment, and (4) had no additional costs when applied. Also a 360-degrees video study seemed suitable to apply: a study where real world scenarios were filmed that could be experienced via a Head-Mounted Display (HMD). However, simultaneously filming a crossing situation where two vehicles just did not collide and driving a vehicle appeared to be hard and dangerous. A VR study was safer to generate the same 360 videos with.

Design of Test Scenarios

Due to time restrictions, finding the preferred safety margins around each side of the vehicle was not possible. Up to 300 traffic situations were possible to test, due to possible variation in the interaction scenarios, crossing direction of the conflicting vehicle, the crossing order of the two conflicting vehicles, and the safety margins tested. Therefore, design choices had to be made. The first choice made was between testing the impact of different crossing directions (i.e. crossing vehicle approached from the left or right side), and testing the impact of the two crossing orders (i.e. subject vehicle crosses in front or behind a second vehicle). Accordingly, five people were asked to judge two traffic scenarios: (1) a vehicle crossing ahead of them, (2) a vehicle crossing behind



Scenario 1
CAV-CAV

Scenario 2
CAV-HDV

Scenario 3
HDV-CAV

Scenario 4
CAV-CAV

Scenario 5
HDV-CAV

Scenario 6
CAV-HDV

Figure A.3: Test scenarios for the experiment; perspective indicates by bold letters and red eye. CAV indicated in blue, HDV indicated in white.

them. The crossing vehicle was approaching from the same direction in this situation. It became clear that it was easier to judge a traffic situation where the crossing vehicle was crossing in front of the subject vehicle. The two main reasons for this were the field of view of 110 degrees of the HMD: to see a vehicle next to you asked for less natural neck-turning movements. The other reason was that people were less focused on the traffic situation when they crossed first, because they assumed they had priority and would not have to 'worry' about the behaviour of the other vehicle. Hence, it was decided that VR was no suitable method to test the variation in crossing order, but was actually suitable for testing the difference in crossing direction. Figure A.3 illustrates all vehicle interaction scenarios that were tested during the experiment.

Approach to determine perceived safety

The experiment had to show what time gap was accepted by the participants in front of their vehicle. The time gap was defined as the time between the crossing (and conflicting) vehicle leaving and the subject vehicle entering their conflict area. It was chosen to show the participants 5 different time gaps, repeated for test scenario presented on Figure A.3. The smallest time gap equaled a value of 0.5 seconds, based on the 0.3 seconds which is now possible with truck platooning (Janssen et al., 2015). The largest time gap was based on the study of Siebert and Wallis (2019), and equaled 4.0 seconds. Furthermore, other suggestions for suitable time gaps laid approximately between 1.0 and 2.0 seconds. Therefore, it was chosen to divide the other time gaps to test more or less equally between 0.5 and 2.0 seconds, which resulted in the following time gaps: 0.5, 1.0, 1.5, 2.0, and 4.0. Since not much research was found that supported required time gaps between 2.0 and 4.0 seconds, it was chosen to not measure time gaps between these values. Furthermore, not more than 5 time gaps per interaction scenario were chosen to test due to time constraints. To keep the participants focused and motivated during the experiment, a duration of maximum 30 minutes was desired. In total, 15 to 20 minutes were reserved for the actual virtual reality test. Otherwise, it was expected that the participants could perhaps suffer from motion sickness (Dużmańska et al., 2018).

The participants had to indicate their feeling of safety per time gap for each of the six scenarios using a 4-point Likert scale: 1) Very safe 2) Pretty safe 3) A little unsafe 4) Very unsafe. Hence, their perceived safety was measured on an ordinal scale. This scale was based on the research of Evans et al. (2006). It ensured that a situation was always scored as either safe or unsafe.

Expectations

The literature suggested multiple parameter values to be used to calculate the required safety margins around a vehicle. These are summarized in Table A.3. The preferred time gap is comparable to the gap acceptance values found in the literature. However, these values from the literature considered the perspective of the vehicle encroaching in front of another vehicle. This experiment had the goal to check whether these gap acceptance values were also accepted by the vehicle being encroached. In combination with the preferred time headway values, expected values for the accepted time gap were determined. These are described below and are later compared with the results of the experiment. It appeared that these expectations were higher than the values found in the experiment.

- When a CAV intersects the planned trajectory of an HDV, the human driver of the HDV prefers a time gap between 2.0 and 2.3 seconds.
- When an HDV intersects the planned trajectory of a CAV, the human occupant of the CAV prefers a time gap between 2.3 and 4.0 seconds.
- When a CAV intersects the planned trajectory of a CAV, the human occupant of the CAV prefers a time gap between 2.0 and 4.0 seconds.

Methodology

This section is divided into two parts. The section first explains the model used for this experiment. Thereafter, the experiment procedure was elaborated.

Model

In total, each participant would be shown 30 vehicle interaction situations (or: 30 videos): 5 time gaps × 3 interaction scenarios × 2 crossing directions. Each of the 30 videos was modelled using the gaming software *Unity*, version 2019.1.1f1. Two input fields were programmed that were connected to the starting time of the two crossing vehicles. Furthermore, the starting positions from the vehicles differed exactly one vehicle length. Thus, when both cars would start driving at the same time, the first vehicle would have just left the conflict area, when the second vehicle enters the conflict area. In that case, the safety margin in front of the subject vehicle equaled 0 seconds. The participants experienced each video from the perspective of the second vehicle, the subject vehicle. To change the value of the safety margin, the subject vehicle was given a later starting time. The difference in starting times equaled the safety margin, i.e. the time gap that was tested. Both vehicles drove with a speed of 50 km/h, and were comparable to a Renault Megane. Moreover, the HDV perspective showed hands on the steering wheel, whereas these were not showed considering the perspective of the CAV.

Set up of VR Experiment

The experiment was promoted among students at Delft University of Technology and among employees at Sweco. The potential participants themselves could online book a time slot to conduct the experiment. A couple of days before the experiment would take place, a reminder was sent to the participant including a request to already fill in a first questionnaire. The goal of this questionnaire was to introduce the type of person: general questions were asked about age, gender, study/work field, driving experience and driving style, and about their experience with automated driving.

Figure A.4 - A shows the Head-Mounted Display that was used for this experiment. By rotating the head, the test environment could be observed. However, the environment was fixed, which means that the participants were not able to look behind model attributes (e.g. bending over the steering wheel had no effect in earlier seeing the crossing vehicle) Figure A.4 - B

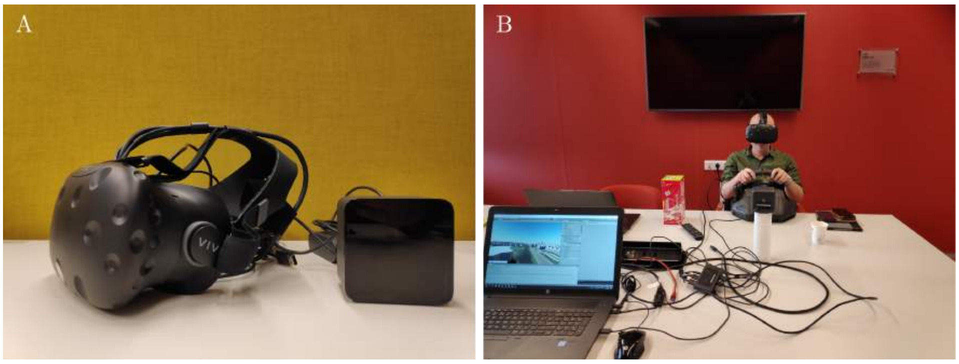


Figure A.4: A) HTC Vive Head-Mounted Display (2PU6100) and HTC Vive Base Station 1.0 (2PR8100); B) Participant conducting experiment at Sweco and Model visible on researcher's laptop.

shows a participant that was conducting an experiment. As can be seen, the participant held his hands on a steering wheel. A steering wheel and a gas and brake pedal were added to the test set up in order to increase the experience of really being in a vehicle. However, it is important to note that these additions could not be used to influence the scenario shown in the virtual environment.

Before a participant started the VR experiment, first an instruction about the experiment had to be read. Thereafter, two example scenarios were shown to the participant in order to get familiar with the virtual environment. When the participants had no further comments or questions, the real experiment could start.

Each participant got shown all 30 traffic situations, however, both the scenarios and the time gaps were shown in a random order. After one video, the participants indicated their feeling of safety orally. Also the urge to intervene in a self-driving car or the urge to brake in a human-driven care were registered by the researcher. Halfway through the experiment, the participant was asked whether he suffered from motion sickness and if he perhaps needed a break. This was rarely the case. After all videos were shown to the participant, the participant had to fill in the second questionnaire, considering their experience of the experiment.

5 Results

This section describes both the descriptive and statistical analyses of the results obtained.

Descriptive Analysis

The experiment was executed by 82 participants: 53 male and 29 female participants, aged between 17 and 62 years old (μ = 32.5; σ = 11.3). 34 persons had experience with vehicles of automation level 1, and 8 people had experience with level 2. Figure A.5 illustrates the frequency of age per gender. The average age among male participants is 35.7 years, whereas the female participants are on average 26.7 years old. Due to the low number of female participants, compared to the male participants, the data obtained was not suitable to independently assess effects of gender and age on the perceived safety. In 2017, the largest age group of drivers within the Netherlands was represented by drivers between 46 and 55 years old, with a percentage of 19.7%. Moreover, 12.2% of the drivers were between 26 and 35 years old, and 14.2% had an age between 36 and 45 years old (Oostvogels, 2018). In this study, all age groups were represented, however, considering a different distribution.

Moreover, none of the participants indicated their driving style as aggressive (on a 5-point scale). Only 12% indicated their driving style only one point below aggressive. According to the literature study, these drivers perhaps keep smaller distances on the road, and thus during the experiment. Furthermore, 43 participants drive 4 hours or less a week, which was below the Dutch average of 6.55 hours in 2018 (CBS, 2019b, 2019c, 2019a; Blankesteijn, 1994). However, no expectations existed that the lower average of driving hours would influence the obtained results.

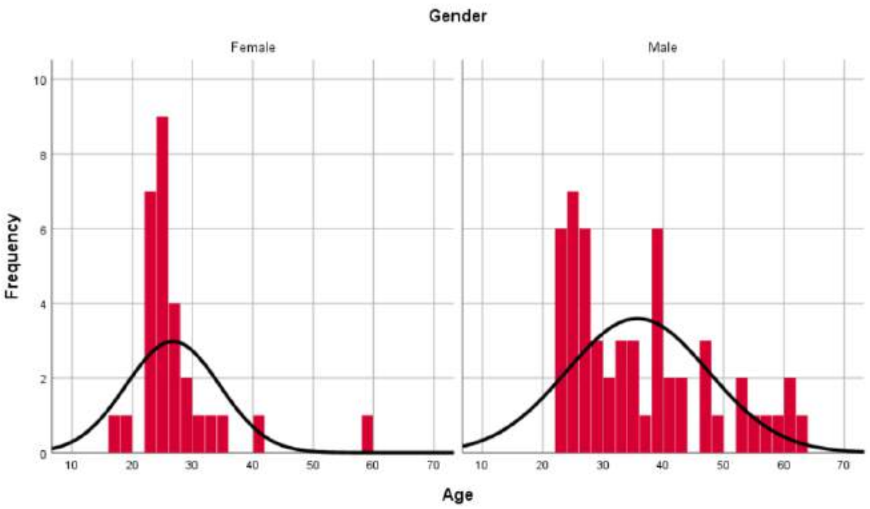


Figure A.5: Distribution Age and Gender

Statistical Analyses

Several statistical tests were executed to determine what time gap values were preferred by human drivers of HDVs and human occupants of CAVs during various vehicle interaction scenarios. Before the second research question was answered, first three other questions were answered here. Namely, it was desired to first research the effects of the time gaps shown, the crossing direction applied, and the interaction scenario exposed had significant effects on the perceived safety of the participants. It appeared that only the time gaps shown were significantly associated with the perceived safety feeling. Below each statistical measure that was applied to determine on the existence of an association with the perceived safety, is explained individually for the time gaps, the crossing directions, and the interaction scenarios. The three corresponding hypotheses are explained below.

1. The scores given are not associated with the time gaps shown.
2. The scores given are not associated with the crossing direction.
3. The scores given are not associated with the interaction scenario shown.

Effect of Time Gaps on Scores

An important first step is to check whether the collected data was valid and could make sense to draw conclusions from. Namely, when an association would exist between the scores given by each participant and the time gap shown to the participant, it could be assumed that the data received from the experiment was not based on chance. The Spearman's correlation coefficient was applied to check whether a significant association existed between the time gaps and the scores. A negative association would be expected (a lower time gap would result in higher scores). In total, 7 correlation coefficients were determined: one applied on the whole data set, and six applied on one data set following from the combination of one interaction scenario and one crossing direction (See Figure A.3). All coefficients had a P-value of 0.000, hence the Spearman's correlation coefficients found were significant. All values laid between -0.733 and -0.779, which all indicated a negative and strong association between the scores given and the time gaps shown. Therefore, the data set obtained was not based on chance.

Effect of Crossing Direction on Scores

In order to determine whether and to what extent the crossing direction of the crossing vehicle would have an impact on the feeling of safety of the participants, first a Chi-Square test for independence was executed on the whole data set to check for a significant association between the scores and the crossing direction.

No significant association was found (P=0.952). Thereafter, fifteen more Chi-Square tests were executed to find an association between the scores and the crossing direction within one interaction scenario per time gap. Again no significant associations were found. 11 P-values were not even valid. The valid P-values were found at the 0.5 s time gap during the CAV-CAV (P=0.510) and HDV-CAV (P=0.085) interaction scenario, and during the 1.5 s time gap during the CAV-CAV (P=0.149) and CAV-HDV (P=0.344) interaction scenario. All valid P-values were lower than a significance level of 0.05, hence, it was concluded that the direction from which the crossing vehicle entered the intersection did not influence the feeling of safety of a driver, not even at one specific time gap.

Effects of Interaction Scenario

After the conclusion that the crossing direction had no influence on the results, the data sets were combined to only three sets of data: one per interaction scenario. However, the question raised to what extent these scenarios led to different scores. Again Chi-Squared tests for Independence were applied for finding a possible association. No significance was found between the scores and any of the interaction scenarios. First, all scores of all scenarios were compared (P=0.219). Thereafter, three Chi-Square test were executed that compared only two interaction scenarios. Neither did these tests led to significant associations (P=0.348, 0.544, 0.084). These results were striking because of the results of the second questionnaire. Here, the participants indicated that they could empathize well with their role of being a human driver and being an occupant of a CAV. Moreover, they indicated that they could empathize well the crossing vehicle being an HDV or CAV. The participants even indicated that the virtual environment seemed realistic to them. Therefore, it was concluded that it really did not make a difference to the participants what interaction scenario they experienced, when considering their scores. Moreover, all data collected from all scenarios were bundled in order to answer the second research question.

Perceived Safe Time gaps

The frequency of the scores given to the time gaps is illustrated in Figure A.6. When plotting the percentages that represented a safe feeling (i.e. scores 1 and 2) at the participants against the corresponding time gaps it seemed that a certain relation exist between these two variables. Figure A.7 suggested a relation between the time gaps and the acceptance rate that fits the data.

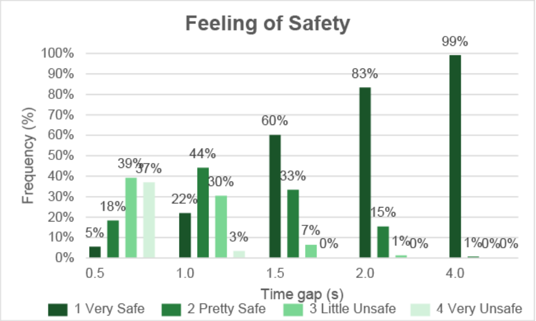


Figure A.6: Frequency Scores per Time gap - All Interaction Scenarios Combined

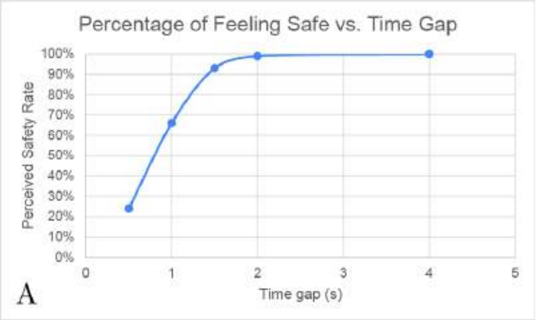


Figure A.7: Possible relationship between the time gap and the percentage of people that will feel safe. Note: this graph only applies for the assumed traffic situation as was described in this research with a speed limit of 50 km/h.

The graph shows that only 24% of the participants felt safe at the time gap of 0.5 seconds. However, a big leap can be seen between the 0.5 and 1.0 second time gap. Here, a steep increase of 42% was observed in *feeling safe*. Another striking increase can be seen between the time gaps of 1.0 and 1.5 seconds. Here, the percentage of participants that felt safe increased from 66% to 93%. After 1.5 seconds it seemed that the effect of a larger time gap does not really affect the perceived safety feeling anymore. At a time gap of 2.0 seconds

99% felt safe, whereas 100% felt safe at 4.0 seconds. Moreover, at 1.5 and 2.0 seconds, the majority of the people that felt safe, felt 'very safe' rather than 'pretty safe'. Eventually, the question rises what the minimum perceived safety rate has to be before a time gap is acceptable to adopt in Smart Traffic.

6 Conclusion

This research was split into two parts. The first part described both technical and non-technical factors that influence actual and perceived safety of both HDVs and CAVs. Moreover, mathematical formulations were established that describe the impact of these factors on the size of the required safety margins around the vehicles for various interaction scenarios during the hybrid traffic period. The goal of the second part was to obtain data about the perceived safety of human drivers at various time gaps during various vehicle interaction scenarios. The obtained data from the experiment was compared to the expected data from the literature. The answers to the research questions are given below.

Part I: Equations A.6 and A.7 are the answer to the first research question. The safety margins represented in these equations were determined by the factors that were expected to always influence the size of the safety margins around the vehicle. The safety margins in these equations are needed due to (1) positioning inaccuracies of the vehicle, (2) trajectory tracking inaccuracies of the vehicle, (3) the clock offset between internal clocks due to inaccuracies in the time synchronisation of these clocks, (4) the preferred time headway, (5) the preferred driver space, and (6) the accepted time gap between one vehicle leaving and one vehicle entering their conflict area. However, the research could not yet define the quantitative values for the safety margins needed around the vehicle per interaction scenario, since not for all safety margins the size could be calculated yet. Especially the margins due to trajectory tracking inaccuracies require further research. Moreover, the effects of the deviations in time synchronisation must also be further investigated in future research.

Part II: When comparing the results of the human experiment to the expected accepted time gap values, an acceptance rate higher than 99% followed. All expected values were higher than 2.0 seconds, which was accepted by 99% of the participants. However, since neither the crossing direction nor the interaction scenario resulted in statistically significantly different scores, presenting three acceptance rates was unnecessary. However, the question raised what time gap would be sufficient to implement to calculate the perceived safety margin in front of a vehicle during the starting phase of the hybrid traffic period.

7 Discussion and Future Research

An important point of discussion, which is moreover highly related to the second research question, contains the question what safety margin should be adopted when iSpaT messages could be assigned as soon as self-driving vehicles drive in public in urban areas.

When considering the preferred time gap in front of the vehicle, it is advised to start with a gap of at least 1.5 seconds. This gap is expected to be accepted by 93% of the drivers, which represents a large majority, and equals the average of the following distances from various studies discussed previously (Michael et al., 2000; Duan et al., 2013; Sayer et al., 2003). Moreover, after 1.5 seconds it seemed that the effect of a larger time gap does not really affect the perceived safety feeling anymore. Furthermore, it was expected that trust in automated vehicles increases with driving experience in automated vehicles, and that human-driven vehicles intend to copy driving behaviour of automated vehicles (Gouy et al., 2014). Therefore, it is expected that when the 1.5 second time gap is applied for a while, the safety margin could further decrease to values of 1.0 second or lower. However, regular checks to see if drivers still feel comfortable and safe with the smaller margins is desired.

An alternative is to let the passengers of the CAV indicate or install their personal preferred safety margins to the car. It was assumed that the CAV communicates its

References

capabilities (like max. speed and acceleration) to the traffic control system, so maybe it would also be possible for the CAV to communicate the preferred safety margins of its passengers.

This research provides many directions for further. The three main directions for future research were described below.

- It would be valuable to expand the equations that were established to calculate the safety margins around a vehicle, with the quantitative effects of the scenario-dependent factors. That would make the formulas also applicable and more efficient during varying environmental conditions;
- The experiment executed only considered vehicle interactions between two vehicles. However, hybrid traffic control systems will control multiple vehicles and will let vehicles weave over the intersections. Researching to what extent the preferred time gaps change when more vehicles are on the road would be interesting.
- The concept of iSpaT messages must be implemented in the urban environment. Therefore, future research could focus on how the traffic controller deals with slow traffic. If desiring CAVs to never stop in front of a traffic light, how will cyclists and pedestrians be able to cross the intersection?

Ashalatha, R., & Chandra, S. (2011). Critical gap through clearing behavior of drivers at unsignalised intersections. *KSCE Journal of Civil Engineering*, *15*(8), 1427–1434.

Blankesteijn, H. (1994, Feb). Geld is tijd. *nrc.nl.* Retrieved from `https://www.nrc.nl/nieuws/1994/02/03/geld-is-tijd-7212423-a290307`

Broughton, K. L., Switzer, F., & Scott, D. (2007). Car following decisions under three visibility conditions and two speeds tested with a driving simulator. *Accident Analysis & Prevention*, *39*(1), 106–116.

CBS. (2019a). *Motorvoertuigenpark; inwoners, type, regio, 1 januari.* Retrieved 2020-01-06, from `https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7374hvv/table?fromstatweb`

CBS. (2019b). *Personenmobiliteit in nederland; persoonskenmerken en vervoerwijzen, regio.* Retrieved 2020-01-06, from `https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83499NED/table?fromstatweb`

CBS. (2019c). *Verkeersprestaties motorvoertuigen; kilometers, voertuigsoort, grondgebied.* Retrieved 2020-01-06, from `https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80302ned/table?ts=1578323426200`

Chai, L., Cai, B., ShangGuan, W., & Wang, J. (2017). Connected and autonomous vehicles coordinating method at intersection utilizing preassigned slots. In *2017 ieee 20th international conference on intelligent transportation systems (itsc)* (pp. 1–6).

Chai, L., Cai, B., ShangGuan, W., Wang, J., & Wang, H. (2018). Connected and autonomous vehicles coordinating approach at intersection based on space–time slot. *Transportmetrica A: Transport Science*, *14*(10), 929–951.

Choi, J. K., & Ji, Y. G. (2015). Investigating the importance of trust on adopting an autonomous vehicle. *International Journal of Human-Computer Interaction*, *31*(10), 692–702.

Chovan, J. D., Tijerina, L., Everson, J., Pierowicz, J., & Hendricks, D. (1994). *Examination of intersection, left turn across path crashes and potential ivhs countermeasures* (Tech. Rep.).

Cody, D., Nowakowski, C., & Bougler, B. (2007). Observation of gap acceptance during intersection approach.

Crawford, A. (1963). The overtaking driver. *Ergonomics*, *6*(2), 153–170.

del Peral-Rosado, J., Granados, G., Raulefs, R., Leitinger, E., Grebien, S., Wilding, T., … others (2018). Whitepaper on new localization methods for 5g wireless systems and the internet-of-things.

del Peral-Rosado, J., Saloranta, J., Destino, G., López-Salcedo, J., & Seco-Granados, G. (2018). Methodology for simulating 5g and gnss high-accuracy positioning. *Sensors*, *18*(10), 3220.

Dixit, V. V., Chand, S., & Nair, D. J. (2016). Autonomous vehicles: disengagements, accidents and reaction times. *PLoS one*, *11*(12), e0168054.

Dresner, K., & Stone, P. (2004). Multiagent traffic management: A reservation-based intersection control mechanism. In *Proceedings of the third international joint conference on autonomous agents and multiagent systems-volume 2* (pp. 530–537).

Dresner, K., & Stone, P. (2006). Human-usable and emergency vehicle-aware control policies for autonomous intersection management. In *Fourth international workshop on agents in traffic and transportation (att), hakodate, japan.*

Dresner, K., & Stone, P. (2008). A multiagent approach to autonomous intersection management. *Journal of artificial intelligence research*, *31*, 591–656.

Duan, J., Li, Z., & Salvendy, G. (2013). Risk illusions in car following: Is a smaller headway always perceived as more dangerous? *Safety science*, *53*, 25–33.

Dużmańska, N., Strojny, P., & Strojny, A. (2018). Can simulator sickness be avoided? a review on temporal aspects of simulator sickness. *Frontiers in psychology*, *9*, 2132.

Evans, S. M., Berry, J. G., Smith, B. J., & Esterman, A. J. (2006). Consumer perceptions of safety in hospitals. *BMC Public Health*, *6*(1), 41.

Ferreira, M., Fernandes, R., Conceição, H., Viriyasitavat, W., & Tonguz, O. K. (2010). Self-organized traffic control. In *Proceedings of the seventh acm international workshop on vehicular internetworking* (pp. 85–90).

Frison, A.-K., Wintersberger, P., Liu, T., & Riener, A. (2019). Why do you like to drive automated?: a context-dependent analysis of highly automated driving to elaborate requirements for intelligent user interfaces. In *Proceedings of the 24th international conference on intelligent user interfaces* (pp. 528–537).

Frison, A.-K., Wintersberger, P., & Riener, A. (2019). Resurrecting the ghost in the shell: a need-centered development approach for optimizing user experience in highly automated vehicles. *Transportation research part F: traffic psychology and behaviour*, *65*, 439–456.

Galileo. (2018). *The path to high gnss accuracy.* Retrieved 2019-11-01, from `https://galileognss.eu/the-path-to-high-gnss-accuracy/`

Gibbs, S. (2017). Google sibling waymo launches fully autonomous ride-hailing service. *The Guardian*, *7*.

Gouy, M., Wiedemann, K., Stevens, A., Brunett, G., & Reed, N. (2014). Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control? *Transportation research part F: traffic psychology and behaviour*, *27*, 264–273.

Guler, S. I., Menendez, M., & Meier, L. (2014). Using connected vehicle technology to improve the efficiency of intersections. *Transportation Research Part C: Emerging Technologies*, *46*, 121–131.

Hamed, M., Easa, S., & Batayneh, R. (1997). Disaggregate gap-acceptance model for unsignalized t-intersections. *Journal of transportation engineering*, *123*(1), 36–42.

Hasan, K. F., Wang, C., Feng, Y., & Tian, Y.-C. (2018). Time synchronization in vehicular ad-hoc networks: A survey on theory and practice. *Vehicular communications*, *14*, 39–51.

Hegeman, G., Hoogendoorn, S., & Brookhuis, K. (2004). Observations overtaking manoeuvres on bi-directional roads. *Advanced OR and AI Methods in Transportation*, *1*, 505–510.

Hennessy, D. A., Howard, S., & Carr, E. (2011). Driver space preference: differences across age, gender and traffic conditions. *Traffic Psychology: an International Perspective. Nova Science Publishers, New York*, 233–249.

Janssen, R., Zwijnenberg, H., Blankers, I., & de Kruijff, J. (2015). Truck platooning. *Driving The Future of Transportation, TNO*.

Lee, J., & Park, B. (2012). Development and evaluation of a cooperative vehicle intersection control algorithm under the connected vehicles environment. *IEEE Transactions on Intelligent Transportation Systems*, *13*(1), 81–90.

Mahmud, S. S., Ferreira, L., Hoque, M. S., & Tavassoli, A. (2018). Overtaking behaviour on rural highways under an heterogeneous traffic environment: Evidence from a developing country. In *Australasian transport research forum (atrf), 40th, 2018, darwin, northern territory, australia.*

Mao, X., Wada, M., & Hashimoto, H. (2003). Nonlinear gps models for position estimate using low-cost gps receiver. In *Proceedings of the 2003 ieee international conference on intelligent transportation systems* (Vol. 1, pp. 637–642).

Marsh, P., & Collett, P. (1987). The car as a weapon. *Et cetera*, *44*(2), 146.

Michael, P. G., Leeming, F. C., & Dwyer, W. O. (2000). Headway on urban streets: observational data and an intervention to decrease tailgating. *Transportation research part F: traffic psychology and behaviour*, *3*(2), 55–64.

Nando Kasteleijn. (2020). *5g komt dit jaar naar nederland, maar kent langzame start.* Retrieved 2020-01-21, from `https://nos.nl/artikel/2316992-5g-komt-dit-jaar-naar-nederland-maar-kent-langzame-start.html`

Nie, L., Guan, J., Lu, C., Zheng, H., & Yin, Z. (2018). Longitudinal speed control of autonomous vehicle based on a self-adaptive pid of radial basis function neural network. *IET Intelligent Transport Systems*, *12*(6), 485–494.

Oostvogels, B. (2018). *Zo oud is de gemiddelde automobilist in nederland.* Retrieved 2019-01-07, from `https://autorai.nl/zo-oud-is-de-gemiddelde-automobilist-in-nederland/`

Park, K. (2018, May). *How 5g reduces data transmission latency.* Retrieved 2019-29-10, from `https://www.edn.com/electronics-blogs/5g-waves/4460644/How-5G-reduces-data-transmission-latency-`

Pereira, M., Beggiato, M., & Petzoldt, T. (2015). Use of adaptive cruise control functions on motorways and urban roads: Changes over time in an on-road study. *Applied ergonomics*, *50*, 105–112.

Sayer, J. R., Mefford, M. L., & Huang, R. W. (2003). The effects of lead-vehicle size on driver following behavior: Is ignorance truly bliss? , 221–225.

Sharon, G., & Stone, P. (2017). A protocol for mixed autonomous and human-operated vehicles at intersections. In *International conference on autonomous agents and multiagent systems* (pp. 151–167).

Shengbo, Q., Keliang, D., & Qingli, L. (2003). An effective gps/dr device and algorithm used in vehicle positioning system. In *Proceedings of the 2003 ieee international conference on intelligent transportation systems* (Vol. 1, pp. 632–636).

Shinar, D., & Schechtman, E. (2002). Headway feedback improves intervehicular distance: A field study. *Human Factors*, *44*(3), 474–481.

Siebert, F. W., Oehl, M., Bersch, F., & Pfister, H.-R. (2017). The exact determination of subjective risk and comfort thresholds in car following. *Transportation research part F: traffic psychology and behaviour*, *46*, 1–13.

Siebert, F. W., Oehl, M., & Pfister, H.-R. (2014). The influence of time headway on subjective driver states in adaptive cruise control. *Transportation research part F: traffic psychology and behaviour*, *25*, 65–73.

Siebert, F. W., & Wallis, F. L. (2019). How speed and visibility influence preferred headway distances in highly automated driving. *Transportation research part F: traffic psychology and behaviour*, *64*, 485–494.

Smith, K., Bjelkemyr, A., Bärgman, J., Johansson, B., & Lindman, M. (2009). *Ivss intersection accidents: Analysis and prevention, final report – volume 1 (main report).*

Suzuki, K., & Yamada, K. (2011). Method for evaluating effectiveness of information presentation in terms of collision avoidance. *International Journal of Intelligent Transportation Systems Research*, *9*(1), 37–46.

Sweco Nederland. (2018). Use case : Traffic orchestration on a hybrid intersection.

SWOV. (2012). Headway times and road safety.

Taieb-Maimon, M., & Shinar, D. (2001). Minimum and comfortable driving headways: Reality versus perception. *Human factors*, *43*(1), 159–172.

Talebpour, A., & Mahmassani, H. S. (2016). Influence of connected and autonomous vehicles on traffic flow stability and throughput. *Transportation Research Part C: Emerging Technologies*, *71*, 143–163.

Tang, T.-Q., He, J., Yang, S.-C., & Shang, H.-Y. (2014). A car-following model accounting for the driver's attribution. *Physica A: Statistical Mechanics and its Applications*, *413*, 583–591.

Tao, M. (2018). *5g promotes the intelligence connected vehicles.* Retrieved 2019-11-02, from `https://www.itu.int/en/ITU-T/Workshops-and-Seminars/20180709/Documents/S3-P4-5G.pdf`

Tennant, C., Howard, S., Franks, B., Bauer, M., & Stares, S. (2016). *Autonomous vehicles-negotiating a place on the road: A study on how drivers feel about interacting with autonomous vehicles on the road (executive summary). retrieved july, 16, 2017.*

Tennessee Coalition for the Safety of Senior Drivers. (2018). Tennessee comprehensive driver license manual.

Ueno, H. (1991). Analysis of accidents in right turns using a fuzzy logic simulation model. *The 13th ESV Proceedings, 1991.*

Vogel, K. (2003). A comparison of headway and time to collision as safety indicators. *Accident analysis & prevention*, *35*(3), 427–433.

Waldrop, M. M. (2015). Autonomous vehicles: No drivers required. *Nature News*, *518*(7537), 20.

WeWantAnyCar. (2016). *Car speedo: How fast are you really going?* Retrieved 2019-11-02, from `https://www.wewantanycar.com/news/car-speedo-how-fast-are-you-going/`

Yang, K., Guler, S. I., & Menendez, M. (2016). Isolated intersection control for various levels of vehicle technology: Conventional, connected, and automated vehicles. *Transportation Research Part C: Emerging Technologies*, *72*, 109–129.

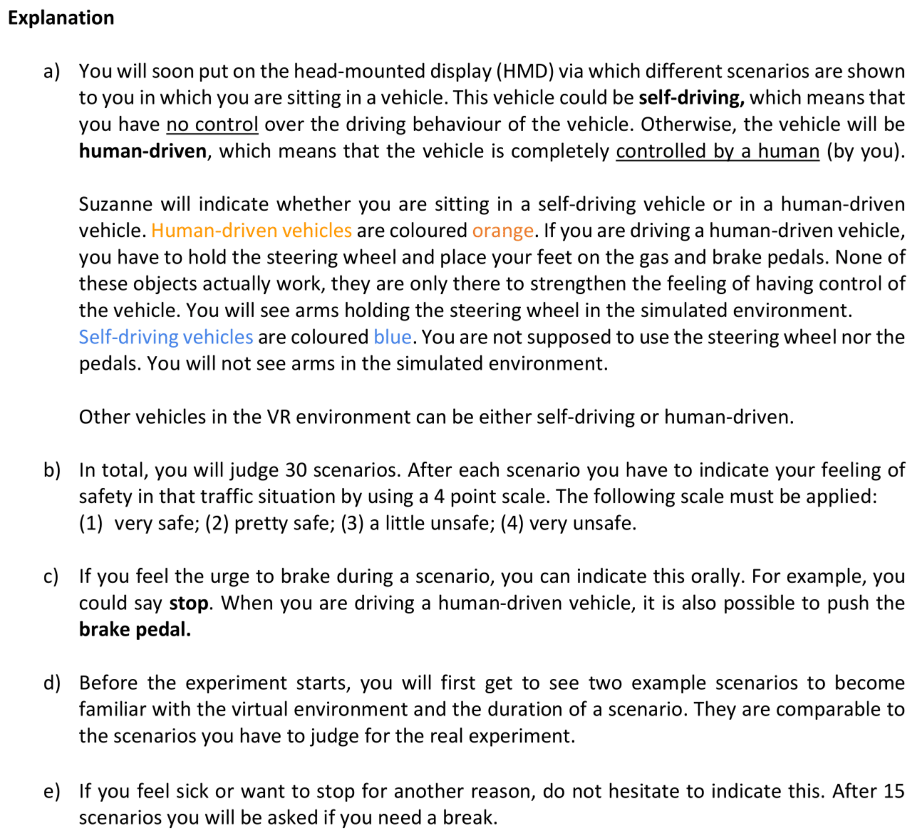
Yang, Q., & Sun, J. (2007). A location method for autonomous vehicle based on integrated gps/ins. In *2007 ieee international conference on vehicular electronics and safety* (pp. 1–4).

Zhang, Q., Ge, Y., Qu, W., Hennessy, D. A., & Zhang, K. (2019). Effects of anger and collision history on driver space preference. *Transportation research part F: traffic psychology and behaviour*, *63*, 108–117.

Zhou, H., Ivan, J. N., Gårder, P. E., & Ravishanker, N. (2017). Gap acceptance for left turns from the major road at unsignalized intersections. *Transport*, *32*(3), 252–261.

B

Instruction Experiment



Explanation

a) You will soon put on the head-mounted display (HMD) via which different scenarios are shown to you in which you are sitting in a vehicle. This vehicle could be **self-driving,** which means that you have no control over the driving behaviour of the vehicle. Otherwise, the vehicle will be **human-driven**, which means that the vehicle is completely controlled by a human (by you).

   Suzanne will indicate whether you are sitting in a self-driving vehicle or in a human-driven vehicle. Human-driven vehicles are coloured orange. If you are driving a human-driven vehicle, you have to hold the steering wheel and place your feet on the gas and brake pedals. None of these objects actually work, they are only there to strengthen the feeling of having control of the vehicle. You will see arms holding the steering wheel in the simulated environment.
   Self-driving vehicles are coloured blue. You are not supposed to use the steering wheel nor the pedals. You will not see arms in the simulated environment.

   Other vehicles in the VR environment can be either self-driving or human-driven.

b) In total, you will judge 30 scenarios. After each scenario you have to indicate your feeling of safety in that traffic situation by using a 4 point scale. The following scale must be applied:
   (1) very safe; (2) pretty safe; (3) a little unsafe; (4) very unsafe.

c) If you feel the urge to brake during a scenario, you can indicate this orally. For example, you could say **stop**. When you are driving a human-driven vehicle, it is also possible to push the **brake pedal.**

d) Before the experiment starts, you will first get to see two example scenarios to become familiar with the virtual environment and the duration of a scenario. They are comparable to the scenarios you have to judge for the real experiment.

e) If you feel sick or want to stop for another reason, do not hesitate to indicate this. After 15 scenarios you will be asked if you need a break.

Figure B.1: Explanation Experiment

C

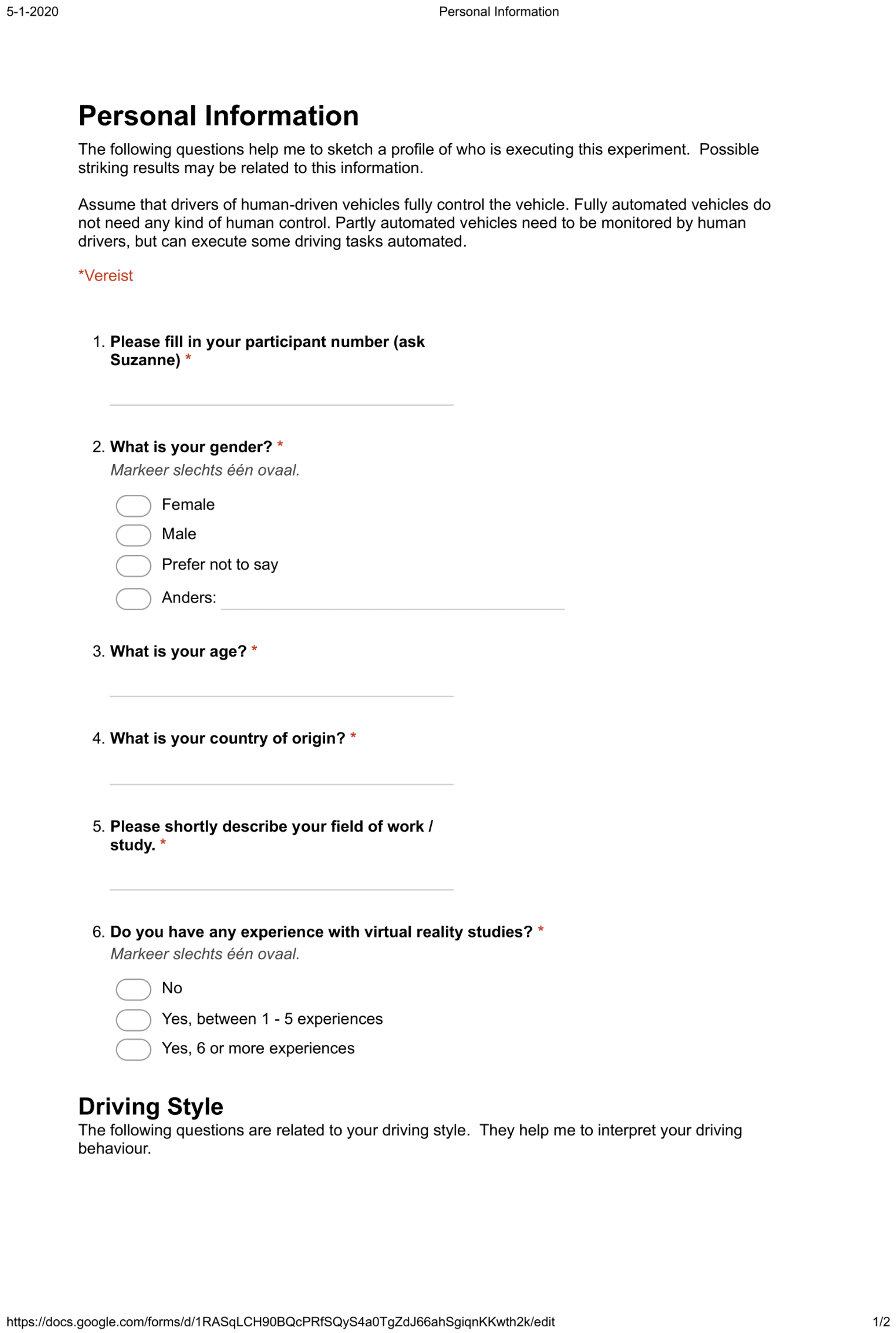
Questionnaires Experiment

C.1. Questionnaire 1: Prior to experiment

See Figures C.1 and C.2.

C.2. Questionnaire 2: After experiment

See Figures C.3 and C.4.



5-1-2020 Personal Information

Personal Information

The following questions help me to sketch a profile of who is executing this experiment. Possible striking results may be related to this information.

Assume that drivers of human-driven vehicles fully control the vehicle. Fully automated vehicles do not need any kind of human control. Partly automated vehicles need to be monitored by human drivers, but can execute some driving tasks automated.

*Vereist

1. **Please fill in your participant number (ask Suzanne)** *

2. **What is your gender?** *
Markeer slechts één ovaal.
○ Female
○ Male
○ Prefer not to say
○ Anders:

3. **What is your age?** *

4. **What is your country of origin?** *

5. **Please shortly describe your field of work / study.** *

6. **Do you have any experience with virtual reality studies?** *
Markeer slechts één ovaal.
○ No
○ Yes, between 1 - 5 experiences
○ Yes, 6 or more experiences

Driving Style

The following questions are related to your driving style. They help me to interpret your driving behaviour.

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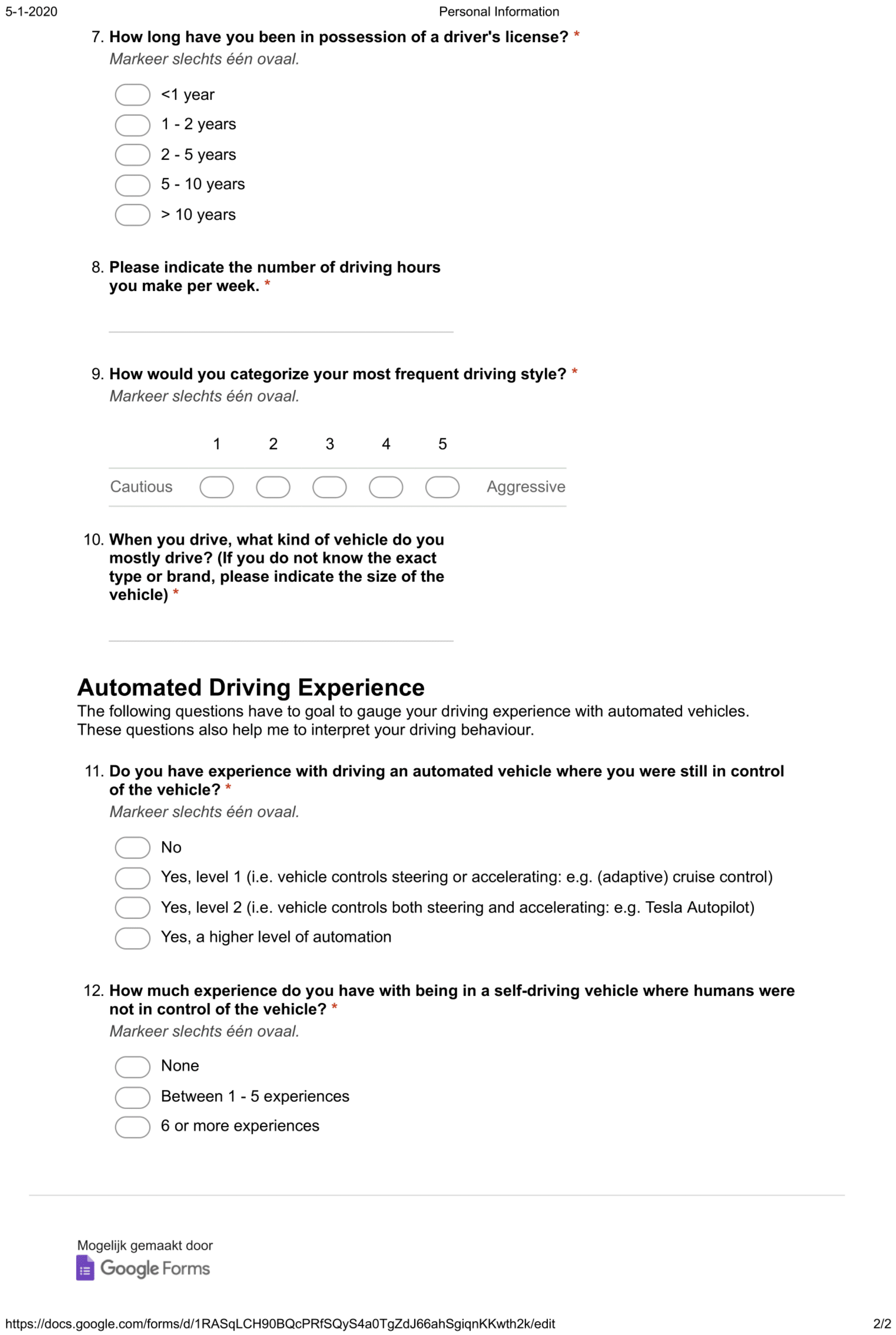
Figure C.1: Questionnaire 1 - Part I



5-1-2020 Personal Information

7. **How long have you been in possession of a driver's license?** *
Markeer slechts één ovaal.

○ <1 year
○ 1 - 2 years
○ 2 - 5 years
○ 5 - 10 years
○ > 10 years

8. **Please indicate the number of driving hours you make per week.** *

____

9. **How would you categorize your most frequent driving style?** *
Markeer slechts één ovaal.

	1	2	3	4	5	
Cautious	○	○	○	○	○	Aggressive

10. **When you drive, what kind of vehicle do you mostly drive? (If you do not know the exact type or brand, please indicate the size of the vehicle)** *

____

Automated Driving Experience

The following questions have to goal to gauge your driving experience with automated vehicles.
These questions also help me to interpret your driving behaviour.

11. **Do you have experience with driving an automated vehicle where you were still in control of the vehicle?** *
Markeer slechts één ovaal.

○ No
○ Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)
○ Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)
○ Yes, a higher level of automation

12. **How much experience do you have with being in a self-driving vehicle where humans were not in control of the vehicle?** *
Markeer slechts één ovaal.

○ None
○ Between 1 - 5 experiences
○ 6 or more experiences

Mogelijk gemaakt door
Google Forms

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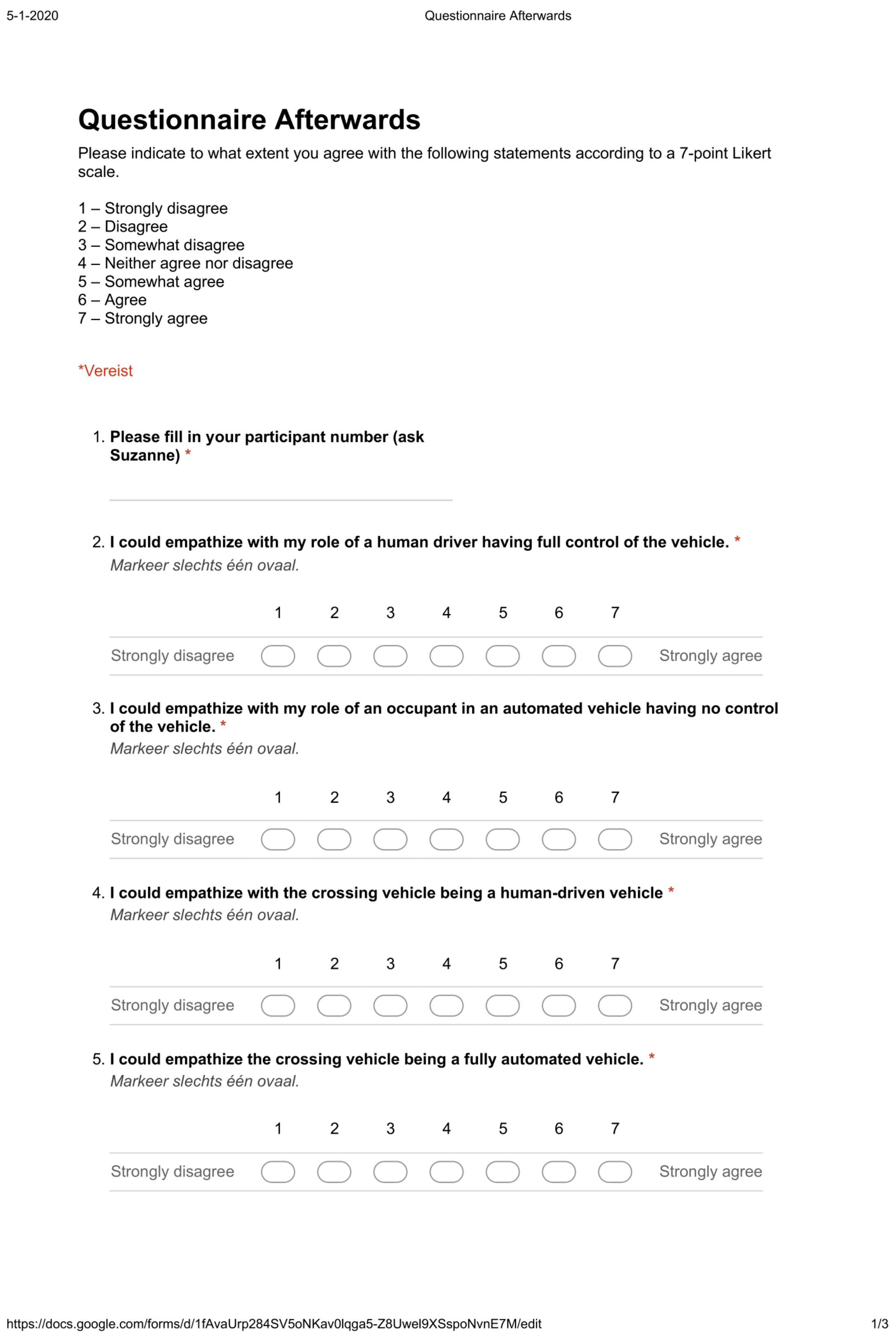
Figure C.2: Questionnaire 1 - Part II



5-1-2020 Questionnaire Afterwards

Questionnaire Afterwards

Please indicate to what extent you agree with the following statements according to a 7-point Likert scale.

1 – Strongly disagree
2 – Disagree
3 – Somewhat disagree
4 – Neither agree nor disagree
5 – Somewhat agree
6 – Agree
7 – Strongly agree

*Vereist

1. **Please fill in your participant number (ask Suzanne)** *

2. **I could empathize with my role of a human driver having full control of the vehicle.** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

3. **I could empathize with my role of an occupant in an automated vehicle having no control of the vehicle.** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

4. **I could empathize with the crossing vehicle being a human-driven vehicle** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

5. **I could empathize the crossing vehicle being a fully automated vehicle.** *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

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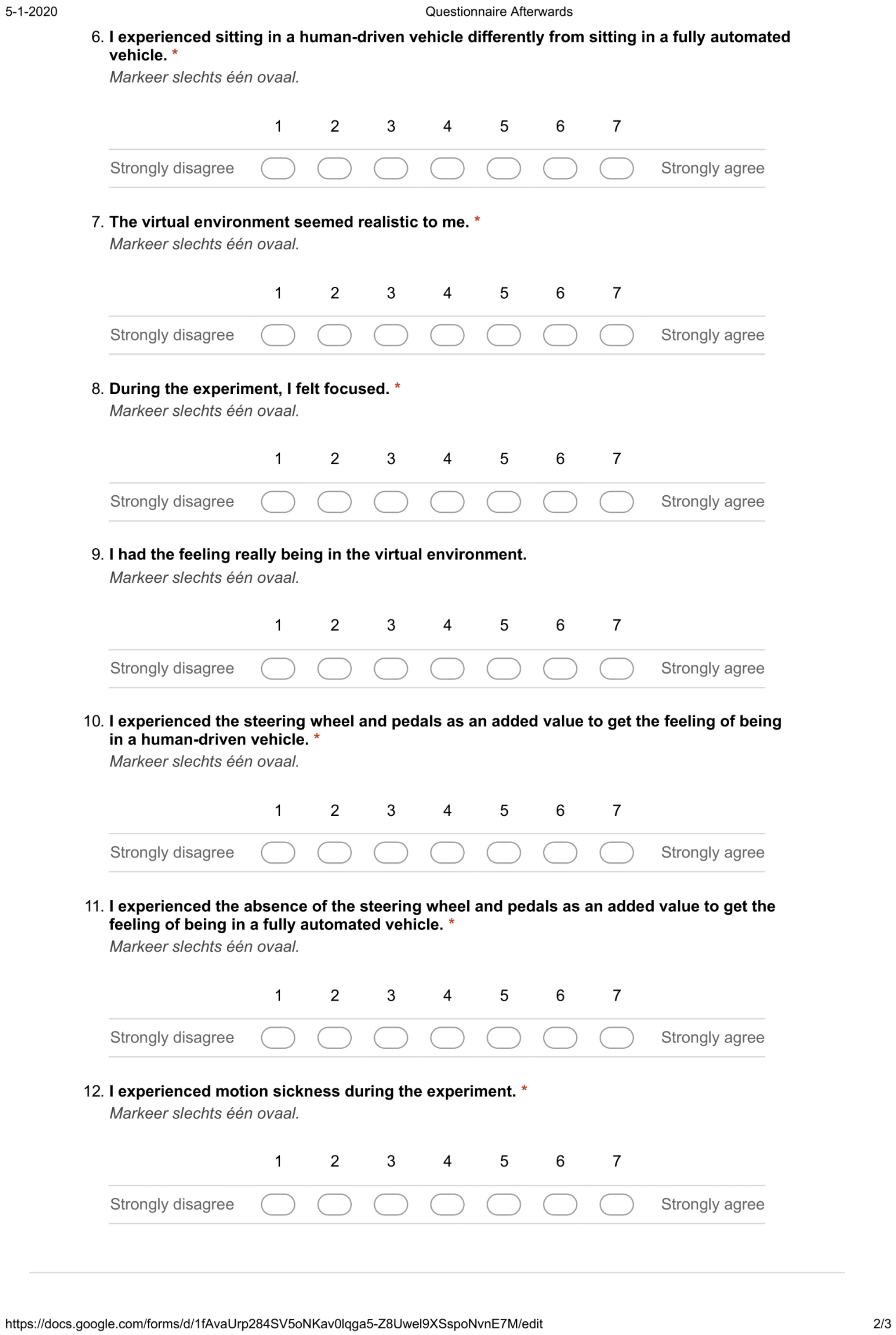
Figure C.3: Questionnaire 2 - Part I



5-1-2020 Questionnaire Afterwards

6. **I experienced sitting in a human-driven vehicle differently from sitting in a fully automated vehicle.** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

7. **The virtual environment seemed realistic to me.** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

8. **During the experiment, I felt focused.** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

9. **I had the feeling really being in the virtual environment.**

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

10. **I experienced the steering wheel and pedals as an added value to get the feeling of being in a human-driven vehicle.** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

11. **I experienced the absence of the steering wheel and pedals as an added value to get the feeling of being in a fully automated vehicle.** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

12. **I experienced motion sickness during the experiment.** *

Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Strongly disagree	○	○	○	○	○	○	○	Strongly agree

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Figure C.4: Questionnaire 2 - Part II

D

Data Collection

Tijdstempel	Please fill in your participant number (ask Suzanne)	What is your gender?	What is your age?	What is your country of origin?	Please shortly describe your field of work / study.	Do you have any experience with virtual reality studies?	How long have you been in possession of a driver's license?	Please indicate the number of driving hours you make per week.	How would you categorize your most frequent driving style?	When you drive, what kind of vehicle do you mostly drive? (If you do not know the exact type or brand, please indicate the size of the vehicle)	Do you have experience with driving an automated vehicle where you were still in control of the vehicle?	How much experience do you have with being in a self-driving vehicle where humans were not in control of the vehicle?
6-12-2019 17:02:30	1	Female	22	The Netherlands	Study TIL	Yes, between 1 - 5 experiences	5 - 10 years	1	2	Mercedes sprinter or BMW 1 serie	No	None
7-12-2019 15:27:11	2	Male	33	Nederland	huisarts	No	> 10 years	5	3	seat leon	No	None
7-12-2019 15:29:30	3	Female	33	Nederland	Maatschappelijk werker	No	> 10 years	1,5	4	Toyota aygo	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
9-12-2019 12:58:19	4	Female	59	nederland	mts weg en waterbouw	Yes, between 1 - 5 experiences	> 10 years	7	3	auto/fiets	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
9-12-2019 9:57:05	5	Male	41	Nederland	Senior ontwerper wegen	Yes, 6 or more experiences	> 10 years	10	3	SUV (Nissan Quasqai)	No	None
9-12-2019 10:16:24	6	Male	23	Nederland	adviseur omgevingsmanagement	No	5 - 10 years	4	4	hatchback - BMW i3	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	6 or more experiences
9-12-2019 9:57:13	7	Male	24	Nederland	Smart Mibility	No	2 - 5 years	6	3	Seat Mii	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	None
9-12-2019 10:52:24	8	Male	27	The Netherlands	GIS / Geography / Mobility	Yes, between 1 - 5 experiences	5 - 10 years	10	4	Kia Picanto / Mitsibushi Colt	No	None
9-12-2019 11:47:33	9	Female	40	Nederland	Product Manager Smart Traffic	Yes, between 1 - 5 experiences	> 10 years	5	2	Mitsubishi Space Star	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
9-12-2019 12:44:08	10	Male	22	Nederland	Civil Engineering/Structural Engineering	No	5 - 10 years	8	3	Fiat 500	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	None
9-12-2019 11:52:35	11	Male	28	Nederland	BIM Modeler in Civil constructions	Yes, between 1 - 5 experiences	> 10 years	10	4	Citroën C1	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
18-12-2019 13:36:1	12	Male	46	Nederland	Verkeersmanagement	No	> 10 years	16	3	SUV	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
9-12-2019 11:58:05	13	Male	53	Nederland	IT / Traffic Policies	No	> 10 years	25	3	Kia e-Niro	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	6 or more experiences
10-12-2019 10:45:1	14	Male	23	Netherlands	Mobilityexpert	No	2 - 5 years	2	2	VW Up or Mazda 7	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	Between 1 - 5 experiences
10-12-2019 10:23:3	15	Male	38	Netherlands	Consultant Smart Mobility	Yes, between 1 - 5 experiences	> 10 years	10	3	Opel Astra	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
9-12-2019 13:59:52	16	Male	42	the Netherlands	Senior Advisor ITS & Mobility	No	> 10 years	10	3	Hyundai Kona electric	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	Between 1 - 5 experiences
9-12-2019 14:47:41	17	Male	24	Nederland	Adviseur Verkeersveiligheid & ontwerp	No	2 - 5 years	6	3	Toyota Yaris	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
9-12-2019 15:15:44	18	Male	25	Netherlands	Student	Yes, 6 or more experiences	5 - 10 years	1	4	Volvo	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
10-12-2019 11:32:3	19	Male	23	Nederland	Engineer	No	2 - 5 years	3	3	Kia picanto	No	Between 1 - 5 experiences
10-12-2019 13:15:3	20	Female	26	nederland	Strategisch consultant mobiliteit	No	2 - 5 years	5	3	mini cooper	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
10-12-2019 14:38:3	21	Male	38	Nederland	Onderzoek naar Niet Gesprongen Explosieven	No	> 10 years	8	4	Volvo V50	No	None
10-12-2019 16:09:2	22	Male	38	Nederland	Software Tester	No	> 10 years	7	2	Peugeot 106	No	None
11-12-2019 9:35:32	23	Male	26	The Netherlands	Product Owner for Smart Traffic	No	2 - 5 years	2	2	Ford Focus Station 1999	No	None
11-12-2019 8:21:35	24	Male	39	Netherlands	Smart Mobility	No	> 10 years	5	3	Renault Megane Estate	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
11-12-2019 8:38:00	25	Male	34	Netherlands	Transport planning	No	> 10 years	4	3	Skoda Fabia station (benzine)	No	None

Tijdstempel	Please fill in your participant number (ask Suzanne)	What is your gender?	What is your age?	What is your country of origin?	Please shortly describe your field of work / study.	Do you have any experience with virtual reality studies?	How long have you been in possession of a driver's license?	Please indicate the number of driving hours you make per week.	How would you categorize your most frequent driving style?	When you drive, what kind of vehicle do you mostly drive? (If you do not know the exact type or brand, please indicate the size of the vehicle)	Do you have experience with driving an automated vehicle where you were still in control of the vehicle?	How much experience do you have with being in a self-driving vehicle where humans were not in control of the vehicle?
11-12-2019 7:14:17	26	Male	31	The Netherlands	Software Developer	No	5 - 10 years	0	2	Renault Master	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
11-12-2019 7:46:28	27	Female	31	Nederland	Verkeerskundige	No	<1 year	1	2	Toyota Avensis	No	None
11-12-2019 10:23:16	28	Female	35	NL	Aerospace engineering (study)/ Asset Management, Project Management (work)	No	> 10 years	15	3	Seat Leon ST	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	Between 1 - 5 experiences
11-12-2019 13:05:08	29	Male	38	Nederland	Verkeersveiligheid en Incident Management	No	> 10 years	10	2	Personenauto	No	None
11-12-2019 13:33:04	30	Male	29	The Netherlands	GIS Adviseur	Yes, between 1 - 5 experiences	> 10 years	4	3	VW T-Roc	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	Between 1 - 5 experiences
11-12-2019 20:20:52	31	Male	24	India	Automated vehicles	Yes, between 1 - 5 experiences	5 - 10 years	5	3	Volkswagen Polo	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	Between 1 - 5 experiences
11-12-2019 20:58:35	32	Female	24	Netherlands	Industrial design engineering	Yes, between 1 - 5 experiences	5 - 10 years	2	3	Volvo v60, audi Q2	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
11-12-2019 20:31:09	33	Female	17	The netherlands	I'm studying applied mathematics and applied physics, I'm in my first year	No	<1 year	0	2	Volkswagen polo (driving lessons), renault megane (at my parents home)	No	None
12-12-2019 14:14:35	34	Female	23	Netherlands	Industrial Design	No	2 - 5 years	1	2	Fiat Panda	No	None
11-12-2019 22:36:45	35	Female	23	Netherlands	Transport & planning	No	2 - 5 years	0,5	2	Family car: Peugeot 508 &peugeot 208	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
11-12-2019 23:03:59	36	Female	24	The Netherlands	Master Biomedical Engineering	No	5 - 10 years	1	2	Volkswagen Polo	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
13-12-2019 9:07:55	37	Female	18	Netherlands	Bouwkunde	No	<1 year	1	3	Audi A6	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
16-12-2019 15:35:59	38	Female	27	Nederland	Mobiliteit	No	5 - 10 years	12	3	Audi A3	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	None
12-12-2019 8:58:23	39	Male	26	Netherlands	Studied Cultural Geography work as a consultant in underground infrastructure	No	2 - 5 years	1	2	Volvo V40 D3	No	None
16-12-2019 13:21:26	40	Female	27	Netherlands	Infrastructure designer	Yes, between 1 - 5 experiences	5 - 10 years	12	4	Hyundai i10	No	None
12-12-2019 8:46:34	41	Male	53	Nederland	Begeleiden van het realiseren van grote infrastructurele werken	No	> 10 years	15	3	Scoda octavia	No	None
16-12-2019 15:06:43	42	Female	23	The Netherlands	Omgevingsmanagement	No	2 - 5 years	10	2	BMW 2 serie	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
12-12-2019 12:06:04	43	Female	24	Netherlands	Student, TIL	Yes, between 1 - 5 experiences	<1 year	0,5	1	Nissan Leaf, electric	No	None
12-12-2019 15:21:06	44	Female	23	netherlands	TIL	No	2 - 5 years	2	2	SUV	No	None
13-12-2019 13:42:50	45	Male	46	Netherlands	assistant professor in traffic engineering	No	> 10 years	2	1	ford focus wagon / station car	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
12-12-2019 18:00:22	46	Female	25	Nederland	MAster Transport Infrastructuur en logistiek	No	5 - 10 years	3	4	Volvo v70 of citroen C1	No	None
13-12-2019 15:59:43	47	Male	32	the Netherlands	Civil engineering student	No	> 10 years	5	2	Toyota Aygo	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
13-12-2019 11:11:26	48	Female	24	Netherlands	Student TIL	No	2 - 5 years	0	3	Station car	No	None
17-12-2019 10:20:53	49	Male	25	Netherlands	TIL	No	5 - 10 years	2	4	BMW X5, Mino Cooper, some rentals like Kia Picanto	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
16-12-2019 10:07:30	50	Male	26	Nederland	Project Coordinator Bodem en ondergrond	Yes, between 1 - 5 experiences	5 - 10 years	14	3	Seat Leon st	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	Between 1 - 5 experiences

Tijdstempel	Please fill in your participant number (ask Suzanne)	What is your gender?	What is your age?	What is your country of origin?	Please shortly describe your field of work / study.	Do you have any experience with virtual reality studies?	How long have you been in possession of a driver's license?	Please indicate the number of driving hours you make per week.	How would you categorize your most frequent driving style?	When you drive, what kind of vehicle do you mostly drive? (If you do not know the exact type or brand, please indicate the size of the vehicle)	Do you have experience with driving an automated vehicle where you were still in control of the vehicle?	How much experience do you have with being in a self-driving vehicle where humans were not in control of the vehicle?
17-12-2019 14:45:0	51	Female	22	The Netherlands	Industrial Design & Engineering, TU Delft	No	2 - 5 years	3	3	Citroen C3, Volkswagen Polo (stadsautos)	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
17-12-2019 13:35:4	52	Female	23	Netherlands	Study TIL	No	2 - 5 years	5	2	Opel Agila or Meriva	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	Between 1 - 5 experiences
13-12-2019 16:20:1	53	Male	25	Netherlands	Traffic engineering	No	5 - 10 years	0	3	Bmw m5	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
16-12-2019 10:54:1	54	Male	38	Poland	ICT Infrastructure	No	> 10 years	8	2	MiniVAN	No	None
13-12-2019 17:09:0	55	Female	24	The Netherlands	Buidling technology/atchitecture and the built environment	No	5 - 10 years	0	2	Jaguar and peugot	No	None
13-12-2019 18:13:5	56	Female	28	NL	Makelaardij	No	5 - 10 years	5	3	Chrysler	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
15-12-2019 18:13:4	57	Female	24	Nederland	Stedenbouwkundig ontwerper	No	5 - 10 years	0	2	Renault twingo	No	None
16-12-2019 11:27:1	58	Male	60	nederland	bodem en ondergrond	No	> 10 years	15	2	toyota avensis station	No	None
16-12-2019 13:31:4	59	Female	25	The Netherlands	Engineer	No	5 - 10 years	1	2	Renault Clio	No	None
16-12-2019 14:28:2	60	Male	41	Netherlands	GIS	Yes, between 1 - 5 experiences	> 10 years	2	2	Kia Picanto	No	None
17-12-2019 10:08:2	61	Female	25	Netherlands	Master student Hydraulic Engineering and Econometrics	No	5 - 10 years	1	2	Toyota Corola Verso	No	None
18-12-2019 8:40:36	62	Male	35	Nederland	Mobiliteit: operationeel verkeersmanagement en tunnelveiligheid	No	> 10 years	14	2	Personenauto (Opel Astra Station)	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	Between 1 - 5 experiences
18-12-2019 8:53:22	63	Male	47	NL	Consultant/projectleader Smart Mobility	No	> 10 years	15	3	KIA Niro Hybrid	No	None
18-12-2019 11:05:4	64	Male	59	Nederland	Mobiliteitsadviseur	Yes, between 1 - 5 experiences	> 10 years	3	3	personenauto: opel astra station, poolauto (BMWi3)	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
18-12-2019 14:04:5	65	Male	29	Nederland	Sweco verkeersmodellen	No	5 - 10 years	1	3	Volvo V70	No	None
18-12-2019 15:05:5	66	Male	32	Netherlands	Transportation	No	> 10 years	4	2	Alfa Romeo Giulietta	No	None
18-12-2019 13:25:4	67	Male	34	Nederland	mobiliteit	No	> 10 years	0,5	2	Nissan Leaf	Yes, level 2 (i.e. vehicle controls both steering and accelerating: e.g. Tesla Autopilot)	None
18-12-2019 13:23:3	68	Male	62	Nl	Planstudie- en Omgevingsmanagement	No	> 10 years	10	3	Suzuki X-cross	No	None
18-12-2019 11:41:0	69	Male	42	nederland	stortplaats adviseur	No	> 10 years	3	3	fiets	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
18-12-2019 13:00:1	70	Male	22	Nederland	Ontwerper	No	2 - 5 years	4	2	Kia Picanto 2018	No	None
18-12-2019 16:58:1	71	Male	49	Netherlands	3D road design	No	> 10 years	12	2	Toyota RAV4	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
19-12-2019 8:15:27	72	Male	25	Netherlands	Road designer	No	5 - 10 years	1	3	Opel Vectra and similar	No	6 or more experiences
18-12-2019 21:20:4	73	Male	57	Nerherlands	Water Management / Climate Change	No	> 10 years	10	3	Station Wagon	No	None
19-12-2019 10:48:4	74	Male	37	Nederland	adviseur/projectleider Bodem	No	> 10 years	11	2	VW Polo	No	None
19-12-2019 11:18:4	75	Male	26	Nederland	Junior adviseur bodem en ondergrond	No	5 - 10 years	2	3	Renault megane	No	Between 1 - 5 experiences
19-12-2019 12:37:2	76	Male	23	NL	Traffic engineer	No	<1 year	2	2	Volvo V40	No	None
19-12-2019 13:23:1	77	Female	29	Nederland	Bodemadviseur	No	5 - 10 years	4	3	Ford Fiesta	No	None
19-12-2019 14:01:2	78	Male	60	nederland	civiele techniek	Yes, between 1 - 5 experiences	> 10 years	12	2	Lexus 200	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
19-12-2019 14:34:0	79	Male	31	Netherlands	Study Human Movement Science	Yes, between 1 - 5 experiences	> 10 years	1	1	Toyota Corolla Hatchback 1999	No	None
19-12-2019 15:07:4	80	Female	27	Nederland	Bodem en ondergrond	No	5 - 10 years	6	2	Compact: hyundai I10	No	None
19-12-2019 15:39:3	81	Male	55	netherlands	bodem en ondergrond	No	> 10 years	15	4	Kia Niro	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None
5-12-2019 14:53:12	82	Male	26	Nederland	Transport & Communications	Yes, between 1 - 5 experiences	5 - 10 years	1	2	Reneault Megane / Citroën C3	Yes, level 1 (i.e. vehicle controls steering or accelerating: e.g. (adaptive) cruise control)	None

Tijdstempel	Please fill in your participant number (ask Suzanne)	What is your gender?	What is your age?	What is your country of origin?	Please shortly describe your field of work / study.	Do you have any experience with virtual reality studies?	How long have you been in possession of a driver's license?	Please indicate the number of driving hours you make per week.	How would you categorize your most frequent driving style?	When you drive, what kind of vehicle do you mostly drive? (If you do not know the exact type or brand, please indicate the size of the vehicle)	Do you have experience with driving an automated vehicle where you were still in control of the vehicle?	How much experience do you have with being in a self-driving vehicle where humans were not in control of the vehicle?
		53						462				
		29										
								5,634146341				

Tijdstempel	Please fill in your participant number (ask Suzanne)	I could empathize with my role of a human driver having full control of the vehicle.	I could empathize with my role of an occupant in an automated vehicle having no control of the vehicle.	I could empathize with the crossing vehicle being a human-driven vehicle	I could empathize the crossing vehicle being a fully automated vehicle.	I experienced sitting in a human-driven vehicle differently from sitting in a fully automated vehicle.	The virtual environment seemed realistic to me.	During the experiment, I felt focused.	I had the feeling really being in the virtual environment.	I experienced the steering wheel and pedals as an added value to get the feeling of being in a human-driven vehicle.	I experienced the absence of the steering wheel and pedals as an added value to get the feeling of being in a fully automated vehicle.	I experienced motion sickness during the experiment.
5-12-2019 15:17:11	0	7	5	5	6	7	4	6	6	7	7	2
6-12-2019 19:21:09	1	6	6	4	4	6	6	6	6	7	7	1
7-12-2019 15:46:55	2	6	2	5	2	6	2	7	5	6	6	1
7-12-2019 16:11:40	3	1	6	3	5	2	2	6	6	3	6	2
9-12-2019 13:36:54	5	5	4	6	5	4	2	5	6	5	4	1
9-12-2019 14:34:58	6	6	6	6	6	2	6	7	7	4	4	2
9-12-2019 15:07:19	17	2	6	4	6	2	4	5	5	2	5	1
9-12-2019 15:43:33	18	7	3	6	6	2	3	3	2	5	2	3
9-12-2019 16:21:15	7	2	5	5	5	7	3	5	3	2	6	1
10-12-2019 10:58:20	8	4	6	3	6	6	4	6	6	7	5	2
10-12-2019 11:25:06	14	5	7	6	6	7	5	7	6	7	1	1
10-12-2019 11:51:01	19	6	6	3	6	5	4	4	4	5	6	1
10-12-2019 13:00:37	9	3	6	4	6	6	2	6	7	5	6	1
10-12-2019 13:38:08	20	6	6	6	6	7	6	7	7	7	7	1
10-12-2019 14:21:34	10	6	4	2	2	6	7	6	6	6	4	1
10-12-2019 15:03:03	21	7	3	6	7	7	5	6	4	7	7	1
10-12-2019 15:55:48	15	6	6	5	5	6	6	6	7	7	7	1
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11-12-2019 9:26:15	4	5	5	5	5	5	5	5	6	4	5	5
11-12-2019 9:53:58	23	5	7	7	5	7	4	1	3	5	7	1
11-12-2019 10:19:49	11	7	7	7	7	6	3	7	5	7	6	1
11-12-2019 10:48:29	28	2	6	2	6	5	2	3	5	6	6	1
11-12-2019 11:21:35	24	7	7	5	5	6	6	7	7	7	7	1
11-12-2019 11:50:24	25	6	2	4	4	4	3	5	7	2	3	1
11-12-2019 12:51:12	26	2	6	3	4	5	3	3	2	3	5	1
11-12-2019 13:24:17	29	6	6	5	5	7	6	6	6	5	4	2
11-12-2019 13:50:26	30	6	6	6	5	5	6	6	6	6	6	1
11-12-2019 14:25:18	27	1	7	4	7	6	3	3	2	2	7	2
11-12-2019 14:51:24	13	6	7	4	5	5	6	7	7	7	5	1
11-12-2019 15:27:50	16	5	6	6	6	3	6	6	4	6	5	2
12-12-2019 9:48:50	31	5	7	5	6	5	6	6	6	7	7	2
12-12-2019 12:56:09	43	5	6	5	6	5	5	5	3	5	5	2
12-12-2019 14:21:18	32	5	7	5	4	2	5	6	6	5	7	1
12-12-2019 15:46:04	33	5	7	4	7	4	6	6	5	5	5	1
12-12-2019 16:51:03	34	3	6	5	6	6	6	7	5	7	7	1
12-12-2019 17:30:04	35	6	7	5	7	6	3	7	5	7	7	1
12-12-2019 18:03:25	46	7	2	7	5	7	6	7	6	5	7	1
13-12-2019 9:29:18	36	5	5	4	4	3	5	6	6	6	6	1
13-12-2019 11:12:08	37	3	7	6	3	7	5	6	2	6	3	2
13-12-2019 14:19:46	45	3	7	4	4	5	6	6	6	5	5	1
15-12-2019 18:38:40	57	7	5	7	3	6	2	6	4	5	6	1
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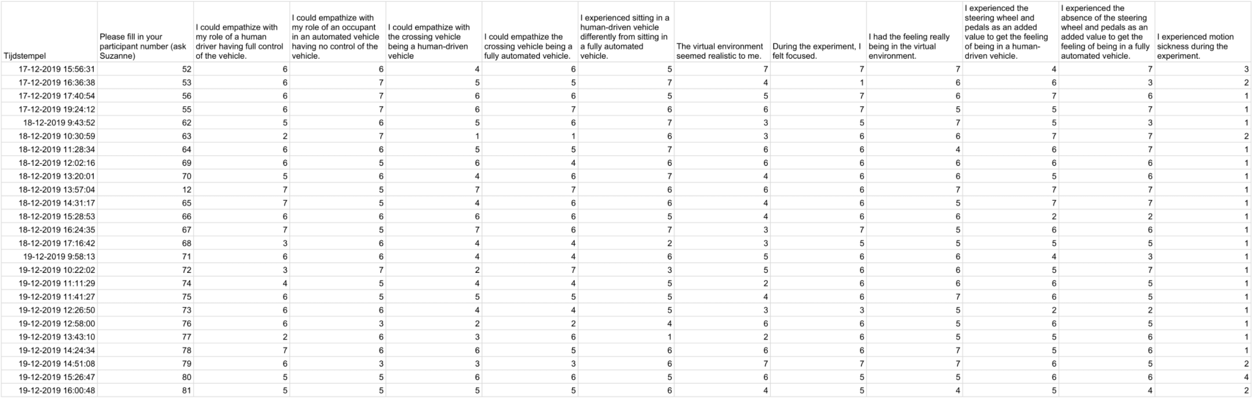
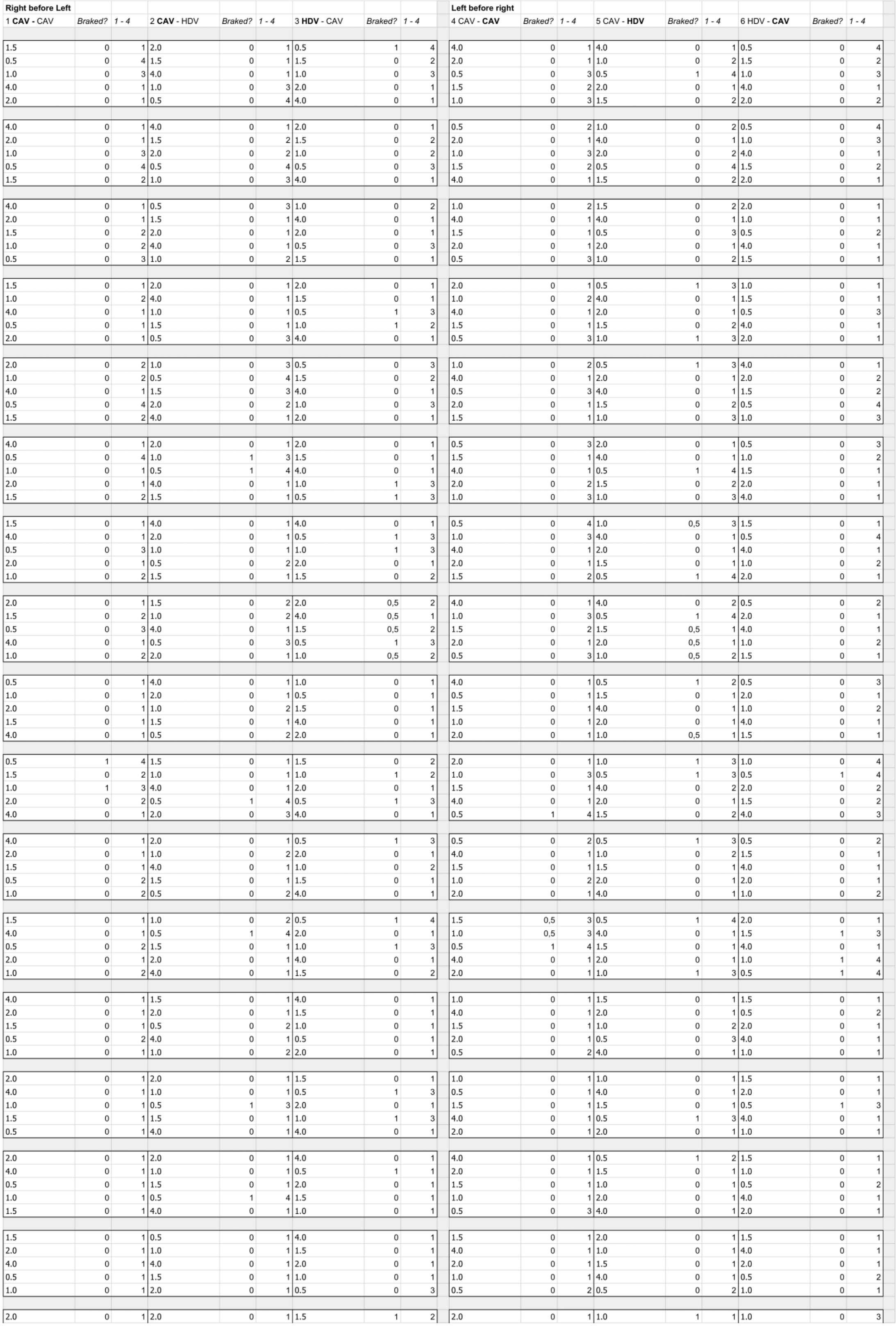
16-12-2019 11:18:09	39	5	6	5	6	6	5	6	5	7	6	1
16-12-2019 11:56:34	58	3	4	4	3	5	6	6	6	3	3	1
16-12-2019 12:26:40	54	6	6	6	6	2	6	6	7	7	6	1
16-12-2019 13:22:00	40	7	7	7	7	7	7	7	7	7	7	1
16-12-2019 13:52:33	59	6	7	7	7	7	6	7	7	7	7	1
16-12-2019 14:20:40	41	6	6	3	3	2	5	7	5	3	6	1
16-12-2019 14:50:37	60	5	6	5	6	6	5	5	6	6	5	3
16-12-2019 15:26:09	42	6	4	6	5	6	3	7	7	5	7	2
16-12-2019 16:00:34	38	4	6	5	6	4	3	2	7	5	6	3
17-12-2019 9:19:52	47	6	3	6	3	5	5	6	6	6	2	1
17-12-2019 10:25:50	61	6	7	3	5	5	4	6	4	6	6	4
17-12-2019 11:05:00	49	7	6	5	5	5	6	6	5	6	6	2
17-12-2019 13:53:24	48	4	6	6	6	6	4	7	6	7	7	3
17-12-2019 14:24:14	44	6	7	6	5	7	6	5	5	6	6	2
17-12-2019 15:09:58	51	6	6	6	6	7	4	6	6	7	5	2

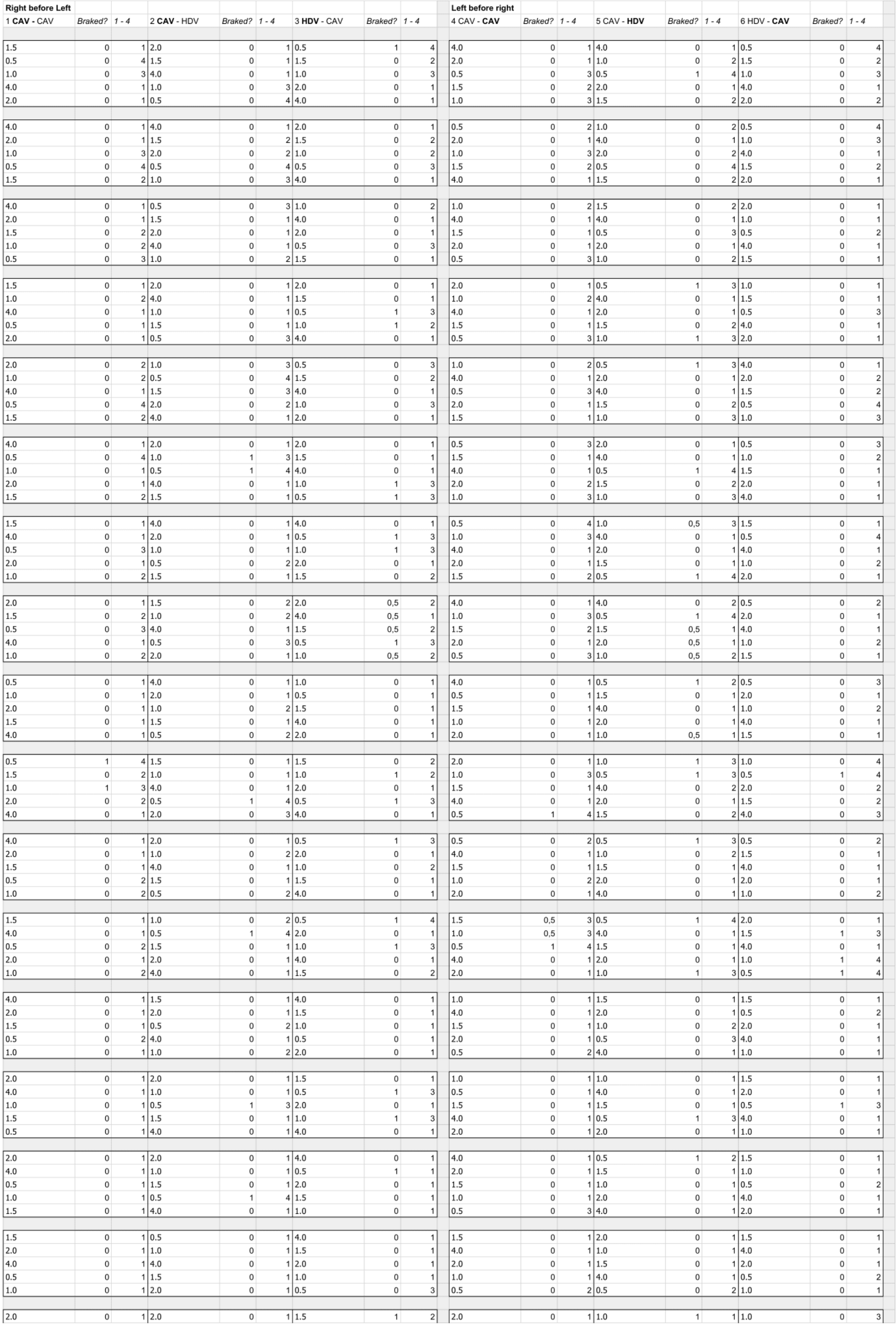


Tijdstempel	Please fill in your participant number (ask Suzanne)	I could empathize with my role of a human driver having full control of the vehicle.	I could empathize with my role of an occupant in an automated vehicle having no control of the vehicle.	I could empathize with the crossing vehicle being a human-driven vehicle	I could empathize the crossing vehicle being a fully automated vehicle.	I experienced sitting in a human-driven vehicle differently from sitting in a fully automated vehicle.	The virtual environment seemed realistic to me.	During the experiment, I felt focused.	I had the feeling really being in the virtual environment.	I experienced the steering wheel and pedals as an added value to get the feeling of being in a human-driven vehicle.	I experienced the absence of the steering wheel and pedals as an added value to get the feeling of being in a fully automated vehicle.	I experienced motion sickness during the experiment.
17-12-2019 15:56:31	52	6	6	4	6	5	7	7	7	4	7	3
17-12-2019 16:36:38	53	6	7	5	5	7	4	1	6	6	3	2
17-12-2019 17:40:54	56	6	7	6	6	5	5	7	6	7	6	1
17-12-2019 19:24:12	55	6	7	6	7	6	6	7	5	5	7	1
18-12-2019 9:43:52	62	5	6	5	6	7	3	5	7	5	3	1
18-12-2019 10:30:59	63	2	7	1	1	6	3	6	6	7	7	2
18-12-2019 11:28:34	64	6	6	5	5	7	6	6	4	6	7	1
18-12-2019 12:02:16	69	6	5	6	4	6	6	6	6	6	6	1
18-12-2019 13:20:01	70	5	6	4	6	7	4	6	6	5	6	1
18-12-2019 13:57:04	12	7	5	7	7	6	6	6	7	7	7	1
18-12-2019 14:31:17	65	7	5	4	6	6	4	6	5	7	7	1
18-12-2019 15:28:53	66	6	6	6	6	5	4	6	6	2	2	1
18-12-2019 16:24:35	67	7	5	7	6	7	3	7	5	6	6	1
18-12-2019 17:16:42	68	3	6	4	4	2	3	5	5	5	5	1
19-12-2019 9:58:13	71	6	6	4	4	6	5	6	6	4	3	1
19-12-2019 10:22:02	72	3	7	2	7	3	5	6	6	5	7	1
19-12-2019 11:11:29	74	4	5	4	4	5	2	6	6	6	5	1
19-12-2019 11:41:27	75	6	5	5	5	5	4	6	7	6	5	1
19-12-2019 12:26:50	73	6	6	4	4	5	3	3	5	2	2	1
19-12-2019 12:58:00	76	6	3	2	2	4	6	6	5	6	5	1
19-12-2019 13:43:10	77	2	6	3	6	1	2	6	5	5	6	1
19-12-2019 14:24:34	78	7	6	6	5	6	6	6	7	5	6	1
19-12-2019 14:51:08	79	6	3	3	3	6	7	7	7	6	5	2
19-12-2019 15:26:47	80	5	5	6	6	5	6	5	5	6	6	4
19-12-2019 16:00:48	81	5	5	5	5	6	4	5	4	5	4	2



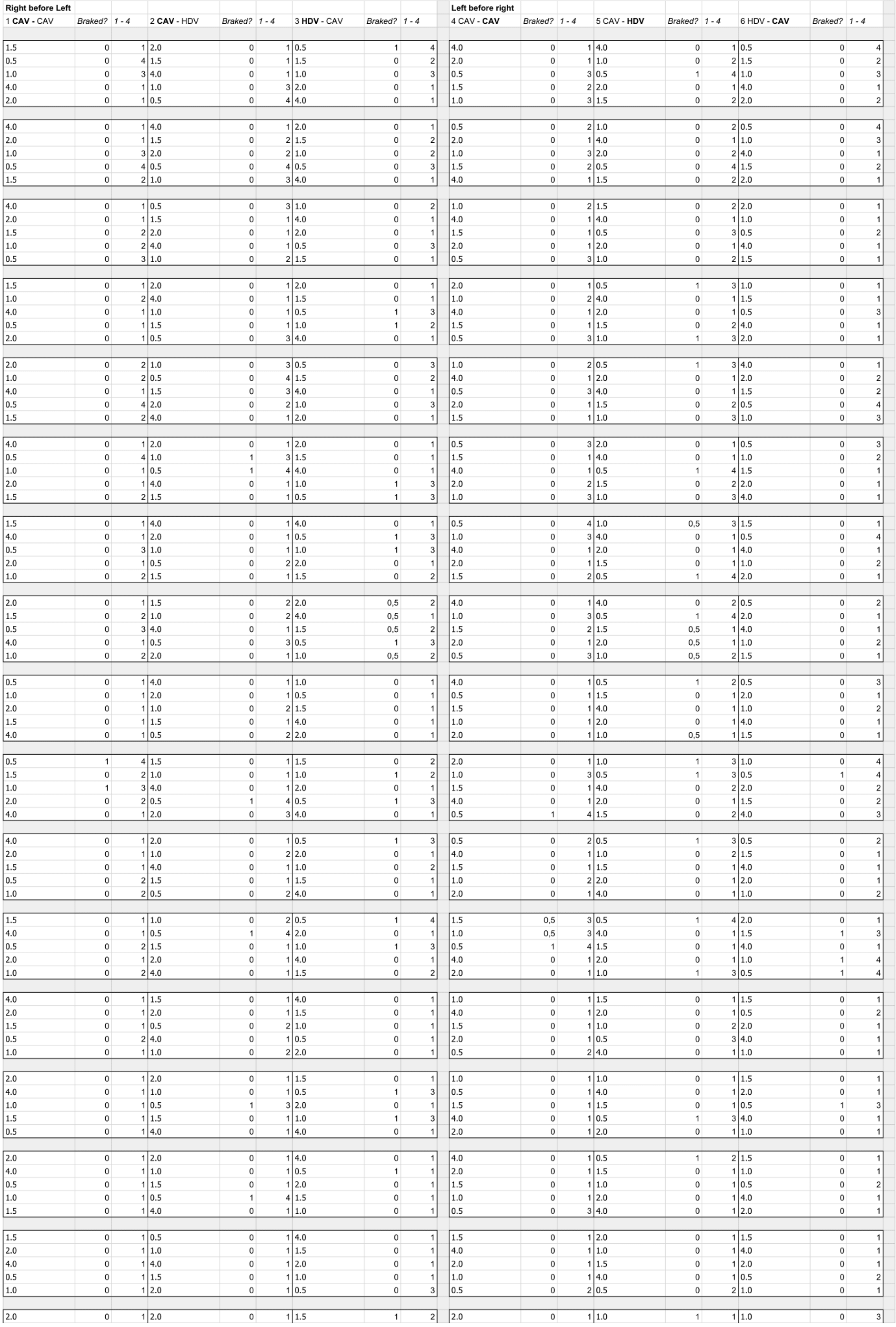
Right before Left									**Left before right**								
1 **CAV -** CAV	*Braked?*	*1 - 4*	2 **CAV** - HDV	*Braked?*	*1 - 4*	3 **HDV** - CAV	*Braked?*	*1 - 4*	4 CAV - **CAV**	*Braked?*	*1 - 4*	5 CAV - **HDV**	*Braked?*	*1 - 4*	6 HDV - **CAV**	*Braked?*	*1 - 4*
1.5	0	1	2.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	0	4
0.5	0	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	0	2	1.5	0	2
1.0	0	3	4.0	0	1	1.0	0	3	0.5	0	3	0.5	1	4	1.0	0	3
4.0	0	1	1.0	0	3	2.0	0	1	1.5	0	2	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	4	4.0	0	1	1.0	0	3	1.5	0	2	2.0	0	2
4.0	0	1	4.0	0	1	2.0	0	1	0.5	0	2	1.0	0	2	0.5	0	4
2.0	0	1	1.5	0	2	1.5	0	2	2.0	0	1	4.0	0	1	1.0	0	3
1.0	0	3	2.0	0	2	1.0	0	2	1.0	0	3	2.0	0	2	4.0	0	1
0.5	0	4	0.5	0	4	0.5	0	3	1.5	0	2	0.5	0	4	1.5	0	2
1.5	0	2	1.0	0	3	4.0	0	1	4.0	0	1	1.5	0	2	2.0	0	1
4.0	0	1	0.5	0	3	1.0	0	2	1.0	0	2	1.5	0	2	2.0	0	1
2.0	0	1	1.5	0	1	4.0	0	1	4.0	0	1	4.0	0	1	1.0	0	1
1.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	0.5	0	3	0.5	0	2
1.0	0	2	4.0	0	1	0.5	0	3	2.0	0	1	2.0	0	1	4.0	0	1
0.5	0	3	1.0	0	2	1.5	0	1	0.5	0	3	1.0	0	2	1.5	0	1
1.5	0	1	2.0	0	1	2.0	0	1	2.0	0	1	0.5	1	3	1.0	0	1
1.0	0	2	4.0	0	1	1.5	0	1	1.0	0	2	4.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	4.0	0	1	2.0	0	1	0.5	0	3
0.5	0	1	1.5	0	1	1.0	1	2	1.5	0	1	1.5	0	2	4.0	0	1
2.0	0	1	0.5	0	3	4.0	0	1	0.5	0	3	1.0	1	3	2.0	0	1
2.0	0	2	1.0	0	3	0.5	0	3	1.0	0	2	0.5	1	3	4.0	0	1
1.0	0	2	0.5	0	4	1.5	0	2	4.0	0	1	2.0	0	1	2.0	0	2
4.0	0	1	1.5	0	3	4.0	0	1	0.5	0	3	4.0	0	1	1.5	0	2
0.5	0	4	2.0	0	2	1.0	0	3	2.0	0	1	1.5	0	2	0.5	0	4
1.5	0	2	4.0	0	1	2.0	0	1	1.5	0	1	1.0	0	3	1.0	0	3
4.0	0	1	2.0	0	1	2.0	0	1	0.5	0	3	2.0	0	1	0.5	0	3
0.5	0	4	1.0	1	3	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	1	4	1.5	0	1
2.0	0	1	4.0	0	1	1.0	1	3	2.0	0	2	1.5	0	2	2.0	0	1
1.5	0	2	1.5	0	1	0.5	1	3	1.0	0	3	1.0	0	3	4.0	0	1
1.5	0	1	4.0	0	1	4.0	0	1	0.5	0	4	1.0	0,5	3	1.5	0	1
4.0	0	1	2.0	0	1	0.5	1	3	1.0	0	3	4.0	0	1	0.5	0	4
0.5	0	3	1.0	0	1	1.0	1	3	4.0	0	1	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	2
1.0	0	2	1.5	0	1	1.5	0	2	1.5	0	2	0.5	1	4	2.0	0	1
2.0	0	1	1.5	0	2	2.0	0,5	2	4.0	0	1	4.0	0	2	0.5	0	2
1.5	0	2	1.0	0	2	4.0	0,5	1	1.0	0	3	0.5	1	4	2.0	0	1
0.5	0	3	4.0	0	1	1.5	0,5	2	1.5	0	2	1.5	0,5	1	4.0	0	1
4.0	0	1	0.5	0	3	0.5	1	3	2.0	0	1	2.0	0,5	1	1.0	0	2
1.0	0	2	2.0	0	1	1.0	0,5	2	0.5	0	3	1.0	0,5	2	1.5	0	1
0.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1	0.5	1	2	0.5	0	3
1.0	0	1	2.0	0	1	0.5	0	1	0.5	0	1	1.5	0	1	2.0	0	1
2.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	1	2.0	0	1	4.0	0	1
4.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.0	0,5	1	1.5	0	1
0.5	1	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	1	3	1.0	0	4
1.5	0	2	1.0	0	1	1.0	1	2	1.0	0	3	0.5	1	3	0.5	1	4
1.0	1	3	4.0	0	1	2.0	0	1	1.5	0	1	4.0	0	2	2.0	0	2
2.0	0	2	0.5	1	4	0.5	1	3	4.0	0	1	2.0	0	1	1.5	0	2
4.0	0	1	2.0	0	3	4.0	0	1	0.5	1	4	1.5	0	2	4.0	0	3
4.0	0	1	2.0	0	1	0.5	1	3	0.5	0	2	0.5	1	3	0.5	0	2
2.0	0	1	1.0	0	2	2.0	0	1	4.0	0	1	1.0	0	2	1.5	0	1
1.5	0	1	4.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1
0.5	0	2	1.5	0	1	1.5	0	1	1.0	0	2	2.0	0	1	2.0	0	1
1.0	0	2	0.5	0	2	4.0	0	1	2.0	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.0	0	2	0.5	1	4	1.5	0,5	3	0.5	1	4	2.0	0	1
4.0	0	1	0.5	1	4	2.0	0	1	1.0	0,5	3	4.0	0	1	1.5	1	3
0.5	0	2	1.5	0	1	1.0	1	3	0.5	1	4	1.5	0	1	4.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	2.0	0	1	1.0	1	4
1.0	0	2	4.0	0	1	1.5	0	2	2.0	0	1	1.0	1	3	0.5	1	4
4.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	1.5	0	1	1.5	0	1
2.0	0	1	2.0	0	1	1.5	0	1	4.0	0	1	2.0	0	1	0.5	0	2
1.5	0	1	0.5	0	2	1.0	0	1	1.5	0	1	1.0	0	2	2.0	0	1
0.5	0	2	4.0	0	1	0.5	0	1	2.0	0	1	0.5	0	3	4.0	0	1
1.0	0	1	1.0	0	2	2.0	0	1	0.5	0	2	4.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	1	1.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	0.5	0	1	4.0	0	1	2.0	0	1
1.0	0	1	0.5	1	3	2.0	0	1	1.5	0	1	1.5	0	1	0.5	1	3
1.5	0	1	1.5	0	1	1.0	1	3	4.0	0	1	0.5	1	3	4.0	0	1
0.5	0	1	4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	0.5	1	2	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	1	2.0	0	1	1.5	0	1	1.0	0	1
0.5	0	1	1.5	0	1	2.0	0	1	1.5	0	1	1.0	0	1	0.5	0	2
1.0	0	1	0.5	1	4	1.5	0	1	1.0	0	1	2.0	0	1	4.0	0	1
1.5	0	1	4.0	0	1	1.0	0	1	0.5	0	3	4.0	0	1	2.0	0	1
1.5	0	1	0.5	0	1	4.0	0	1	1.5	0	1	2.0	0	1	1.5	0	1
2.0	0	1	1.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1
4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.5	0	1	2.0	0	1
0.5	0	1	1.5	0	1	1.0	0	1	1.0	0	1	4.0	0	1	0.5	0	2
1.0	0	1	2.0	0	1	0.5	0	3	0.5	0	2	0.5	0	2	1.0	0	1
2.0	0	1	2.0	0	1	1.5	1	2	2.0	0	1	1.0	1	1	1.0	0	3

Right before Left									**Left before right**								
1 **CAV -** CAV	*Braked?*	*1 - 4*	2 **CAV** - HDV	*Braked?*	*1 - 4*	3 **HDV** - CAV	*Braked?*	*1 - 4*	4 CAV - **CAV**	*Braked?*	*1 - 4*	5 CAV - **HDV**	*Braked?*	*1 - 4*	6 HDV - **CAV**	*Braked?*	*1 - 4*
1.5	0	1	2.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	0	4
0.5	0	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	0	2	1.5	0	2
1.0	0	3	4.0	0	1	1.0	0	3	0.5	0	3	0.5	1	4	1.0	0	3
4.0	0	1	1.0	0	3	2.0	0	1	1.5	0	2	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	4	4.0	0	1	1.0	0	3	1.5	0	2	2.0	0	2
4.0	0	1	4.0	0	1	2.0	0	1	0.5	0	2	1.0	0	2	0.5	0	4
2.0	0	1	1.5	0	2	1.5	0	2	2.0	0	1	4.0	0	1	1.0	0	3
1.0	0	3	2.0	0	2	1.0	0	2	1.0	0	3	2.0	0	2	4.0	0	1
0.5	0	4	0.5	0	4	0.5	0	3	1.5	0	2	0.5	0	4	1.5	0	2
1.5	0	2	1.0	0	3	4.0	0	1	4.0	0	1	1.5	0	2	2.0	0	1
4.0	0	1	0.5	0	3	1.0	0	2	1.0	0	2	1.5	0	2	2.0	0	1
2.0	0	1	1.5	0	1	4.0	0	1	4.0	0	1	4.0	0	1	1.0	0	1
1.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	0.5	0	3	0.5	0	2
1.0	0	2	4.0	0	1	0.5	0	3	2.0	0	1	2.0	0	1	4.0	0	1
0.5	0	3	1.0	0	2	1.5	0	1	0.5	0	3	1.0	0	2	1.5	0	1
1.5	0	1	2.0	0	1	2.0	0	1	2.0	0	1	0.5	1	3	1.0	0	1
1.0	0	2	4.0	0	1	1.5	0	1	1.0	0	2	4.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	4.0	0	1	2.0	0	1	0.5	0	3
0.5	0	1	1.5	0	1	1.0	1	2	1.5	0	1	1.5	0	2	4.0	0	1
2.0	0	1	0.5	0	3	4.0	0	1	0.5	0	3	1.0	1	3	2.0	0	1
2.0	0	2	1.0	0	3	0.5	0	3	1.0	0	2	0.5	1	3	4.0	0	1
1.0	0	2	0.5	0	4	1.5	0	2	4.0	0	1	2.0	0	1	2.0	0	2
4.0	0	1	1.5	0	3	4.0	0	1	0.5	0	3	4.0	0	1	1.5	0	2
0.5	0	4	2.0	0	2	1.0	0	3	2.0	0	1	1.5	0	2	0.5	0	4
1.5	0	2	4.0	0	1	2.0	0	1	1.5	0	1	1.0	0	3	1.0	0	3
4.0	0	1	2.0	0	1	2.0	0	1	0.5	0	3	2.0	0	1	0.5	0	3
0.5	0	4	1.0	1	3	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	1	4	1.5	0	1
2.0	0	1	4.0	0	1	1.0	1	3	2.0	0	2	1.5	0	2	2.0	0	1
1.5	0	2	1.5	0	1	0.5	1	3	1.0	0	3	1.0	0	3	4.0	0	1
1.5	0	1	4.0	0	1	4.0	0	1	0.5	0	4	1.0	0,5	3	1.5	0	1
4.0	0	1	2.0	0	1	0.5	1	3	1.0	0	3	4.0	0	1	0.5	0	4
0.5	0	3	1.0	0	1	1.0	1	3	4.0	0	1	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	2
1.0	0	2	1.5	0	1	1.5	0	2	1.5	0	2	0.5	1	4	2.0	0	1
2.0	0	1	1.5	0	2	2.0	0,5	2	4.0	0	1	4.0	0	2	0.5	0	2
1.5	0	2	1.0	0	2	4.0	0,5	1	1.0	0	3	0.5	1	4	2.0	0	1
0.5	0	3	4.0	0	1	1.5	0,5	2	1.5	0	2	1.5	0,5	1	4.0	0	1
4.0	0	1	0.5	0	3	0.5	1	3	2.0	0	1	2.0	0,5	1	1.0	0	2
1.0	0	2	2.0	0	1	1.0	0,5	2	0.5	0	3	1.0	0,5	2	1.5	0	1
0.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1	0.5	1	2	0.5	0	3
1.0	0	1	2.0	0	1	0.5	0	1	0.5	0	1	1.5	0	1	2.0	0	1
2.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	1	2.0	0	1	4.0	0	1
4.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.0	0,5	1	1.5	0	1
0.5	1	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	1	3	1.0	0	4
1.5	0	2	1.0	0	1	1.0	1	2	1.0	0	3	0.5	1	3	0.5	1	4
1.0	1	3	4.0	0	1	2.0	0	1	1.5	0	1	4.0	0	2	2.0	0	2
2.0	0	2	0.5	1	4	0.5	1	3	4.0	0	1	2.0	0	1	1.5	0	2
4.0	0	1	2.0	0	3	4.0	0	1	0.5	1	4	1.5	0	2	4.0	0	3
4.0	0	1	2.0	0	1	0.5	1	3	0.5	0	2	0.5	1	3	0.5	0	2
2.0	0	1	1.0	0	2	2.0	0	1	4.0	0	1	1.0	0	2	1.5	0	1
1.5	0	1	4.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1
0.5	0	2	1.5	0	1	1.5	0	1	1.0	0	2	2.0	0	1	2.0	0	1
1.0	0	2	0.5	0	2	4.0	0	1	2.0	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.0	0	2	0.5	1	4	1.5	0,5	3	0.5	1	4	2.0	0	1
4.0	0	1	0.5	1	4	2.0	0	1	1.0	0,5	3	4.0	0	1	1.5	1	3
0.5	0	2	1.5	0	1	1.0	1	3	0.5	1	4	1.5	0	1	4.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	2.0	0	1	1.0	1	4
1.0	0	2	4.0	0	1	1.5	0	2	2.0	0	1	1.0	1	3	0.5	1	4
4.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	1.5	0	1	1.5	0	1
2.0	0	1	2.0	0	1	1.5	0	1	4.0	0	1	2.0	0	1	0.5	0	2
1.5	0	1	0.5	0	2	1.0	0	1	1.5	0	1	1.0	0	2	2.0	0	1
0.5	0	2	4.0	0	1	0.5	0	1	2.0	0	1	0.5	0	3	4.0	0	1
1.0	0	1	1.0	0	2	2.0	0	1	0.5	0	2	4.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	1	1.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	0.5	0	1	4.0	0	1	2.0	0	1
1.0	0	1	0.5	1	3	2.0	0	1	1.5	0	1	1.5	0	1	0.5	1	3
1.5	0	1	1.5	0	1	1.0	1	3	4.0	0	1	0.5	1	3	4.0	0	1
0.5	0	1	4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	0.5	1	2	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	1	2.0	0	1	1.5	0	1	1.0	0	1
0.5	0	1	1.5	0	1	2.0	0	1	1.5	0	1	1.0	0	1	0.5	0	2
1.0	0	1	0.5	1	4	1.5	0	1	1.0	0	1	2.0	0	1	4.0	0	1
1.5	0	1	4.0	0	1	1.0	0	1	0.5	0	3	4.0	0	1	2.0	0	1
1.5	0	1	0.5	0	1	4.0	0	1	1.5	0	1	2.0	0	1	1.5	0	1
2.0	0	1	1.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1
4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.5	0	1	2.0	0	1
0.5	0	1	1.5	0	1	1.0	0	1	1.0	0	1	4.0	0	1	0.5	0	2
1.0	0	1	2.0	0	1	0.5	0	3	0.5	0	2	0.5	0	2	1.0	0	1
2.0	0	1	2.0	0	1	1.5	1	2	2.0	0	1	1.0	1	1	1.0	0	3



Right before Left									**Left before right**								
1 **CAV -** CAV	*Braked?*	*1 - 4*	2 **CAV** - HDV	*Braked?*	*1 - 4*	3 **HDV** - CAV	*Braked?*	*1 - 4*	4 CAV - **CAV**	*Braked?*	*1 - 4*	5 CAV - **HDV**	*Braked?*	*1 - 4*	6 HDV - **CAV**	*Braked?*	*1 - 4*
1.5	0	1	2.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	0	4
0.5	0	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	0	2	1.5	0	2
1.0	0	3	4.0	0	1	1.0	0	3	0.5	0	3	0.5	1	4	1.0	0	3
4.0	0	1	1.0	0	3	2.0	0	1	1.5	0	2	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	4	4.0	0	1	1.0	0	3	1.5	0	2	2.0	0	2
4.0	0	1	4.0	0	1	2.0	0	1	0.5	0	2	1.0	0	2	0.5	0	4
2.0	0	1	1.5	0	2	1.5	0	2	2.0	0	1	4.0	0	1	1.0	0	3
1.0	0	3	2.0	0	2	1.0	0	2	1.0	0	3	2.0	0	2	4.0	0	1
0.5	0	4	0.5	0	4	0.5	0	3	1.5	0	2	0.5	0	4	1.5	0	2
1.5	0	2	1.0	0	3	4.0	0	1	4.0	0	1	1.5	0	2	2.0	0	1
4.0	0	1	0.5	0	3	1.0	0	2	1.0	0	2	1.5	0	2	2.0	0	1
2.0	0	1	1.5	0	1	4.0	0	1	4.0	0	1	4.0	0	1	1.0	0	1
1.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	0.5	0	3	0.5	0	2
1.0	0	2	4.0	0	1	0.5	0	3	2.0	0	1	2.0	0	1	4.0	0	1
0.5	0	3	1.0	0	2	1.5	0	1	0.5	0	3	1.0	0	2	1.5	0	1
1.5	0	1	2.0	0	1	2.0	0	1	2.0	0	1	0.5	1	3	1.0	0	1
1.0	0	2	4.0	0	1	1.5	0	1	1.0	0	2	4.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	4.0	0	1	2.0	0	1	0.5	0	3
0.5	0	1	1.5	0	1	1.0	1	2	1.5	0	1	1.5	0	2	4.0	0	1
2.0	0	1	0.5	0	3	4.0	0	1	0.5	0	3	1.0	1	3	2.0	0	1
2.0	0	2	1.0	0	3	0.5	0	3	1.0	0	2	0.5	1	3	4.0	0	1
1.0	0	2	0.5	0	4	1.5	0	2	4.0	0	1	2.0	0	1	2.0	0	2
4.0	0	1	1.5	0	3	4.0	0	1	0.5	0	3	4.0	0	1	1.5	0	2
0.5	0	4	2.0	0	2	1.0	0	3	2.0	0	1	1.5	0	2	0.5	0	4
1.5	0	2	4.0	0	1	2.0	0	1	1.5	0	1	1.0	0	3	1.0	0	3
4.0	0	1	2.0	0	1	2.0	0	1	0.5	0	3	2.0	0	1	0.5	0	3
0.5	0	4	1.0	1	3	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	1	4	1.5	0	1
2.0	0	1	4.0	0	1	1.0	1	3	2.0	0	2	1.5	0	2	2.0	0	1
1.5	0	2	1.5	0	1	0.5	1	3	1.0	0	3	1.0	0	3	4.0	0	1
1.5	0	1	4.0	0	1	4.0	0	1	0.5	0	4	1.0	0,5	3	1.5	0	1
4.0	0	1	2.0	0	1	0.5	1	3	1.0	0	3	4.0	0	1	0.5	0	4
0.5	0	3	1.0	0	1	1.0	1	3	4.0	0	1	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	2
1.0	0	2	1.5	0	1	1.5	0	2	1.5	0	2	0.5	1	4	2.0	0	1
2.0	0	1	1.5	0	2	2.0	0,5	2	4.0	0	1	4.0	0	2	0.5	0	2
1.5	0	2	1.0	0	2	4.0	0,5	1	1.0	0	3	0.5	1	4	2.0	0	1
0.5	0	3	4.0	0	1	1.5	0,5	2	1.5	0	2	1.5	0,5	1	4.0	0	1
4.0	0	1	0.5	0	3	0.5	1	3	2.0	0	1	2.0	0,5	1	1.0	0	2
1.0	0	2	2.0	0	1	1.0	0,5	2	0.5	0	3	1.0	0,5	2	1.5	0	1
0.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1	0.5	1	2	0.5	0	3
1.0	0	1	2.0	0	1	0.5	0	1	0.5	0	1	1.5	0	1	2.0	0	1
2.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	1	2.0	0	1	4.0	0	1
4.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.0	0,5	1	1.5	0	1
0.5	1	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	1	3	1.0	0	4
1.5	0	2	1.0	0	1	1.0	1	2	1.0	0	3	0.5	1	3	0.5	1	4
1.0	1	3	4.0	0	1	2.0	0	1	1.5	0	1	4.0	0	2	2.0	0	2
2.0	0	2	0.5	1	4	0.5	1	3	4.0	0	1	2.0	0	1	1.5	0	2
4.0	0	1	2.0	0	3	4.0	0	1	0.5	1	4	1.5	0	2	4.0	0	3
4.0	0	1	2.0	0	1	0.5	1	3	0.5	0	2	0.5	1	3	0.5	0	2
2.0	0	1	1.0	0	2	2.0	0	1	4.0	0	1	1.0	0	2	1.5	0	1
1.5	0	1	4.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1
0.5	0	2	1.5	0	1	1.5	0	1	1.0	0	2	2.0	0	1	2.0	0	1
1.0	0	2	0.5	0	2	4.0	0	1	2.0	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.0	0	2	0.5	1	4	1.5	0,5	3	0.5	1	4	2.0	0	1
4.0	0	1	0.5	1	4	2.0	0	1	1.0	0,5	3	4.0	0	1	1.5	1	3
0.5	0	2	1.5	0	1	1.0	1	3	0.5	1	4	1.5	0	1	4.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	2.0	0	1	1.0	1	4
1.0	0	2	4.0	0	1	1.5	0	2	2.0	0	1	1.0	1	3	0.5	1	4
4.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	1.5	0	1	1.5	0	1
2.0	0	1	2.0	0	1	1.5	0	1	4.0	0	1	2.0	0	1	0.5	0	2
1.5	0	1	0.5	0	2	1.0	0	1	1.5	0	1	1.0	0	2	2.0	0	1
0.5	0	2	4.0	0	1	0.5	0	1	2.0	0	1	0.5	0	3	4.0	0	1
1.0	0	1	1.0	0	2	2.0	0	1	0.5	0	2	4.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	1	1.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	0.5	0	1	4.0	0	1	2.0	0	1
1.0	0	1	0.5	1	3	2.0	0	1	1.5	0	1	1.5	0	1	0.5	1	3
1.5	0	1	1.5	0	1	1.0	1	3	4.0	0	1	0.5	1	3	4.0	0	1
0.5	0	1	4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	0.5	1	2	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	1	2.0	0	1	1.5	0	1	1.0	0	1
0.5	0	1	1.5	0	1	2.0	0	1	1.5	0	1	1.0	0	1	0.5	0	2
1.0	0	1	0.5	1	4	1.5	0	1	1.0	0	1	2.0	0	1	4.0	0	1
1.5	0	1	4.0	0	1	1.0	0	1	0.5	0	3	4.0	0	1	2.0	0	1
1.5	0	1	0.5	0	1	4.0	0	1	1.5	0	1	2.0	0	1	1.5	0	1
2.0	0	1	1.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1
4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.5	0	1	2.0	0	1
0.5	0	1	1.5	0	1	1.0	0	1	1.0	0	1	4.0	0	1	0.5	0	2
1.0	0	1	2.0	0	1	0.5	0	3	0.5	0	2	0.5	0	2	1.0	0	1
2.0	0	1	2.0	0	1	1.5	1	2	2.0	0	1	1.0	1	1	1.0	0	3

Right before Left									**Left before right**								
1 **CAV -** CAV	*Braked?*	*1 - 4*	2 **CAV** - HDV	*Braked?*	*1 - 4*	3 **HDV** - CAV	*Braked?*	*1 - 4*	4 CAV - **CAV**	*Braked?*	*1 - 4*	5 CAV - **HDV**	*Braked?*	*1 - 4*	6 HDV - **CAV**	*Braked?*	*1 - 4*
1.5	0	1	2.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	0	4
0.5	0	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	0	2	1.5	0	2
1.0	0	3	4.0	0	1	1.0	0	3	0.5	0	3	0.5	1	4	1.0	0	3
4.0	0	1	1.0	0	3	2.0	0	1	1.5	0	2	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	4	4.0	0	1	1.0	0	3	1.5	0	2	2.0	0	2
4.0	0	1	4.0	0	1	2.0	0	1	0.5	0	2	1.0	0	2	0.5	0	4
2.0	0	1	1.5	0	2	1.5	0	2	2.0	0	1	4.0	0	1	1.0	0	3
1.0	0	3	2.0	0	2	1.0	0	2	1.0	0	3	2.0	0	2	4.0	0	1
0.5	0	4	0.5	0	4	0.5	0	3	1.5	0	2	0.5	0	4	1.5	0	2
1.5	0	2	1.0	0	3	4.0	0	1	4.0	0	1	1.5	0	2	2.0	0	1
4.0	0	1	0.5	0	3	1.0	0	2	1.0	0	2	1.5	0	2	2.0	0	1
2.0	0	1	1.5	0	1	4.0	0	1	4.0	0	1	4.0	0	1	1.0	0	1
1.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	0.5	0	3	0.5	0	2
1.0	0	2	4.0	0	1	0.5	0	3	2.0	0	1	2.0	0	1	4.0	0	1
0.5	0	3	1.0	0	2	1.5	0	1	0.5	0	3	1.0	0	2	1.5	0	1
1.5	0	1	2.0	0	1	2.0	0	1	2.0	0	1	0.5	1	3	1.0	0	1
1.0	0	2	4.0	0	1	1.5	0	1	1.0	0	2	4.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	4.0	0	1	2.0	0	1	0.5	0	3
0.5	0	1	1.5	0	1	1.0	1	2	1.5	0	1	1.5	0	2	4.0	0	1
2.0	0	1	0.5	0	3	4.0	0	1	0.5	0	3	1.0	1	3	2.0	0	1
2.0	0	2	1.0	0	3	0.5	0	3	1.0	0	2	0.5	1	3	4.0	0	1
1.0	0	2	0.5	0	4	1.5	0	2	4.0	0	1	2.0	0	1	2.0	0	2
4.0	0	1	1.5	0	3	4.0	0	1	0.5	0	3	4.0	0	1	1.5	0	2
0.5	0	4	2.0	0	2	1.0	0	3	2.0	0	1	1.5	0	2	0.5	0	4
1.5	0	2	4.0	0	1	2.0	0	1	1.5	0	1	1.0	0	3	1.0	0	3
4.0	0	1	2.0	0	1	2.0	0	1	0.5	0	3	2.0	0	1	0.5	0	3
0.5	0	4	1.0	1	3	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	1	4	1.5	0	1
2.0	0	1	4.0	0	1	1.0	1	3	2.0	0	2	1.5	0	2	2.0	0	1
1.5	0	2	1.5	0	1	0.5	1	3	1.0	0	3	1.0	0	3	4.0	0	1
1.5	0	1	4.0	0	1	4.0	0	1	0.5	0	4	1.0	0,5	3	1.5	0	1
4.0	0	1	2.0	0	1	0.5	1	3	1.0	0	3	4.0	0	1	0.5	0	4
0.5	0	3	1.0	0	1	1.0	1	3	4.0	0	1	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	2
1.0	0	2	1.5	0	1	1.5	0	2	1.5	0	2	0.5	1	4	2.0	0	1
2.0	0	1	1.5	0	2	2.0	0,5	2	4.0	0	1	4.0	0	2	0.5	0	2
1.5	0	2	1.0	0	2	4.0	0,5	1	1.0	0	3	0.5	1	4	2.0	0	1
0.5	0	3	4.0	0	1	1.5	0,5	2	1.5	0	2	1.5	0,5	1	4.0	0	1
4.0	0	1	0.5	0	3	0.5	1	3	2.0	0	1	2.0	0,5	1	1.0	0	2
1.0	0	2	2.0	0	1	1.0	0,5	2	0.5	0	3	1.0	0,5	2	1.5	0	1
0.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1	0.5	1	2	0.5	0	3
1.0	0	1	2.0	0	1	0.5	0	1	0.5	0	1	1.5	0	1	2.0	0	1
2.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	1	2.0	0	1	4.0	0	1
4.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.0	0,5	1	1.5	0	1
0.5	1	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	1	3	1.0	0	4
1.5	0	2	1.0	0	1	1.0	1	2	1.0	0	3	0.5	1	3	0.5	1	4
1.0	1	3	4.0	0	1	2.0	0	1	1.5	0	1	4.0	0	2	2.0	0	2
2.0	0	2	0.5	1	4	0.5	1	3	4.0	0	1	2.0	0	1	1.5	0	2
4.0	0	1	2.0	0	3	4.0	0	1	0.5	1	4	1.5	0	2	4.0	0	3
4.0	0	1	2.0	0	1	0.5	1	3	0.5	0	2	0.5	1	3	0.5	0	2
2.0	0	1	1.0	0	2	2.0	0	1	4.0	0	1	1.0	0	2	1.5	0	1
1.5	0	1	4.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1
0.5	0	2	1.5	0	1	1.5	0	1	1.0	0	2	2.0	0	1	2.0	0	1
1.0	0	2	0.5	0	2	4.0	0	1	2.0	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.0	0	2	0.5	1	4	1.5	0,5	3	0.5	1	4	2.0	0	1
4.0	0	1	0.5	1	4	2.0	0	1	1.0	0,5	3	4.0	0	1	1.5	1	3
0.5	0	2	1.5	0	1	1.0	1	3	0.5	1	4	1.5	0	1	4.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	2.0	0	1	1.0	1	4
1.0	0	2	4.0	0	1	1.5	0	2	2.0	0	1	1.0	1	3	0.5	1	4
4.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	1.5	0	1	1.5	0	1
2.0	0	1	2.0	0	1	1.5	0	1	4.0	0	1	2.0	0	1	0.5	0	2
1.5	0	1	0.5	0	2	1.0	0	1	1.5	0	1	1.0	0	2	2.0	0	1
0.5	0	2	4.0	0	1	0.5	0	1	2.0	0	1	0.5	0	3	4.0	0	1
1.0	0	1	1.0	0	2	2.0	0	1	0.5	0	2	4.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	1	1.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	0.5	0	1	4.0	0	1	2.0	0	1
1.0	0	1	0.5	1	3	2.0	0	1	1.5	0	1	1.5	0	1	0.5	1	3
1.5	0	1	1.5	0	1	1.0	1	3	4.0	0	1	0.5	1	3	4.0	0	1
0.5	0	1	4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	0.5	1	2	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	1	2.0	0	1	1.5	0	1	1.0	0	1
0.5	0	1	1.5	0	1	2.0	0	1	1.5	0	1	1.0	0	1	0.5	0	2
1.0	0	1	0.5	1	4	1.5	0	1	1.0	0	1	2.0	0	1	4.0	0	1
1.5	0	1	4.0	0	1	1.0	0	1	0.5	0	3	4.0	0	1	2.0	0	1
1.5	0	1	0.5	0	1	4.0	0	1	1.5	0	1	2.0	0	1	1.5	0	1
2.0	0	1	1.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1
4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.5	0	1	2.0	0	1
0.5	0	1	1.5	0	1	1.0	0	1	1.0	0	1	4.0	0	1	0.5	0	2
1.0	0	1	2.0	0	1	0.5	0	3	0.5	0	2	0.5	0	2	1.0	0	1
2.0	0	1	2.0	0	1	1.5	1	2	2.0	0	1	1.0	1	1	1.0	0	3



Right before Left									Left before right								
1 **CAV -** CAV	*Braked?*	*1 - 4*	2 **CAV** - HDV	*Braked?*	*1 - 4*	3 **HDV** - CAV	*Braked?*	*1 - 4*	4 CAV - **CAV**	*Braked?*	*1 - 4*	5 CAV - **HDV**	*Braked?*	*1 - 4*	6 HDV - **CAV**	*Braked?*	*1 - 4*
1.5	0	1	2.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	0	4
0.5	0	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	0	2	1.5	0	2
1.0	0	3	4.0	0	1	1.0	0	3	0.5	0	3	0.5	1	4	1.0	0	3
4.0	0	1	1.0	0	3	2.0	0	1	1.5	0	2	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	4	4.0	0	1	1.0	0	3	1.5	0	2	2.0	0	2
4.0	0	1	4.0	0	1	2.0	0	1	0.5	0	2	1.0	0	2	0.5	0	4
2.0	0	1	1.5	0	2	1.5	0	2	2.0	0	1	4.0	0	1	1.0	0	3
1.0	0	3	2.0	0	2	1.0	0	2	1.0	0	3	2.0	0	2	4.0	0	1
0.5	0	4	0.5	0	4	0.5	0	3	1.5	0	2	0.5	0	4	1.5	0	2
1.5	0	2	1.0	0	3	4.0	0	1	4.0	0	1	1.5	0	2	2.0	0	1
4.0	0	1	0.5	0	3	1.0	0	2	1.0	0	2	1.5	0	2	2.0	0	1
2.0	0	1	1.5	0	1	4.0	0	1	4.0	0	1	4.0	0	1	1.0	0	1
1.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	0.5	0	3	0.5	0	2
1.0	0	2	4.0	0	1	0.5	0	3	2.0	0	1	2.0	0	1	4.0	0	1
0.5	0	3	1.0	0	2	1.5	0	1	0.5	0	3	1.0	0	2	1.5	0	1
1.5	0	1	2.0	0	1	2.0	0	1	2.0	0	1	0.5	1	3	1.0	0	1
1.0	0	2	4.0	0	1	1.5	0	1	1.0	0	2	4.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	4.0	0	1	2.0	0	1	0.5	0	3
0.5	0	1	1.5	0	1	1.0	1	2	1.5	0	1	1.5	0	2	4.0	0	1
2.0	0	1	0.5	0	3	4.0	0	1	0.5	0	3	1.0	1	3	2.0	0	1
2.0	0	2	1.0	0	3	0.5	0	3	1.0	0	2	0.5	1	3	4.0	0	1
1.0	0	2	0.5	0	4	1.5	0	2	4.0	0	1	2.0	0	1	2.0	0	2
4.0	0	1	1.5	0	3	4.0	0	1	0.5	0	3	4.0	0	1	1.5	0	2
0.5	0	4	2.0	0	2	1.0	0	3	2.0	0	1	1.5	0	2	0.5	0	4
1.5	0	2	4.0	0	1	2.0	0	1	1.5	0	1	1.0	0	3	1.0	0	3
4.0	0	1	2.0	0	1	2.0	0	1	0.5	0	3	2.0	0	1	0.5	0	3
0.5	0	4	1.0	1	3	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.0	0	1	0.5	1	4	4.0	0	1	4.0	0	1	0.5	1	4	1.5	0	1
2.0	0	1	4.0	0	1	1.0	1	3	2.0	0	2	1.5	0	2	2.0	0	1
1.5	0	2	1.5	0	1	0.5	1	3	1.0	0	3	1.0	0	3	4.0	0	1
1.5	0	1	4.0	0	1	4.0	0	1	0.5	0	4	1.0	0,5	3	1.5	0	1
4.0	0	1	2.0	0	1	0.5	1	3	1.0	0	3	4.0	0	1	0.5	0	4
0.5	0	3	1.0	0	1	1.0	1	3	4.0	0	1	2.0	0	1	4.0	0	1
2.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	2
1.0	0	2	1.5	0	1	1.5	0	2	1.5	0	2	0.5	1	4	2.0	0	1
2.0	0	1	1.5	0	2	2.0	0,5	2	4.0	0	1	4.0	0	2	0.5	0	2
1.5	0	2	1.0	0	2	4.0	0,5	1	1.0	0	3	0.5	1	4	2.0	0	1
0.5	0	3	4.0	0	1	1.5	0,5	2	1.5	0	2	1.5	0,5	1	4.0	0	1
4.0	0	1	0.5	0	3	0.5	1	3	2.0	0	1	2.0	0,5	1	1.0	0	2
1.0	0	2	2.0	0	1	1.0	0,5	2	0.5	0	3	1.0	0,5	2	1.5	0	1
0.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1	0.5	1	2	0.5	0	3
1.0	0	1	2.0	0	1	0.5	0	1	0.5	0	1	1.5	0	1	2.0	0	1
2.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.5	0	1	4.0	0	1	1.0	0	1	2.0	0	1	4.0	0	1
4.0	0	1	0.5	0	2	2.0	0	1	2.0	0	1	1.0	0,5	1	1.5	0	1
0.5	1	4	1.5	0	1	1.5	0	2	2.0	0	1	1.0	1	3	1.0	0	4
1.5	0	2	1.0	0	1	1.0	1	2	1.0	0	3	0.5	1	3	0.5	1	4
1.0	1	3	4.0	0	1	2.0	0	1	1.5	0	1	4.0	0	2	2.0	0	2
2.0	0	2	0.5	1	4	0.5	1	3	4.0	0	1	2.0	0	1	1.5	0	2
4.0	0	1	2.0	0	3	4.0	0	1	0.5	1	4	1.5	0	2	4.0	0	3
4.0	0	1	2.0	0	1	0.5	1	3	0.5	0	2	0.5	1	3	0.5	0	2
2.0	0	1	1.0	0	2	2.0	0	1	4.0	0	1	1.0	0	2	1.5	0	1
1.5	0	1	4.0	0	1	1.0	0	2	1.5	0	1	1.5	0	1	4.0	0	1
0.5	0	2	1.5	0	1	1.5	0	1	1.0	0	2	2.0	0	1	2.0	0	1
1.0	0	2	0.5	0	2	4.0	0	1	2.0	0	1	4.0	0	1	1.0	0	2
1.5	0	1	1.0	0	2	0.5	1	4	1.5	0,5	3	0.5	1	4	2.0	0	1
4.0	0	1	0.5	1	4	2.0	0	1	1.0	0,5	3	4.0	0	1	1.5	1	3
0.5	0	2	1.5	0	1	1.0	1	3	0.5	1	4	1.5	0	1	4.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	2.0	0	1	1.0	1	4
1.0	0	2	4.0	0	1	1.5	0	2	2.0	0	1	1.0	1	3	0.5	1	4
4.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	1.5	0	1	1.5	0	1
2.0	0	1	2.0	0	1	1.5	0	1	4.0	0	1	2.0	0	1	0.5	0	2
1.5	0	1	0.5	0	2	1.0	0	1	1.5	0	1	1.0	0	2	2.0	0	1
0.5	0	2	4.0	0	1	0.5	0	1	2.0	0	1	0.5	0	3	4.0	0	1
1.0	0	1	1.0	0	2	2.0	0	1	0.5	0	2	4.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	1.5	0	1	1.0	0	1	1.0	0	1	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	3	0.5	0	1	4.0	0	1	2.0	0	1
1.0	0	1	0.5	1	3	2.0	0	1	1.5	0	1	1.5	0	1	0.5	1	3
1.5	0	1	1.5	0	1	1.0	1	3	4.0	0	1	0.5	1	3	4.0	0	1
0.5	0	1	4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.0	0	1
2.0	0	1	2.0	0	1	4.0	0	1	4.0	0	1	0.5	1	2	1.5	0	1
4.0	0	1	1.0	0	1	0.5	1	1	2.0	0	1	1.5	0	1	1.0	0	1
0.5	0	1	1.5	0	1	2.0	0	1	1.5	0	1	1.0	0	1	0.5	0	2
1.0	0	1	0.5	1	4	1.5	0	1	1.0	0	1	2.0	0	1	4.0	0	1
1.5	0	1	4.0	0	1	1.0	0	1	0.5	0	3	4.0	0	1	2.0	0	1
1.5	0	1	0.5	0	1	4.0	0	1	1.5	0	1	2.0	0	1	1.5	0	1
2.0	0	1	1.0	0	1	1.5	0	1	4.0	0	1	1.0	0	1	4.0	0	1
4.0	0	1	4.0	0	1	2.0	0	1	2.0	0	1	1.5	0	1	2.0	0	1
0.5	0	1	1.5	0	1	1.0	0	1	1.0	0	1	4.0	0	1	0.5	0	2
1.0	0	1	2.0	0	1	0.5	0	3	0.5	0	2	0.5	0	2	1.0	0	1
2.0	0	1	2.0	0	1	1.5	1	2	2.0	0	1	1.0	1	1	1.0	0	3

Figure D.1: Data collected during experiment - Personal Information excluded

E

Results: Descriptive Analysis

E.1. Descriptive Analysis Questionnaire 1

See Figure E.1.

E.2. Descriptive Analysis Questionnaire 2

See Figure E.2

Figure E.1: Descriptive Analysis - Answers to Questionnaire 1

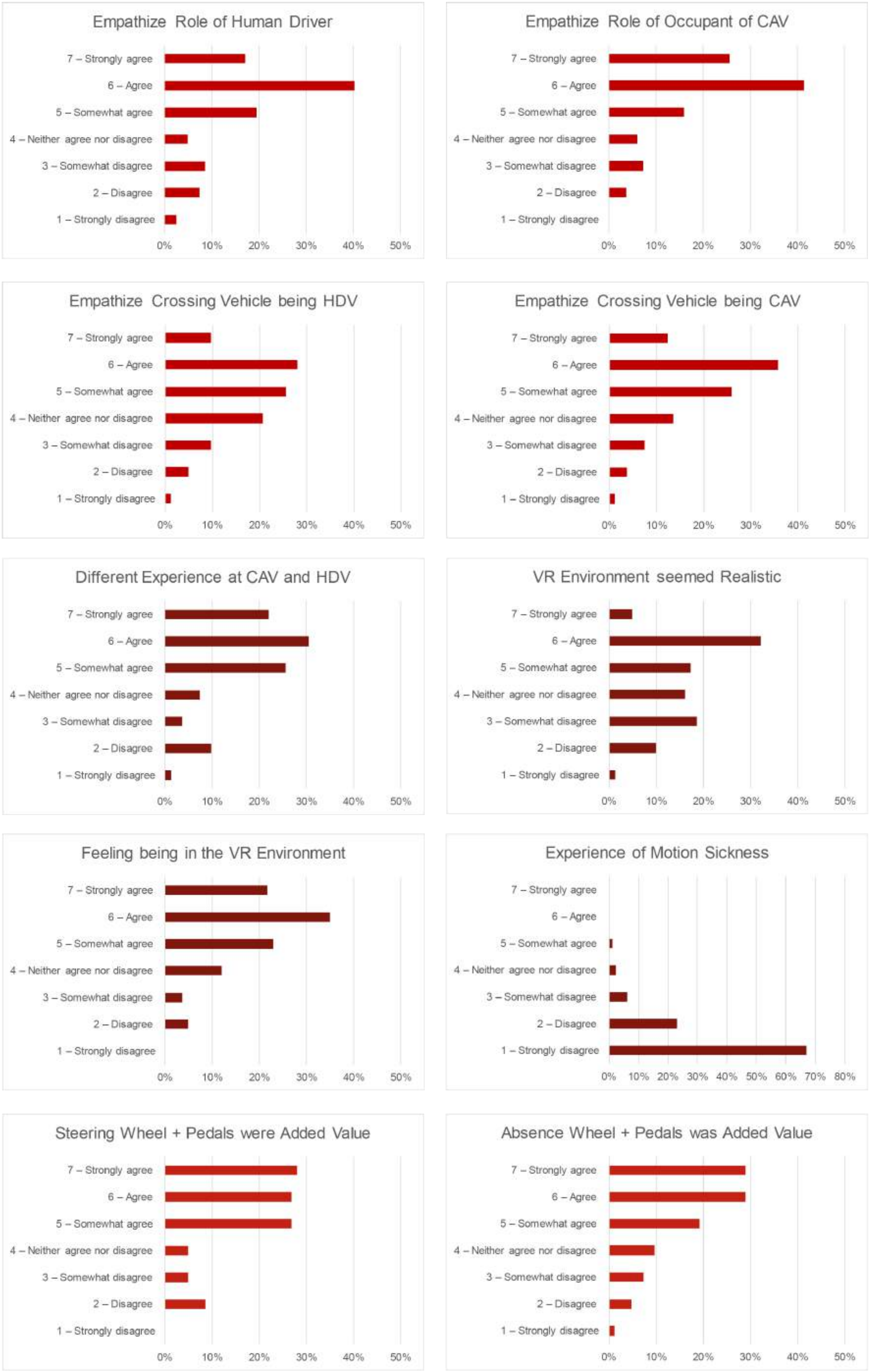


Figure E.2: Descriptive Analysis - Answers to Questionnaire 2

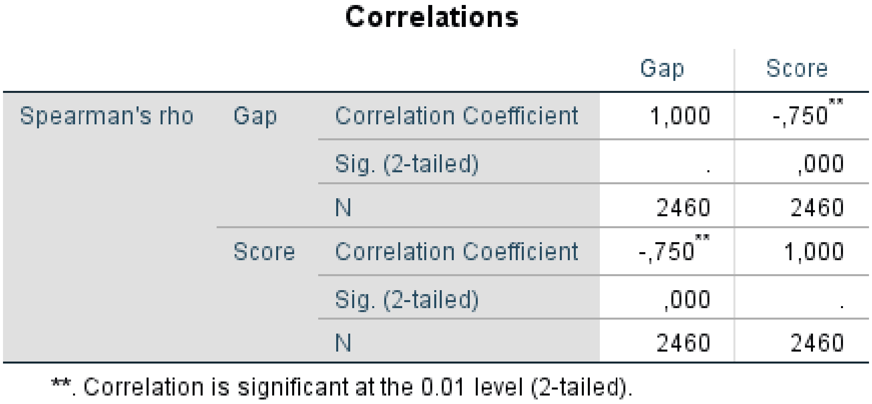
F

Results: Statistical Analyses

F.1. Effect of Time gap

See Figure F.1, and Tables F.1 and F.2.

Table F.1: Output Spearman's Correlation Test applied to all Data. Significant at a 0.01 significance level.



Correlations

			Gap	Score
Spearman's rho	Gap	Correlation Coefficient	1,000	-,750**
		Sig. (2-tailed)	.	,000
		N	2460	2460
	Score	Correlation Coefficient	-,750**	1,000
		Sig. (2-tailed)	,000	.
		N	2460	2460

**. Correlation is significant at the 0.01 level (2-tailed).

F.2. Effect of Crossing Direction on Score - All Data

See Figure F.2, and Tables F.3 and F.4.

F.3. Effect of Crossing Direction on Score

All time gaps and all interaction scenarios combined: see Table F.5.
Per time gap per interaction scenario: See Figures F.3 to F.11

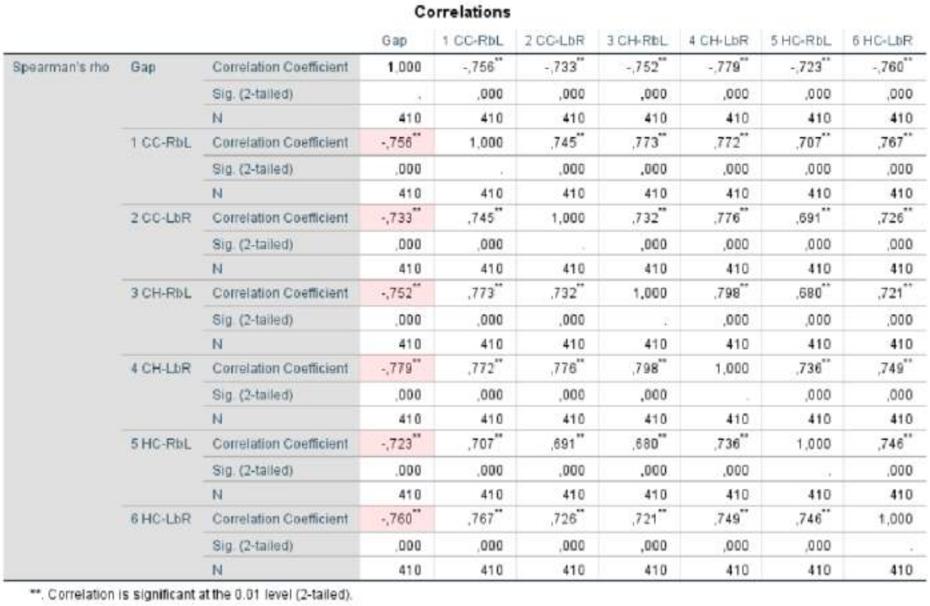
F.4. Scores per time gap - Data crossing direction combined

See Figure F.12.

F.5. Difference interaction scenarios

See Figures F.13 and F.14.

Table F.2: Output Spearman's Correlation Test. Red values show correlation values within the 6 scenarios. All correlation coefficients are significant at a 0.01 significance level.

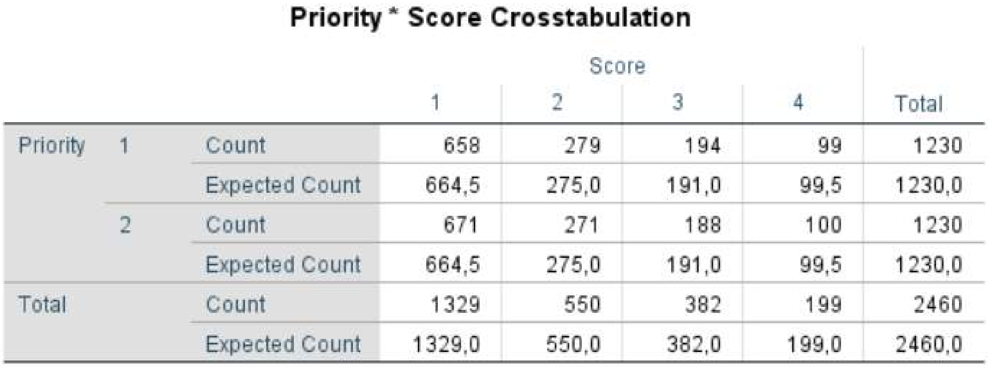


Correlations

			Gap	1 CC-RbL	2 CC-LbR	3 CH-RbL	4 CH-LbR	5 HC-RbL	6 HC-LbR
Spearman's rho	Gap	Correlation Coefficient	1,000	-,756**	-,733**	-,752**	-,779**	-,723**	-,760**
		Sig. (2-tailed)	.	,000	,000	,000	,000	,000	,000
		N	410	410	410	410	410	410	410
	1 CC-RbL	Correlation Coefficient	-,756**	1,000	,745**	,773**	,772**	,707**	,767**
		Sig. (2-tailed)	,000	.	,000	,000	,000	,000	,000
		N	410	410	410	410	410	410	410
	2 CC-LbR	Correlation Coefficient	-,733**	,745**	1,000	,732**	,776**	,691**	,726**
		Sig. (2-tailed)	,000	,000	.	,000	,000	,000	,000
		N	410	410	410	410	410	410	410
	3 CH-RbL	Correlation Coefficient	-,752**	,773**	,732**	1,000	,798**	,680**	,721**
		Sig. (2-tailed)	,000	,000	,000	.	,000	,000	,000
		N	410	410	410	410	410	410	410
	4 CH-LbR	Correlation Coefficient	-,779**	,772**	,776**	,798**	1,000	,736**	,749**
		Sig. (2-tailed)	,000	,000	,000	,000	.	,000	,000
		N	410	410	410	410	410	410	410
	5 HC-RbL	Correlation Coefficient	-,723**	,707**	,691**	,680**	,736**	1,000	,746**
		Sig. (2-tailed)	,000	,000	,000	,000	,000	.	,000
		N	410	410	410	410	410	410	410
	6 HC-LbR	Correlation Coefficient	-,760**	,767**	,726**	,721**	,749**	,746**	1,000
		Sig. (2-tailed)	,000	,000	,000	,000	,000	,000	.
		N	410	410	410	410	410	410	410

**. Correlation is significant at the 0.01 level (2-tailed).

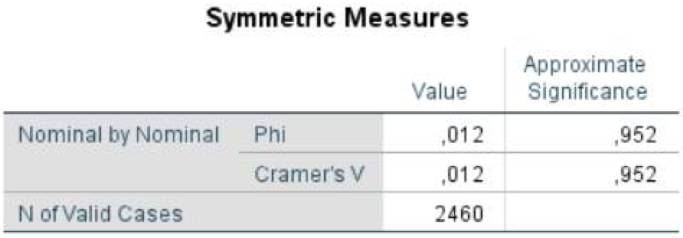
Table F.3: Counts Crossing Direction (Yield), where 1 is right-before-left, and 2 left-before-right, versus Scores given



Priority * Score Crosstabulation

			Score				Total
			1	2	3	4	
Priority	1	Count	658	279	194	99	1230
		Expected Count	664,5	275,0	191,0	99,5	1230,0
	2	Count	671	271	188	100	1230
		Expected Count	664,5	275,0	191,0	99,5	1230,0
Total		Count	1329	550	382	199	2460
		Expected Count	1329,0	550,0	382,0	199,0	2460,0

Table F.4: Insignificant influence of crossing direction on score



Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,012	,952
	Cramer's V	,012	,952
N of Valid Cases		2460	

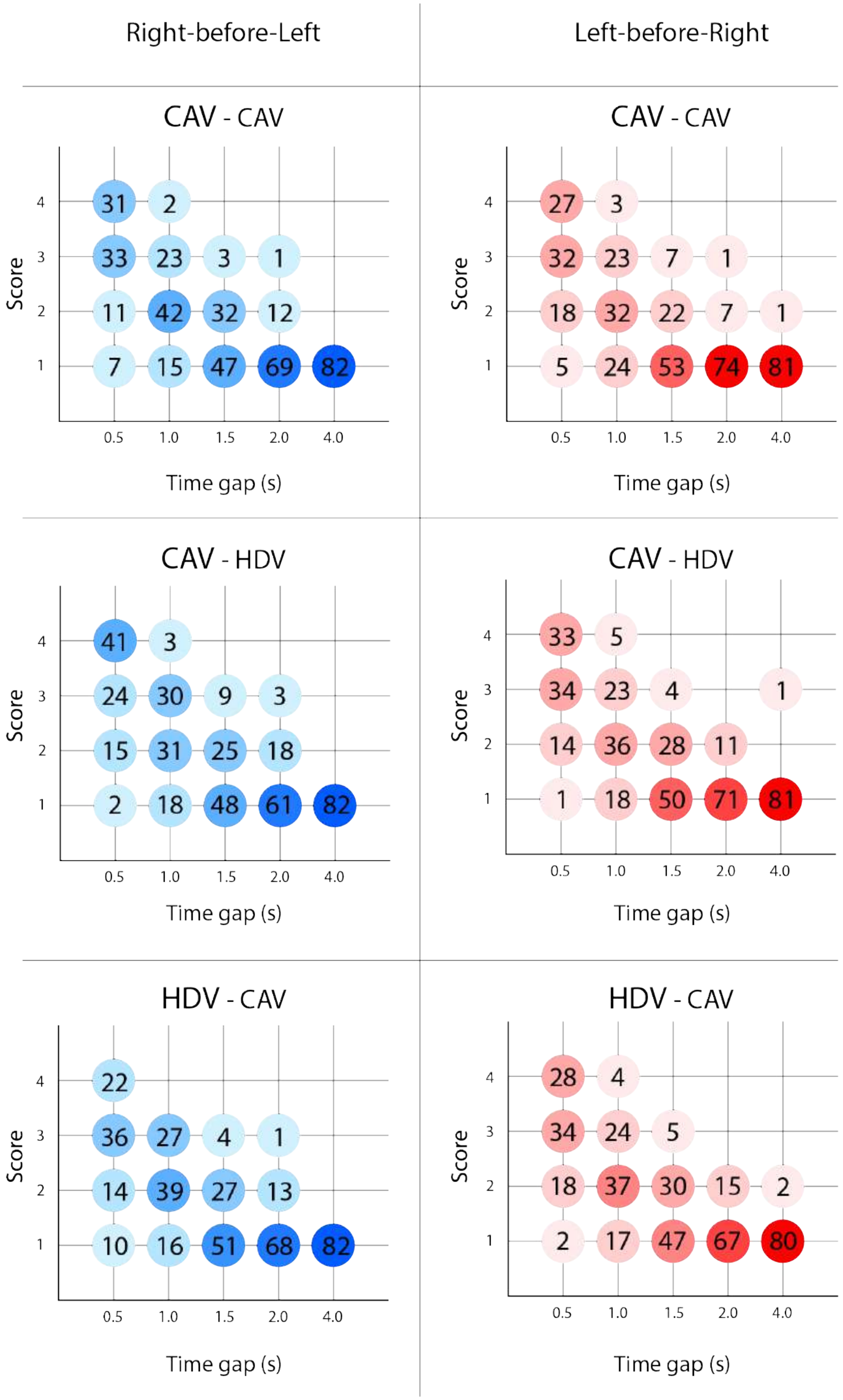


Figure F.1: Frequency of scores given indicated by colour and number. Monotonic relationship is shown in each situation. [1 - very safe; 2 - pretty safe; 3 - a little unsafe; 4 - very unsafe]

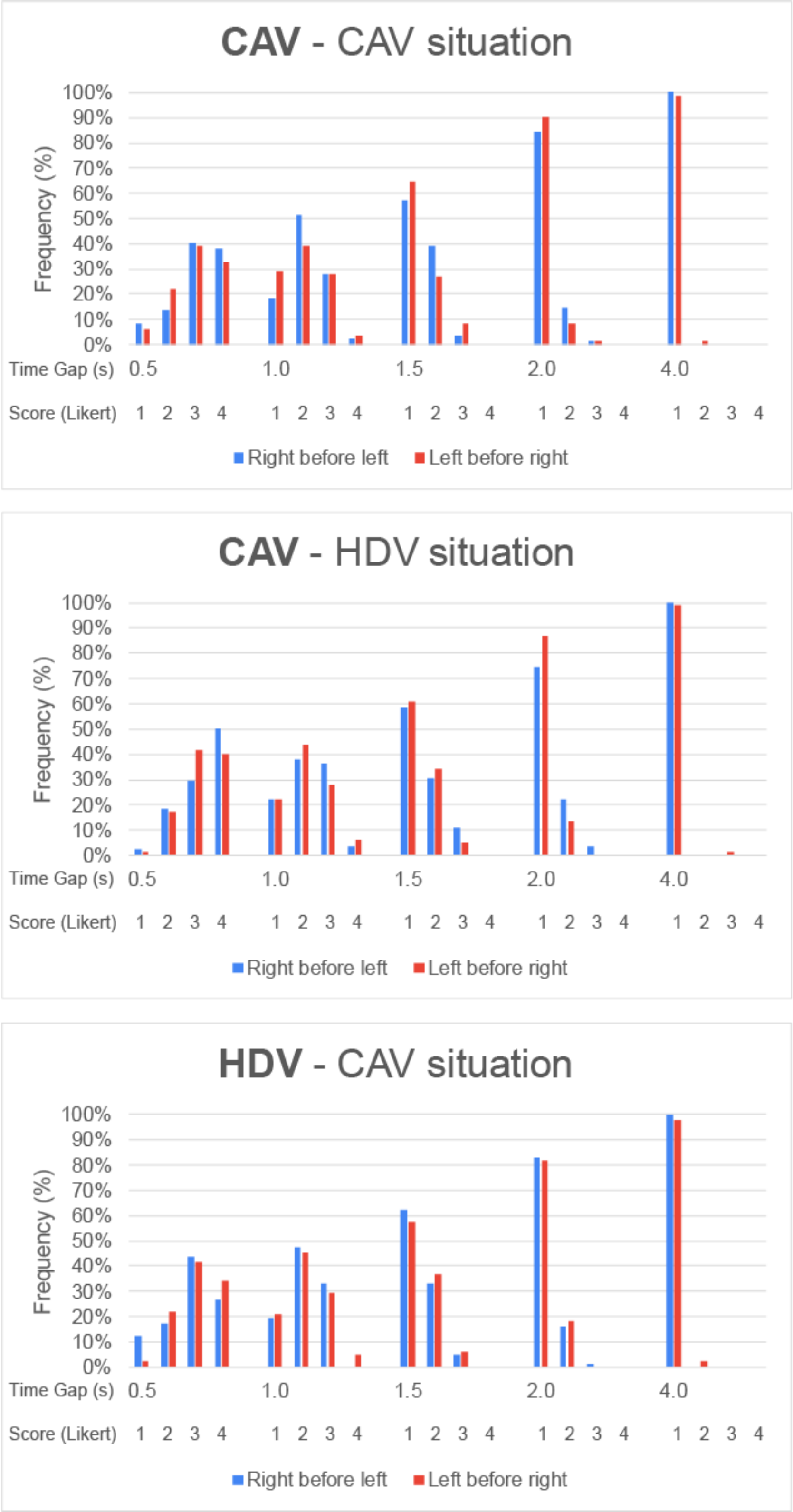
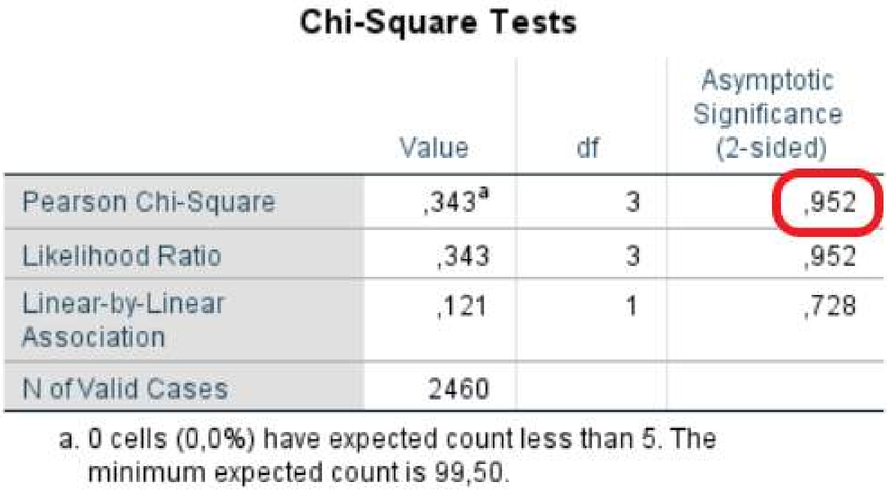


Figure F.2: Scores given per time gap [1 - very safe; 2 - pretty safe; 3 - a little unsafe; 4 - very unsafe]. Difference in crossing direction distinguished per interaction scenario.

Table F.5: High Pearson Chi-Square value indicates no significant association between scores and crossing direction



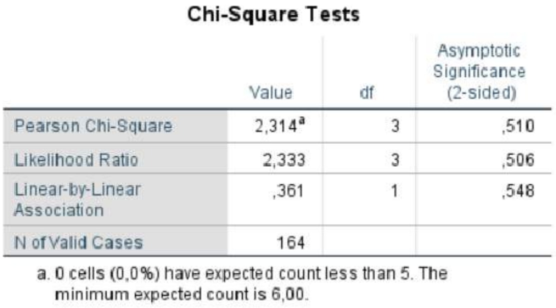
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	,343[a]	3	,952
Likelihood Ratio	,343	3	,952
Linear-by-Linear Association	,121	1	,728
N of Valid Cases	2460		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 99,50.

CAV CAV - **0.5** sec time gap

Pearson chi-square

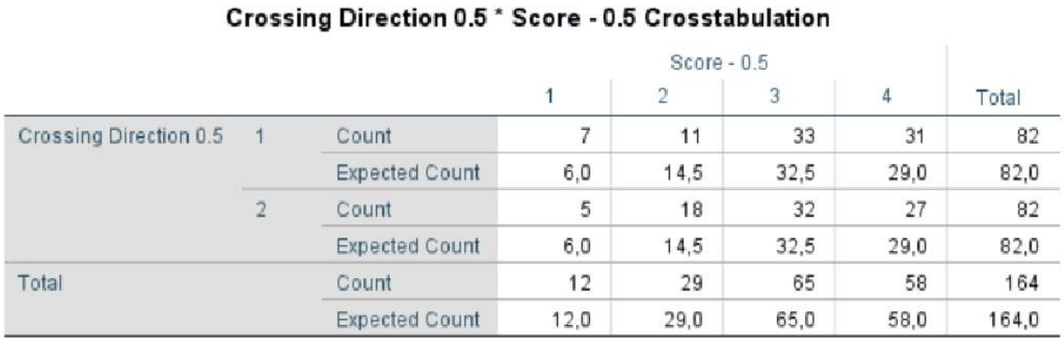


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2,314[a]	3	,510
Likelihood Ratio	2,333	3	,506
Linear-by-Linear Association	,361	1	,548
N of Valid Cases	164		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 6,00.

Counts

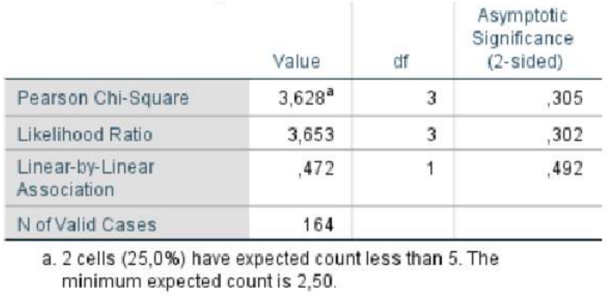


Crossing Direction 0.5 * Score - 0.5 Crosstabulation

			Score - 0.5				
			1	2	3	4	Total
Crossing Direction 0.5	1	Count	7	11	33	31	82
		Expected Count	6,0	14,5	32,5	29,0	82,0
	2	Count	5	18	32	27	82
		Expected Count	6,0	14,5	32,5	29,0	82,0
Total		Count	12	29	65	58	164
		Expected Count	12,0	29,0	65,0	58,0	164,0

CAV CAV - **1.0** sec time gap

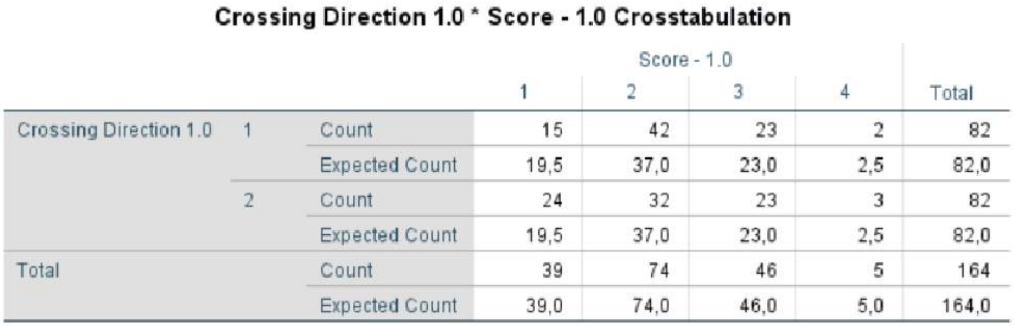
Pearson chi-square



	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3,628[a]	3	,305
Likelihood Ratio	3,653	3	,302
Linear-by-Linear Association	,472	1	,492
N of Valid Cases	164		

a. 2 cells (25,0%) have expected count less than 5. The minimum expected count is 2,50.

Counts



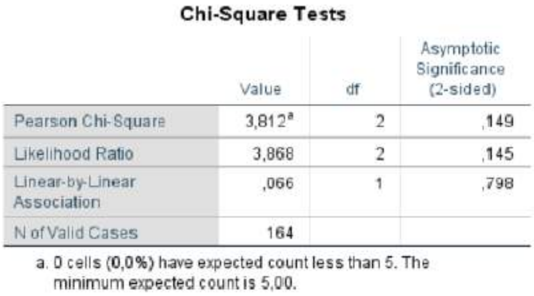
Crossing Direction 1.0 * Score - 1.0 Crosstabulation

			Score - 1.0				
			1	2	3	4	Total
Crossing Direction 1.0	1	Count	15	42	23	2	82
		Expected Count	19,5	37,0	23,0	2,5	82,0
	2	Count	24	32	23	3	82
		Expected Count	19,5	37,0	23,0	2,5	82,0
Total		Count	39	74	46	5	164
		Expected Count	39,0	74,0	46,0	5,0	164,0

Figure F.3: Interaction Scenario: CAV CAV - Time gaps: 0.5 and 1.0 seconds

CAV CAV - **1.5** sec time gap

Pearson chi-square

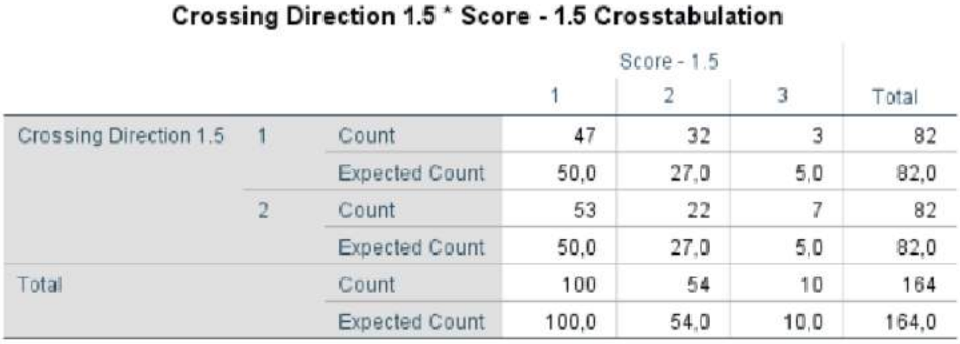


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3,812[a]	2	,149
Likelihood Ratio	3,868	2	,145
Linear-by-Linear Association	,066	1	,798
N of Valid Cases	164		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 5,00.

Counts

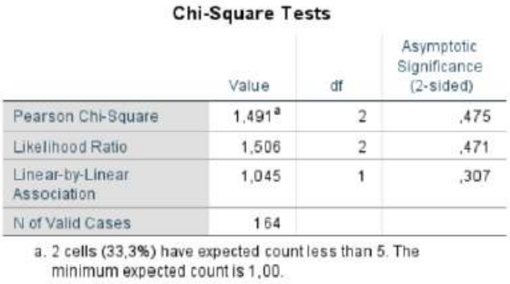


Crossing Direction 1.5 * Score - 1.5 Crosstabulation

			Score - 1.5			Total
			1	2	3	
Crossing Direction 1.5	1	Count	47	32	3	82
		Expected Count	50,0	27,0	5,0	82,0
	2	Count	53	22	7	82
		Expected Count	50,0	27,0	5,0	82,0
Total		Count	100	54	10	164
		Expected Count	100,0	54,0	10,0	164,0

CAV CAV - **2.0** sec time gap

Pearson chi-square

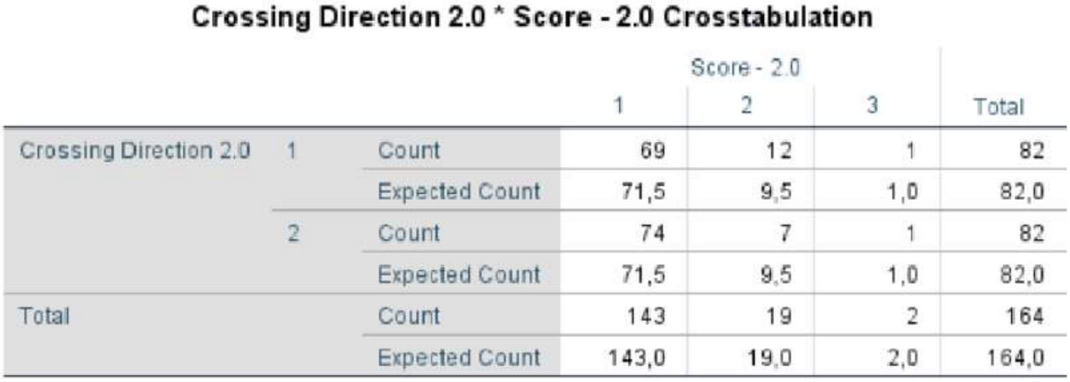


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1,491[a]	2	,475
Likelihood Ratio	1,506	2	,471
Linear-by-Linear Association	1,045	1	,307
N of Valid Cases	164		

a. 2 cells (33,3%) have expected count less than 5. The minimum expected count is 1,00.

Counts



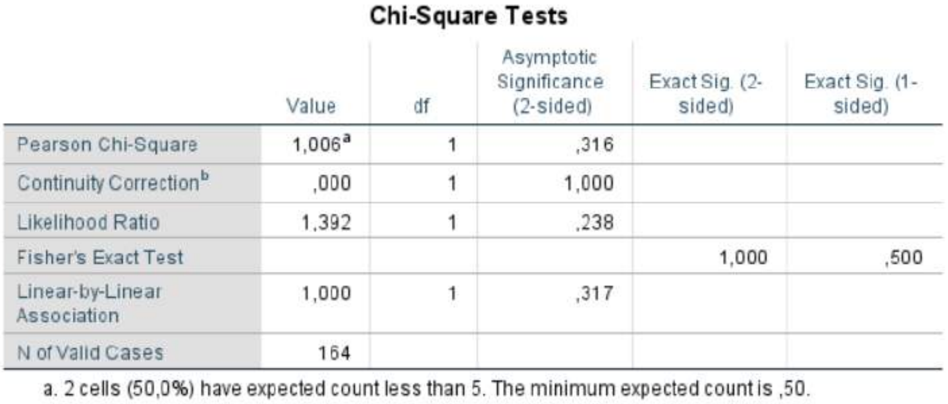
Crossing Direction 2.0 * Score - 2.0 Crosstabulation

			Score - 2.0			Total
			1	2	3	
Crossing Direction 2.0	1	Count	69	12	1	82
		Expected Count	71,5	9,5	1,0	82,0
	2	Count	74	7	1	82
		Expected Count	71,5	9,5	1,0	82,0
Total		Count	143	19	2	164
		Expected Count	143,0	19,0	2,0	164,0

Figure F.4: Interaction Scenario: CAV CAV - Time gaps: 1.5 and 2.0 seconds

CAV CAV - **4.0** sec time gap

Pearson chi-square

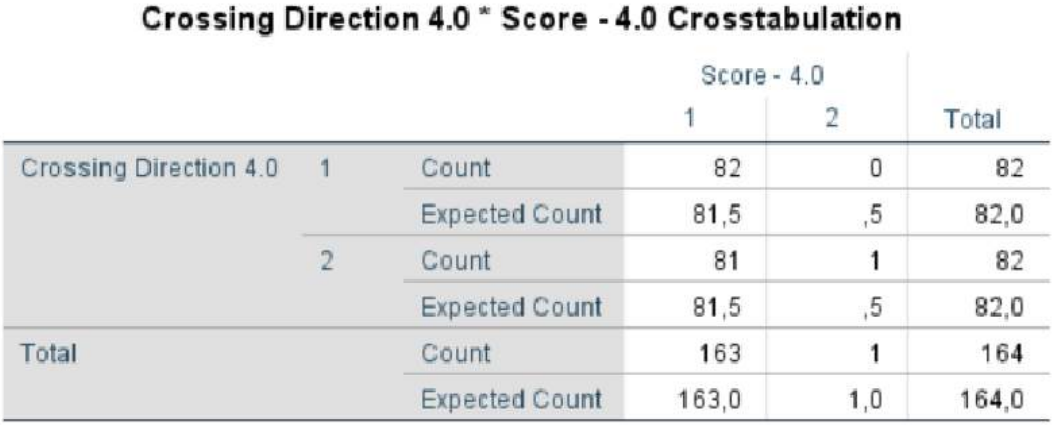


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1,006[a]	1	,316		
Continuity Correction[b]	,000	1	1,000		
Likelihood Ratio	1,392	1	,238		
Fisher's Exact Test				1,000	,500
Linear-by-Linear Association	1,000	1	,317		
N of Valid Cases	164				

a. 2 cells (50,0%) have expected count less than 5. The minimum expected count is ,50.

Counts



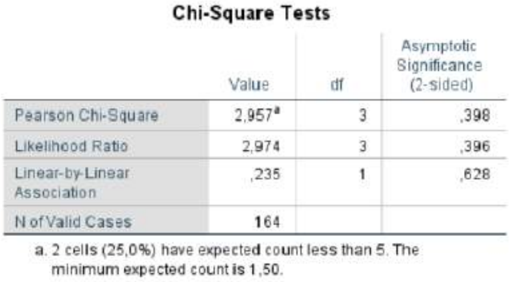
Crossing Direction 4.0 * Score - 4.0 Crosstabulation

			Score - 4.0		
			1	2	Total
Crossing Direction 4.0	1	Count	82	0	82
		Expected Count	81,5	,5	82,0
	2	Count	81	1	82
		Expected Count	81,5	,5	82,0
Total		Count	163	1	164
		Expected Count	163,0	1,0	164,0

Figure F.5: Interaction Scenario: CAV CAV - Time gap: 4.0 seconds

CAV HDV - 0.5 sec time gap

Pearson chi-square

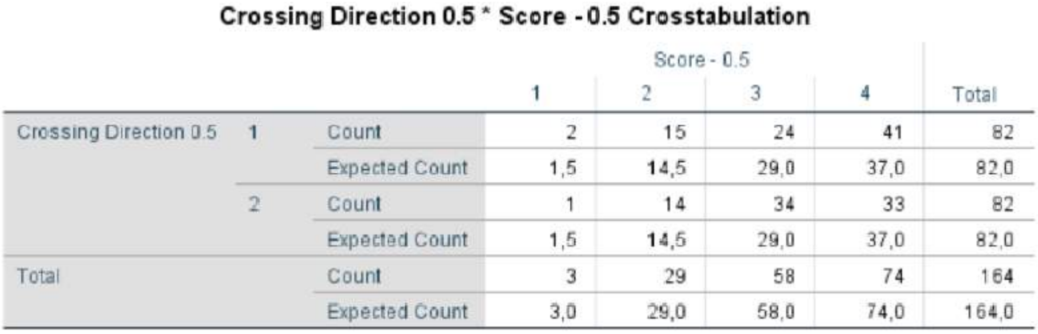


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2,957[a]	3	,398
Likelihood Ratio	2,974	3	,396
Linear-by-Linear Association	,235	1	,628
N of Valid Cases	164		

a. 2 cells (25,0%) have expected count less than 5. The minimum expected count is 1,50.

Counts

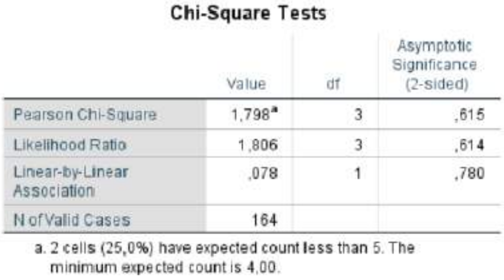


Crossing Direction 0.5 * Score - 0.5 Crosstabulation

			Score - 0.5				
			1	2	3	4	Total
Crossing Direction 0.5	1	Count	2	15	24	41	82
		Expected Count	1,5	14,5	29,0	37,0	82,0
	2	Count	1	14	34	33	82
		Expected Count	1,5	14,5	29,0	37,0	82,0
Total		Count	3	29	58	74	164
		Expected Count	3,0	29,0	58,0	74,0	164,0

CAV HDV - 1.0 sec time gap

Pearson chi-square

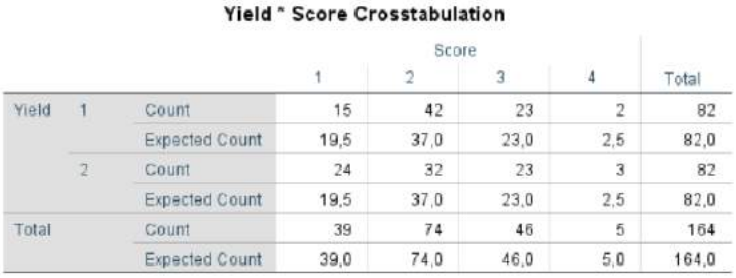


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1,798[a]	3	,615
Likelihood Ratio	1,806	3	,614
Linear-by-Linear Association	,078	1	,780
N of Valid Cases	164		

a. 2 cells (25,0%) have expected count less than 5. The minimum expected count is 4,00.

Counts



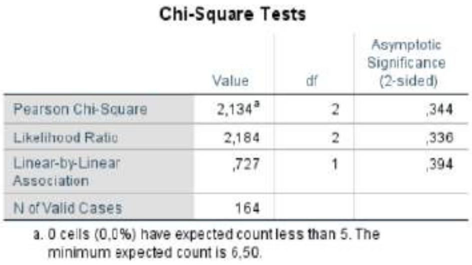
Yield * Score Crosstabulation

			Score				
			1	2	3	4	Total
Yield	1	Count	15	42	23	2	82
		Expected Count	19,5	37,0	23,0	2,5	82,0
	2	Count	24	32	23	3	82
		Expected Count	19,5	37,0	23,0	2,5	82,0
Total		Count	39	74	46	5	164
		Expected Count	39,0	74,0	46,0	5,0	164,0

Figure F.6: Interaction Scenario: CAV HDV - Time gaps: 0.5 and 1.0 seconds

CAV HDV - **1.5** sec time gap

Pearson chi-square

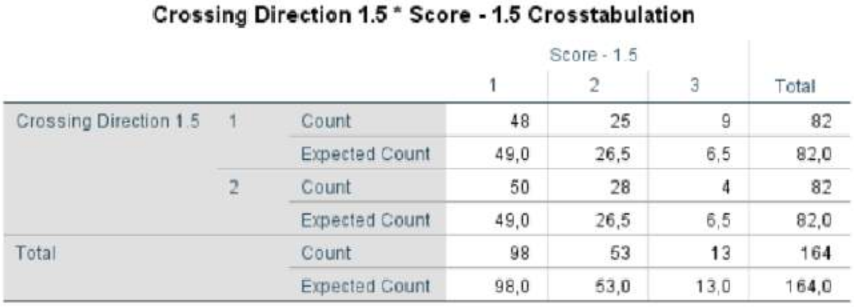


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2,134ᵃ	2	,344
Likelihood Ratio	2,184	2	,336
Linear-by-Linear Association	,727	1	,394
N of Valid Cases	164		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 6,50.

Counts



Crossing Direction 1.5 * Score - 1.5 Crosstabulation

			Score - 1.5			
			1	2	3	Total
Crossing Direction 1.5	1	Count	48	25	9	82
		Expected Count	49,0	26,5	6,5	82,0
	2	Count	50	28	4	82
		Expected Count	49,0	26,5	6,5	82,0
Total		Count	98	53	13	164
		Expected Count	98,0	53,0	13,0	164,0

CAV HDV - **2.0** sec time gap

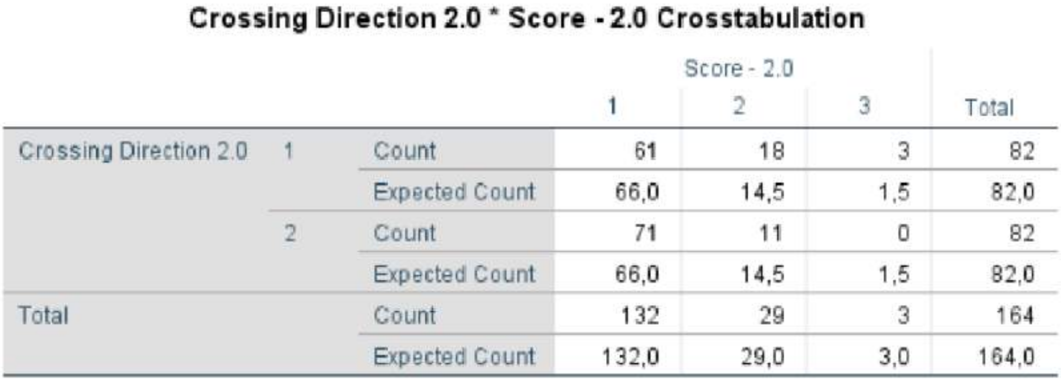
Pearson chi-square

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	5,447ᵃ	2	,066
Likelihood Ratio	6,624	2	,036
Linear-by-Linear Association	5,009	1	,025
N of Valid Cases	164		

a. 2 cells (33,3%) have expected count less than 5. The minimum expected count is 1,50.

Counts



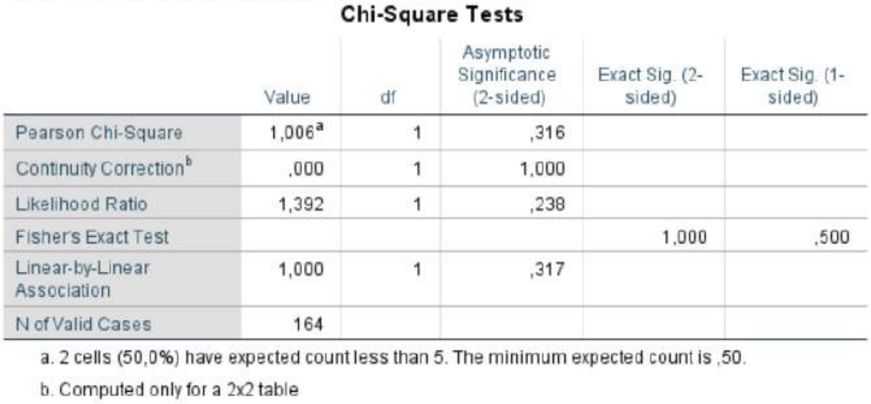
Crossing Direction 2.0 * Score - 2.0 Crosstabulation

			Score - 2.0			
			1	2	3	Total
Crossing Direction 2.0	1	Count	61	18	3	82
		Expected Count	66,0	14,5	1,5	82,0
	2	Count	71	11	0	82
		Expected Count	66,0	14,5	1,5	82,0
Total		Count	132	29	3	164
		Expected Count	132,0	29,0	3,0	164,0

Figure F.7: Interaction Scenario: CAV HDV - Time gaps: 1.5 and 2.0 seconds

CAV HDV - 4.0 sec time gap

Pearson chi-square



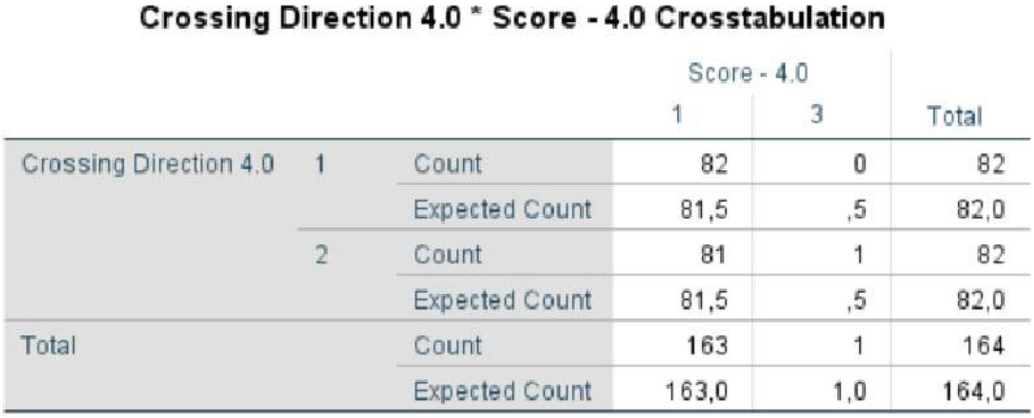
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1,006[a]	1	,316		
Continuity Correction[b]	,000	1	1,000		
Likelihood Ratio	1,392	1	,238		
Fisher's Exact Test				1,000	,500
Linear-by-Linear Association	1,000	1	,317		
N of Valid Cases	164				

a. 2 cells (50,0%) have expected count less than 5. The minimum expected count is ,50.

b. Computed only for a 2x2 table

Counts



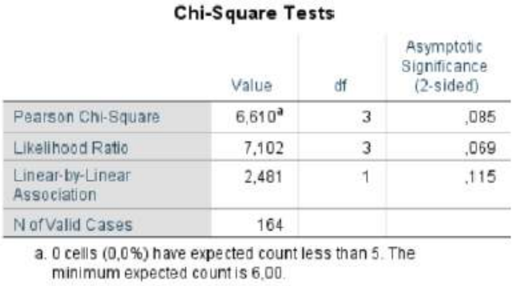
Crossing Direction 4.0 * Score - 4.0 Crosstabulation

			Score - 4.0		
			1	3	Total
Crossing Direction 4.0	1	Count	82	0	82
		Expected Count	81,5	,5	82,0
	2	Count	81	1	82
		Expected Count	81,5	,5	82,0
Total		Count	163	1	164
		Expected Count	163,0	1,0	164,0

Figure F.8: Interaction Scenario: CAV HDV - Time gap: 4.0 seconds

HDV CAV - 0.5 sec time gap

Pearson chi-square

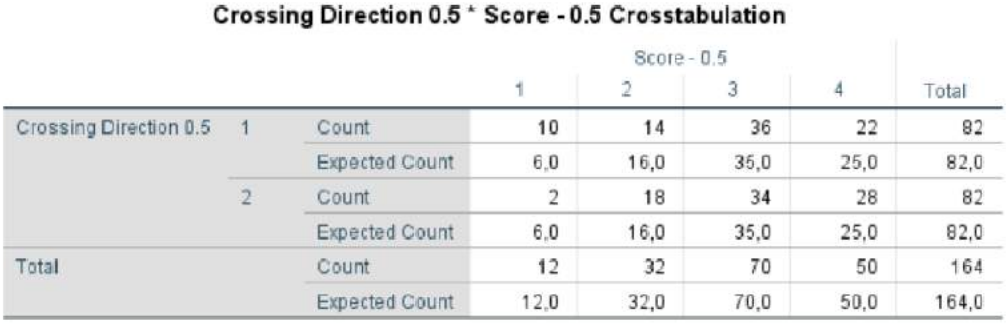


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6,610[a]	3	,085
Likelihood Ratio	7,102	3	,069
Linear-by-Linear Association	2,481	1	,115
N of Valid Cases	164		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 6,00.

Counts

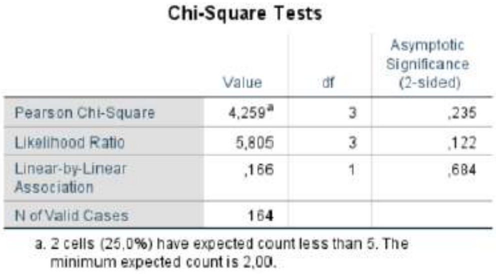


Crossing Direction 0.5 * Score - 0.5 Crosstabulation

			Score - 0.5				
			1	2	3	4	Total
Crossing Direction 0.5	1	Count	10	14	36	22	82
		Expected Count	6,0	16,0	35,0	25,0	82,0
	2	Count	2	18	34	28	82
		Expected Count	6,0	16,0	35,0	25,0	82,0
Total		Count	12	32	70	50	164
		Expected Count	12,0	32,0	70,0	50,0	164,0

HDV CAV - 1.0 sec time gap

Pearson chi-square

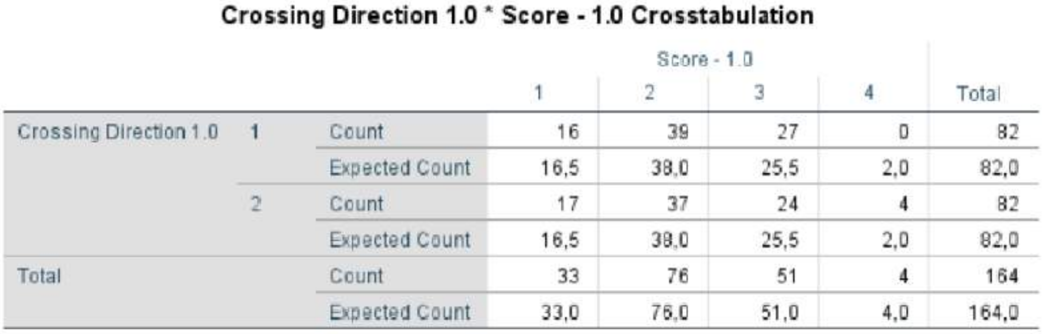


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	4,259[a]	3	,235
Likelihood Ratio	5,805	3	,122
Linear-by-Linear Association	,166	1	,684
N of Valid Cases	164		

a. 2 cells (25,0%) have expected count less than 5. The minimum expected count is 2,00.

Counts



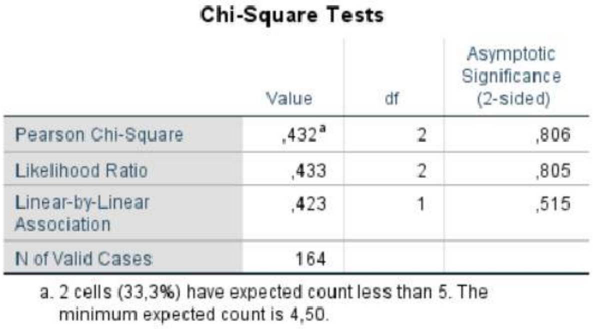
Crossing Direction 1.0 * Score - 1.0 Crosstabulation

			Score - 1.0				
			1	2	3	4	Total
Crossing Direction 1.0	1	Count	16	39	27	0	82
		Expected Count	16,5	38,0	25,5	2,0	82,0
	2	Count	17	37	24	4	82
		Expected Count	16,5	38,0	25,5	2,0	82,0
Total		Count	33	76	51	4	164
		Expected Count	33,0	76,0	51,0	4,0	164,0

Figure F.9: Interaction Scenario: HDV CAV - Time gaps: 0.5 and 1.0 seconds

HDV CAV - 1.5 sec time gap

Pearson chi-square

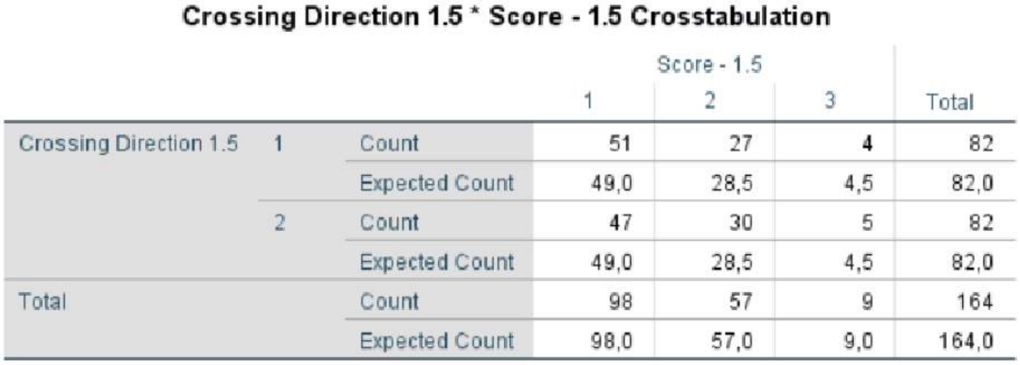


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	,432[a]	2	,806
Likelihood Ratio	,433	2	,805
Linear-by-Linear Association	,423	1	,515
N of Valid Cases	164		

a. 2 cells (33,3%) have expected count less than 5. The minimum expected count is 4,50.

Counts

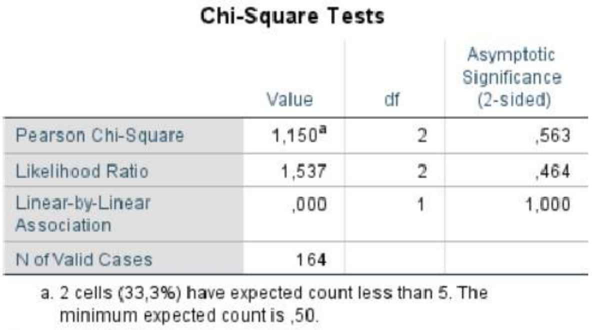


Crossing Direction 1.5 * Score - 1.5 Crosstabulation

			Score - 1.5			
			1	2	3	Total
Crossing Direction 1.5	1	Count	51	27	4	82
		Expected Count	49,0	28,5	4,5	82,0
	2	Count	47	30	5	82
		Expected Count	49,0	28,5	4,5	82,0
Total		Count	98	57	9	164
		Expected Count	98,0	57,0	9,0	164,0

HDV CAV - 2.0 sec time gap

Pearson chi-square

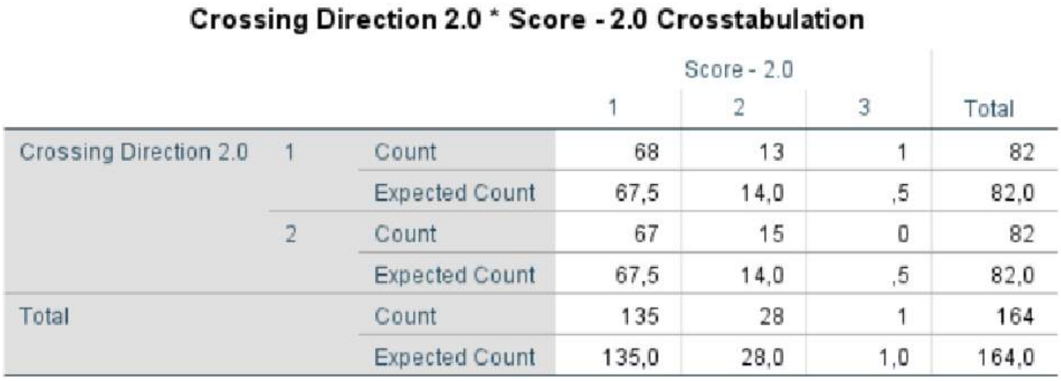


Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1,150[a]	2	,563
Likelihood Ratio	1,537	2	,464
Linear-by-Linear Association	,000	1	1,000
N of Valid Cases	164		

a. 2 cells (33,3%) have expected count less than 5. The minimum expected count is ,50.

Counts



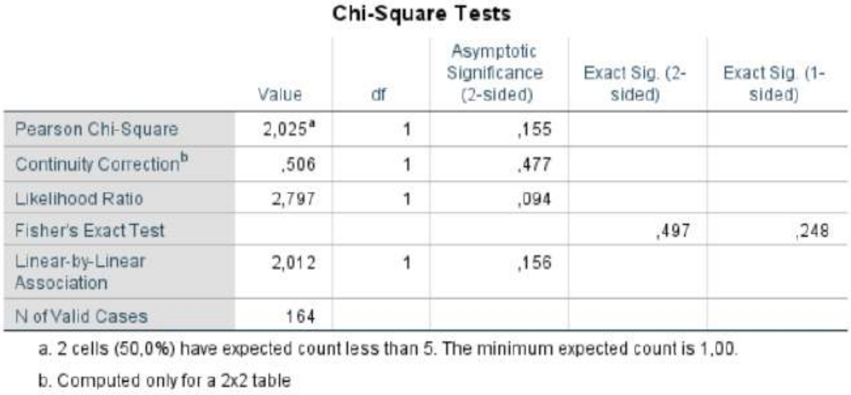
Crossing Direction 2.0 * Score - 2.0 Crosstabulation

			Score - 2.0			
			1	2	3	Total
Crossing Direction 2.0	1	Count	68	13	1	82
		Expected Count	67,5	14,0	,5	82,0
	2	Count	67	15	0	82
		Expected Count	67,5	14,0	,5	82,0
Total		Count	135	28	1	164
		Expected Count	135,0	28,0	1,0	164,0

Figure F.10: Interaction Scenario: HDV CAV - Time gaps: 1.5 and 2.0 seconds

HDV CAV - **4.0** sec time gap

Pearson chi-square



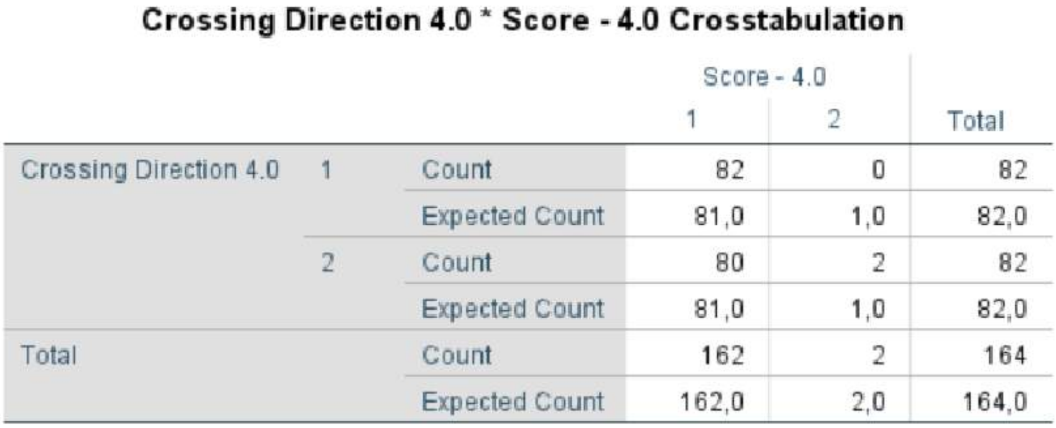
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2,025[a]	1	,155		
Continuity Correction[b]	,506	1	,477		
Likelihood Ratio	2,797	1	,094		
Fisher's Exact Test				,497	,248
Linear-by-Linear Association	2,012	1	,156		
N of Valid Cases	164				

a. 2 cells (50,0%) have expected count less than 5. The minimum expected count is 1,00.

b. Computed only for a 2x2 table

Counts



Crossing Direction 4.0 * Score - 4.0 Crosstabulation

			Score - 4.0		
			1	2	Total
Crossing Direction 4.0	1	Count	82	0	82
		Expected Count	81,0	1,0	82,0
	2	Count	80	2	82
		Expected Count	81,0	1,0	82,0
Total		Count	162	2	164
		Expected Count	162,0	2,0	164,0

Figure F.11: Interaction Scenario: HDV CAV - Time gap: 4.0 seconds

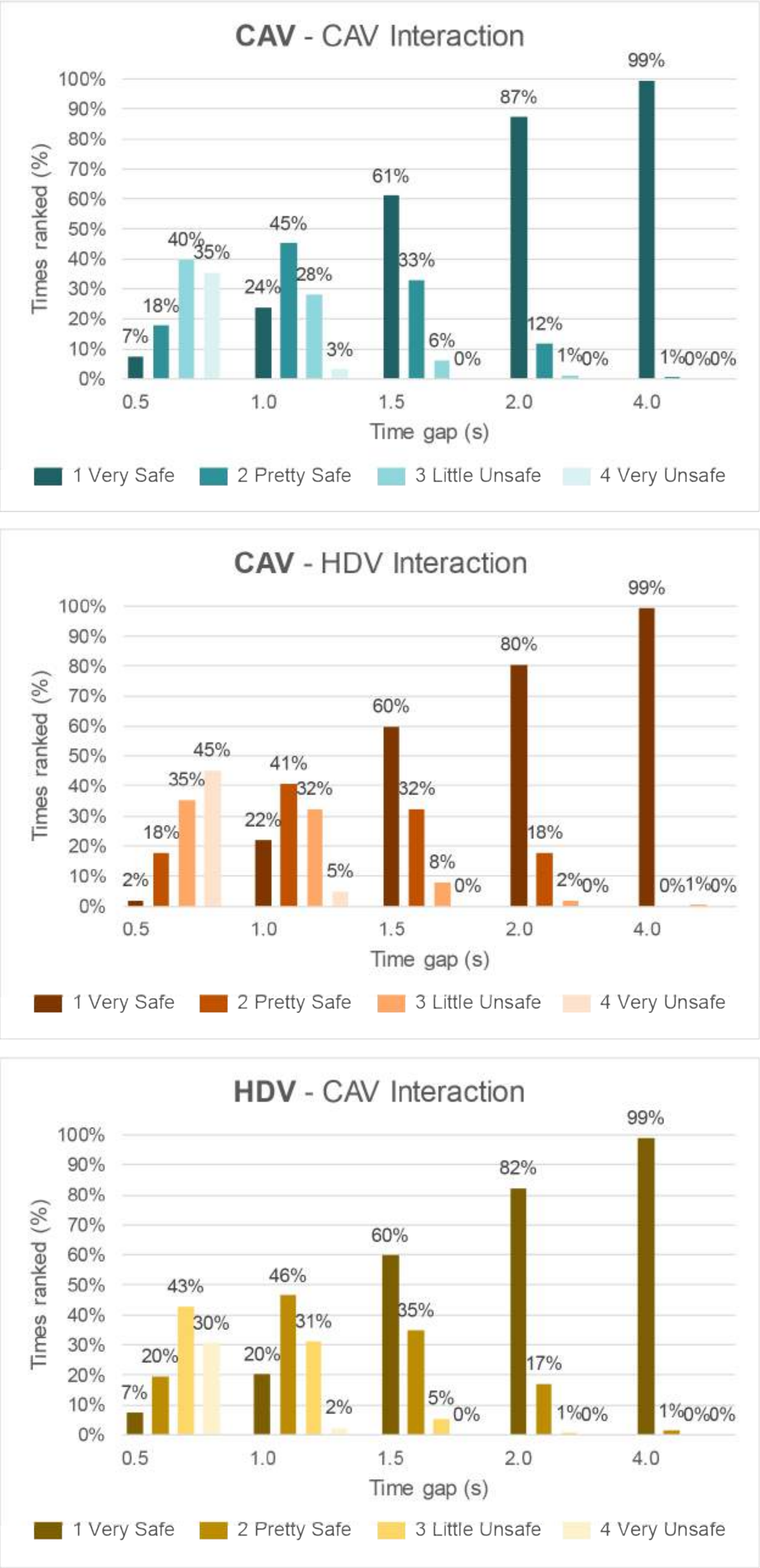
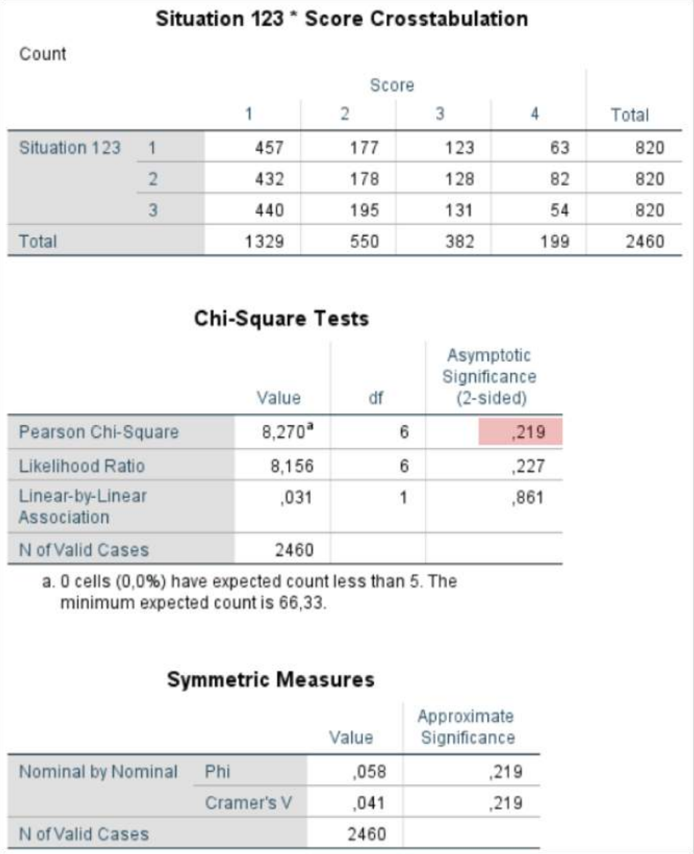


Figure F.12: Scores given per time gap. Crossing direction combined and visualized per interaction scenario.

Chi-Square test for independence - All Interaction Scenarios



Situation 123 * Score Crosstabulation

Count

		Score				Total
		1	2	3	4	
Situation 123	1	457	177	123	63	820
	2	432	178	128	82	820
	3	440	195	131	54	820
Total		1329	550	382	199	2460

Chi-Square Tests

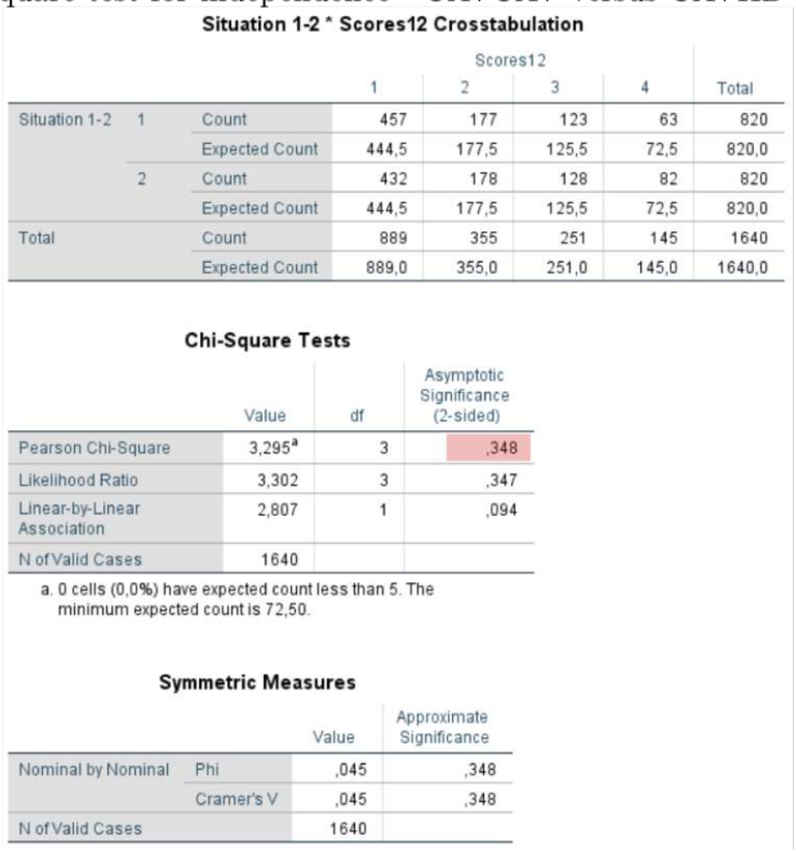
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8,270[a]	6	,219
Likelihood Ratio	8,156	6	,227
Linear-by-Linear Association	,031	1	,861
N of Valid Cases	2460		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 66,33.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,058	,219
	Cramer's V	,041	,219
N of Valid Cases		2460	

Chi-Square test for independence - CAVCAV versus CAVHDV



Situation 1-2 * Scores12 Crosstabulation

			Scores12				Total
			1	2	3	4	
Situation 1-2	1	Count	457	177	123	63	820
		Expected Count	444,5	177,5	125,5	72,5	820,0
	2	Count	432	178	128	82	820
		Expected Count	444,5	177,5	125,5	72,5	820,0
Total		Count	889	355	251	145	1640
		Expected Count	889,0	355,0	251,0	145,0	1640,0

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3,295[a]	3	,348
Likelihood Ratio	3,302	3	,347
Linear-by-Linear Association	2,807	1	,094
N of Valid Cases	1640		

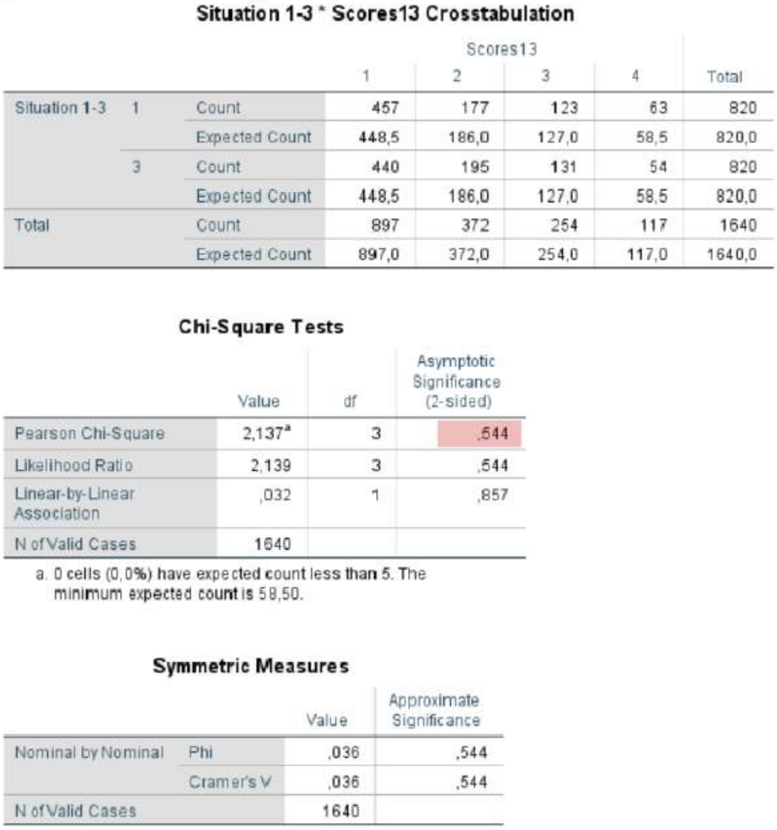
a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 72,50.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,045	,348
	Cramer's V	,045	,348
N of Valid Cases		1640	

Figure F.13: Chi-Square test for independence of interaction scenarios - test 1 and 2

Chi-Square test for independence - CAVCAV versus HDVCAV



Situation 1-3 * Scores13 Crosstabulation

			Scores13				
			1	2	3	4	Total
Situation 1-3	1	Count	457	177	123	63	820
		Expected Count	448,5	186,0	127,0	58,5	820,0
	3	Count	440	195	131	54	820
		Expected Count	448,5	186,0	127,0	58,5	820,0
Total		Count	897	372	254	117	1640
		Expected Count	897,0	372,0	254,0	117,0	1640,0

Chi-Square Tests

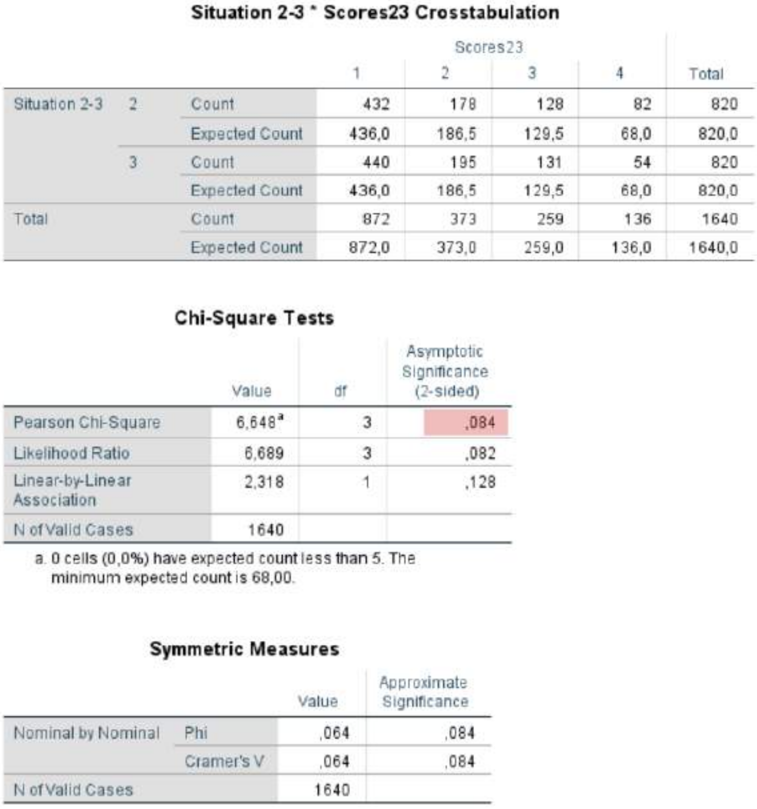
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2,137a	3	,544
Likelihood Ratio	2,139	3	,544
Linear-by-Linear Association	,032	1	,857
N of Valid Cases	1640		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 58,50.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,036	,544
	Cramer's V	,036	,544
N of Valid Cases		1640	

Chi-Square test for independence - CAVHDV versus HDVCAV



Situation 2-3 * Scores23 Crosstabulation

			Scores23				
			1	2	3	4	Total
Situation 2-3	2	Count	432	178	128	82	820
		Expected Count	436,0	186,5	129,5	68,0	820,0
	3	Count	440	195	131	54	820
		Expected Count	436,0	186,5	129,5	68,0	820,0
Total		Count	872	373	259	136	1640
		Expected Count	872,0	373,0	259,0	136,0	1640,0

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	6,648a	3	,084
Likelihood Ratio	6,689	3	,082
Linear-by-Linear Association	2,318	1	,128
N of Valid Cases	1640		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 68,00.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,064	,084
	Cramer's V	,064	,084
N of Valid Cases		1640	

Figure F.14: Chi-Square test for independence of interaction scenarios - test 3 and 4

G

Correlations independent variables and dependent variables

In total, 7 statistical tests were executed in order to find an association between an independent variable and the dependent variable *score*. Only three (weak) correlations were found. However, the correlation between gender and score was defined to be invalid to apply to the whole population, because of the unequal distribution between men and women in the sample. The variables considered, the test applied, the P-value and correlation coefficient found are described in Table G.1.

Table G.1: Results Research Association between Dependent Variable and any Independent Variable. * This correlation may not apply to the whole population

	Test Applied	**Association?**	**(If yes) P-value**	**(If yes) Correlation Coefficient**
Affinity vs. Score	Chi-Square / Cramer's V	Yes	0.015	0.065
AV Experience vs. Score	Chi-Square / Cramer's V	No	-	-
Gender vs. Score	Chi-Square / Cramer's V	Yes	0.002	0.077*
Driving Experience vs. Score	Spearman's Correlation	No	-	-
Driving Style vs. Score	Spearman's Correlation	Yes	0.025	0.045
Driving Hours vs. Score	Spearman's Correlation	No	-	-
Age vs. Score	Spearman's Correlation	No	-	-

Besides, also the correlations between independent variables were described. A new correlation coefficient is used here: Kendall's tau-b. This coefficient is very similar to the Spearman's correlation coefficient, but it can better deal with smaller sample sizes (?, ?). This is favorable for studying the correlations between the independent variables, since for each independent variable only 82 values were available (compared to 30 traffic situations × 82 participants = 2460 values for the tests where Spearman's correlation value was used).

In total, four associations were found between independent variables:

- *Gender* and *Driving Experience*: A moderate and positive association was found by applying a Chi-Square test. However, this association may be different or does not exist in the population.
- *Driving hours* and *Driving Experience*: A Kendall's tau-b value of 0.412 was found, which indicates a moderate and positive relationship.
- *Age* and *Driving Hours*: The Kendall's tau-b value equaled 0.496, which again illustrates a moderate and positive relationship. Note that all age groups were covered in the sample, but not in the same distribution as the real population.
- *Age* and *Driving Experience*: Again a positive, but stronger relationship. The Kendall's tau-b value of 0.753 indicates a strong and positive relationship. Again note that all age groups were covered in the sample, but not in the same distribution as the real population.

Table **??** shows the correlation coefficients found between two independent variables. For each correlation, either the Cramer's V or Kendalls tau-b value was displayed, depending on the type of data. When at least one of the independent variables was nominal data, the Chi-Square test had to be applied. When both vehicles were ordinal data, the Kendall's tau-b was applied.

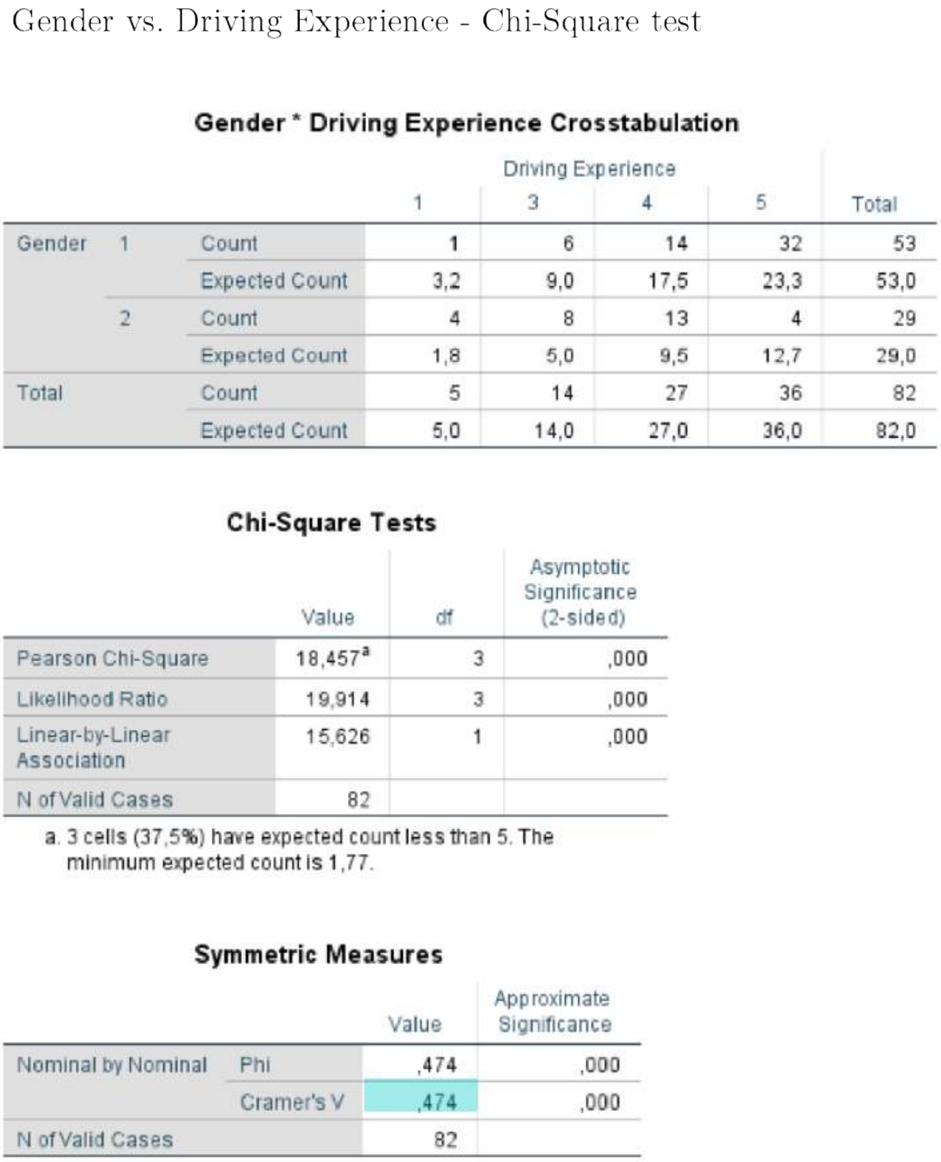
Table G.2: Correlations between independent variables. X = No association; Red value = Cramer's V; Green value = Kendall's tau-b

	Affinity	**AV Experience**	**Gender**	**Driving Experience**	**Driving Style**	**Driving Hours**	**Age**
Affinity	-						
AV Experience	X	-					
Gender	X	X	-				
Driving Experience	X	X	0.474	-			
Driving Style	X	X	X	X	-		
Driving Hours	X	X	X	0.412	X	-	
Age	X	X	X	0.753	X	0.496	-

For all tests, the hypotheses below were applied. The null-hypothesis was rejected when a significant correlation coefficient resulted from SPSS.

- H_0: The two variables are not associated.
- H_1: The two variables are associated.

Figures G.1 to G.3 show the complete outcome of the statistical tests that resulted in significant correlation values. The P-values are shown in these figures too.



Gender vs. Driving Experience - Chi-Square test

Gender * Driving Experience Crosstabulation

			Driving Experience				Total
			1	3	4	5	
Gender	1	Count	1	6	14	32	53
		Expected Count	3,2	9,0	17,5	23,3	53,0
	2	Count	4	8	13	4	29
		Expected Count	1,8	5,0	9,5	12,7	29,0
Total		Count	5	14	27	36	82
		Expected Count	5,0	14,0	27,0	36,0	82,0

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18,457[a]	3	,000
Likelihood Ratio	19,914	3	,000
Linear-by-Linear Association	15,626	1	,000
N of Valid Cases	82		

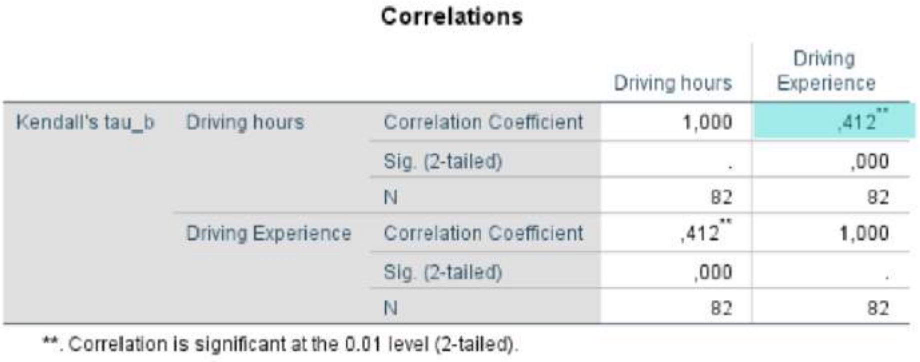
a. 3 cells (37,5%) have expected count less than 5. The minimum expected count is 1,77.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,474	,000
	Cramer's V	,474	,000
N of Valid Cases		82	

Figure G.1: Cramer's V Correlation Value (blue) - Gender vs. Driving Experience

Driving hours vs. Driving Experience - Kendall's tau-b value

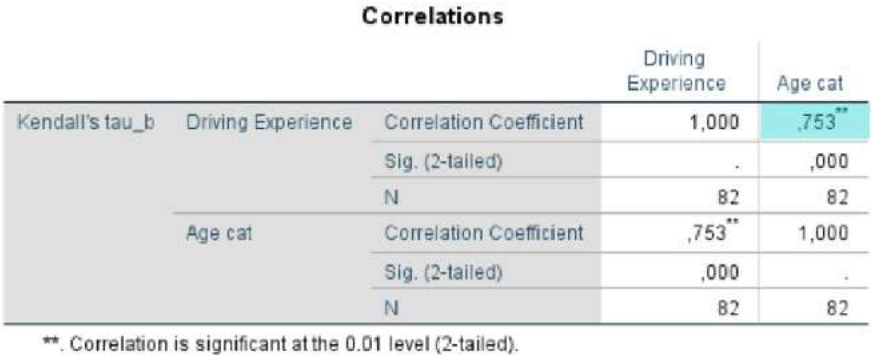


Correlations

			Driving hours	Driving Experience
Kendall's tau_b	Driving hours	Correlation Coefficient	1,000	,412**
		Sig. (2-tailed)	.	,000
		N	82	82
	Driving Experience	Correlation Coefficient	,412**	1,000
		Sig. (2-tailed)	,000	.
		N	82	82

**. Correlation is significant at the 0.01 level (2-tailed).

Age vs. Driving Experience - Kendall's tau-b value

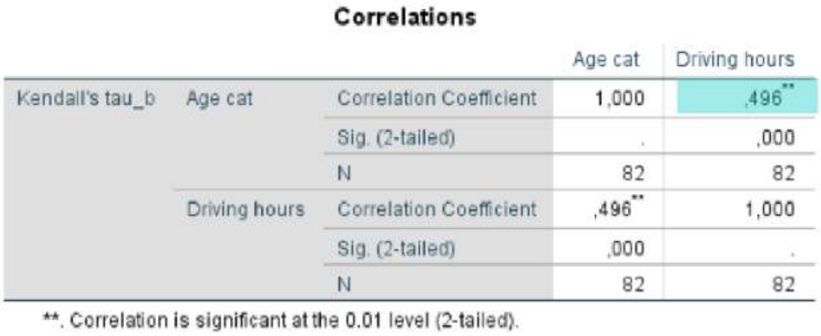


Correlations

			Driving Experience	Age cat
Kendall's tau_b	Driving Experience	Correlation Coefficient	1,000	,753**
		Sig. (2-tailed)	.	,000
		N	82	82
	Age cat	Correlation Coefficient	,753**	1,000
		Sig. (2-tailed)	,000	.
		N	82	82

**. Correlation is significant at the 0.01 level (2-tailed).

Age vs. Driving Hours - Kendall's tau-b value



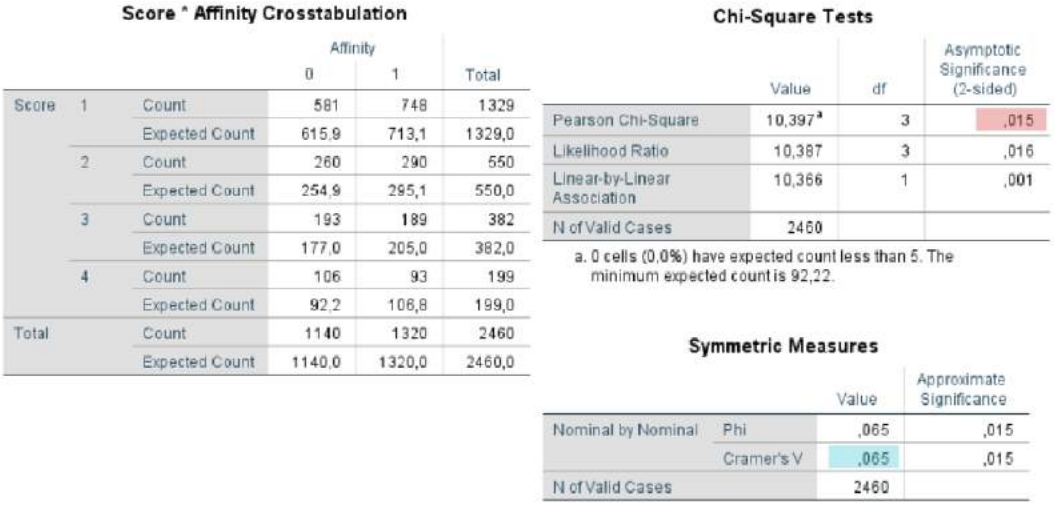
Correlations

			Age cat	Driving hours
Kendall's tau_b	Age cat	Correlation Coefficient	1,000	,496**
		Sig. (2-tailed)	.	,000
		N	82	82
	Driving hours	Correlation Coefficient	,496**	1,000
		Sig. (2-tailed)	,000	.
		N	82	82

**. Correlation is significant at the 0.01 level (2-tailed).

Figure G.2: Kendall's tau-b Correlation Value (blue) - Age vs. Driving Experience vs. Driving Hours

Chi-Square test for independence - Score vs. Affiinity (Smart) Mobility



Score * Affinity Crosstabulation

			Affinity		
			0	1	Total
Score	1	Count	581	748	1329
		Expected Count	615,9	713,1	1329,0
	2	Count	260	290	550
		Expected Count	254,9	295,1	550,0
	3	Count	193	189	382
		Expected Count	177,0	205,0	382,0
	4	Count	106	93	199
		Expected Count	92,2	106,8	199,0
Total		Count	1140	1320	2460
		Expected Count	1140,0	1320,0	2460,0

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	10,397ᵃ	3	,015
Likelihood Ratio	10,387	3	,016
Linear-by-Linear Association	10,366	1	,001
N of Valid Cases	2460		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 92,22.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,065	,015
	Cramer's V	,065	,015
N of Valid Cases		2460	

Chi-Square test for independence - Score vs. Gender

Score * Gender Crosstabulation

			Gender		
			1	2	Total
Score	1	Count	896	433	1329
		Expected Count	859,0	470,0	1329,0
	2	Count	354	196	550
		Expected Count	355,5	194,5	550,0
	3	Count	227	155	382
		Expected Count	246,9	135,1	382,0
	4	Count	113	86	199
		Expected Count	128,6	70,4	199,0
Total		Count	1590	870	2460
		Expected Count	1590,0	870,0	2460,0

Chi-Square Tests

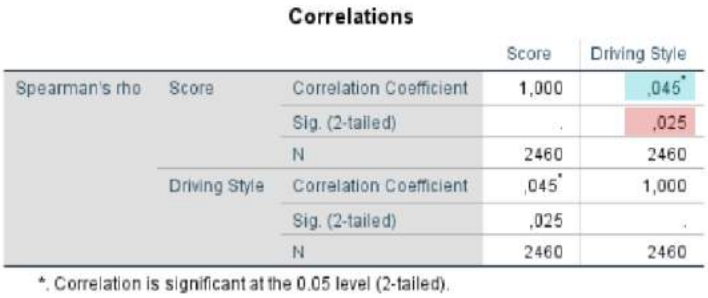
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	14,428ᵃ	3	,002
Likelihood Ratio	14,247	3	,003
Linear-by-Linear Association	14,253	1	,000
N of Valid Cases	2460		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 70,38.

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,077	,002
	Cramer's V	,077	,002
N of Valid Cases		2460	

Spearman's Rho Correlation - Score vs. Driving Style



Correlations

			Score	Driving Style
Spearman's rho	Score	Correlation Coefficient	1,000	,045*
		Sig. (2-tailed)	.	,025
		N	2460	2460
	Driving Style	Correlation Coefficient	,045*	1,000
		Sig. (2-tailed)	,025	.
		N	2460	2460

*. Correlation is significant at the 0.05 level (2-tailed).

Figure G.3: Significant associations Dependent and Independent variables. Significance value in blue; Correlation coefficient in red.