A Quantification of the Operation of ADAS while Driving and the Potential Associated Risks

Assessing the probability of distraction

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Abstract

The rapidly increasing prevalence and use of Advanced Driver Assistance Systems (ADAS) results in growing attention on how users interact with these different systems. Research in the human factor area of ADAS becomes more and more pressing with this increase in use, and it is important to focus on the users' perspective and their behaviour regarding ADAS usage on the road. This study aims to quantify the operation of ADAS (e.g., turning the systems on/off or adjusting settings) in the Netherlands and assess the associated risk. Previous research namely suggests that operating ADAS can lead to distractions, which can decrease road safety. A questionnaire was conducted, involving 212 participants, to gain prevalence data on the operation of six different ADAS in the Netherlands, including Adaptive Cruise Control (ACC), Lane Keeping Assistance (LKA), Blind Spot Warning (BSW), Forward Collision Warning (FCW), Indirect Driver Monitoring System (IDMS), and Intelligent Speed Assistance (ISA). Next to quantifying this data, statistical models (Generalized Linear Mixed Models (GLMM)) were fitted to the data to assess the potential associated risk. The results show that ACC and LKA are operated to the highest extent, and the operation of some ADAS (e.g. IDMS, LKA, FCW, BSW) happens quite frequently on the dashboard screen. If all cars on the road have these systems, 1 out of 2 drivers could likely get distracted by the operation of ADAS. Regarding the severity of this distracting task, this study found that drivers spend around 0.1% of their driving time on the operation (also in case all cars on the road have the systems in their car). Those results mainly raise concerns about the design of ADAS operations and future research is recommended to address those human-machine interaction issues to understand and mitigate distractions while operating ADAS.

Keywords: ADAS · Road safety · Distraction · Operation · Human factors

Contents

1. Introduction

Advanced Driver Assistance Systems (ADAS) are increasingly common in cars. Some of those systems are even mandatory in newly manufactured vehicles from July 2022 onwards (European Commission, 2022), so an increase in availability and usage is expected in the upcoming years. Generally, those systems have the potential to increase traffic safety and driving comfort, and can also be beneficial for traffic flow and the environment (MuConsult, 2023). However, this potential is only realized when drivers use those systems as intended (Ayoub et al., 2022; Hagl & Kouabenan, 2020), and a previously performed study (see Appendix I) suggests that, currently, this may not be the case. By not using the systems as intended, for example by turning them off or by over-relying on the systems, road safety can deteriorate rather than increase as a result of the usage of ADAS (Hagl & Kouabenan, 2020). According to SWOV (2019a), there is a balance; on the one hand, ADAS is preventing accidents from happening, however, on the other hand, ADAS causes new prompts for accidents. Several accidents on public roads involving ADAS have occurred, highlighting the already visible practical manifestation of risks associated with automizing cars (Onderzoeksraad voor Veiligheid, 2019). Recently, it even became apparent that also proper usage of some systems may increase crash risk (Verbond van Verzekeraars, 2024).

So, in assessing the risk, it is important to pay attention to both the safety of the technological innovation itself and the combination of this technology with the user (Onderzoeksraad voor Veiligheid, 2019). This is particularly crucial to ensure that the introduction of new prompts for accidents caused by ADAS does not outweigh the number of accidents prevented by their use. For instance, the design should ensure safety on the road and benefit traffic flow but should also be resistant to fault usage or usage by inexperienced users. Additionally, the systems should not distract the driver, however, according to the Ministerie van Infrastructuur and Waterstaat (I&W; 2024), at this point, around 30% of the users are distracted by the systems. Within the human factors area of ADAS, there is growing awareness of the interaction between technology and users, leading to increased research related to this (Ayoub et al., 2022; Hagl & Kouabenan, 2020; IIHS, 2024; MuConsult, 2023; Onderzoeksraad voor Veiligheid, 2019; SWOV, 2019a; Verbond van Verzekeraars, 2021). Nevertheless, there is still limited information about the operation of ADAS by users. A preceding study highlighted reasons to think that this operation happens while driving, which can deteriorate road safety due to drivers looking away from the road when operating it or by causing cognitive overload (see Appendix I). This preceding study posed significant questions for further research, and among those questions is the need to quantify the scope of drivers operating ADAS while driving in the Netherlands, as well as to assess the potential risk of this operation. The current study will address this quantification by conducting a survey and subsequently trying to assess the potential risk of the operation of ADAS by fitting a statistical model to the gathered data.

Before further details on the current study are provided, first, a small study that preceded this study will be shortly elaborated upon. Subsequently, a theoretical background will be given focusing on assessing the risk. For a more elaborate theoretical framework focusing on the operation of ADAS and the associated potential risk, the preceding study in Appendix I can be consulted. Further, the methods of the conducted survey and the data analysis are given, and the results of both the quantification and the risk analysis will be presented. Lastly, limitations of the performed study will be elaborated upon and further recommendations for research will be provided.

1.1 Preceding study

This section will provide a brief summary of a previously conducted study, which serves as the background for the current study. A complete overview of the previously performed study can be found in Appendix I.

Firstly, a literature study was conducted, which showed that the operation of ADAS while driving might be a possible distractor for drivers. Distracted driving can cause great consequences for traffic safety, for example by affecting reaction time, glance behaviour and subjective workload (European Commission, 2018), and should thus be lowered as much as possible. Additionally, the operation of those systems is in some cars located on the dashboard screen, which causes drivers to take their eyes off the road for a rather long time. This form of visual distraction is dangerous and might result in accidents due to too little attention to the road ahead (Shaaban et al., 2018). The literature review also indicated several reasons to think that drivers do operate the systems while driving, for example, due to frustrations caused by de systems. What did not become clear from the literature review was to which extent the operation of ADAS happens.

The subsequent interviews performed showed that Adaptive Cruise Control (ACC), Lane Keeping Assistance (LKA) and Intelligent Speed Assistance (ISA) were the systems that were operated the most during driving. The operation involved drivers turning the systems off (and sometimes on) and adjusting settings. However, those operations were only occasionally done. In some cars, the operation of ADAS indeed happens on the dashboard screen, and therefore, drivers are required to take their eyes off the road. Regardless, the exact numbers of this operation remain unknown. Further, LKA is amongst the systems that cause the most frustration for drivers. This frustration is usually caused by the system wanting to stay between lines while the situation requires crossing a line. Lastly, although the opinions were divided, most participants believed that ADAS has the potential to make driving safer, however, they also agreed that currently, this is not yet the case due to the systems not working properly in all situations.

1.2 Assessing the potential risk

One commonly used method for estimating the risk of distracting tasks in a car is estimating an odds ratio, which indicates the likelihood of an accident happening due to a specific action (expressed in percentages), compared to a baseline where that action is not taking place. Nevertheless, estimating the risk using odds ratios only shows a small portion of the actual risk, as it only shows the tasks that have a higher chance of a crash or near-crash (European Commission, 2018). What is also important to estimate is the duration and frequency of this task, or in other words the prevalence data (European Commission, 2018). For example, a distracting task with a high odds ratio that is not happening often might not be as dangerous as a distracting task with a low odds ratio that is happening very often. Further, crash studies are also often performed to estimate a potential risk, and for this, data from police reports or insurance companies is used. Again, those studies often overlook exposure data, making it challenging to assess relative risk accurately (Backer-Grøndahl & Sagberg, 2011). Although there are already studies gathering prevalence data of ADAS usage (Dingus et al., 2006; Ministerie van I&W, 2024; Verbond van Verzekeraars, 2021), the combination of information about the prevalence and the risks or odds ratios in one study is highly limited. Acknowledging the importance of both forms of data, this study focuses on assessing the risk of operating ADAS while driving, including both the prevalence data and the associated potential risk. It has to be noted that no information about crashes is available for this research, thus crash data is not included in this study.

1.2.1 Prevalence data

Starting with the prevalence data, the probability that the system is used is of importance to assess the potential risk of operating ADAS while driving. It is essential to know how many drivers are using ADAS at this moment, since all drivers who do not use or do not have ADAS in their cars, do, at this point, not pose a risk to road safety by operating the systems. Nevertheless, more and more car drivers will likely have those systems in their cars (VMS Insight, 2023), which is also important to take into account. Previous research already monitored the usage of ADAS in the Netherlands (MuConsult, 2023; Van Mierlo, 2023), however, there are systems in the current study that are not prevalent in their study (e.g. Traffic Light Recognition or Head-up Display). Hence, it is needed to gain more knowledge about how many drivers are using the different systems in the Netherlands.

Secondly, it is also important to know the probability that the system is operated. This is important as a distracting task that happens quite frequently but is only associated with rather low increased risk might be more dangerous than a task that is likely to lead to a high risk increase but does only happen very occasionally (Adedeji et al., 2020). The Ministerie van I&W (2024) provides a table in which it is visible how many of their respondents turn their system on or off, however, no information is provided about the frequency of this action. Information about adjusting settings for

ADAS cannot be found. Both information about the frequency of distracting tasks happening and about the duration of these tasks are crucial for determining whether a specific form of distraction is likely to affect the crash risk and to which extent (European Commission, 2018). Hence, research should reveal the number of times a system was operated either by turning it on or off or by adjusting the settings, and the self-reported duration of such an action.

1.2.2 Causes of potential risk

The Ministerie van I&W (2024) shows that there has been an increase in distraction due to the operation of ADAS over the past few years. In 2021, around 21% of their participants were severely or somewhat distracted by the operation of ADAS, while in 2022, this was already 32%. They also mention that in 2023 it was even higher, but a reason for this increase could not be given. That the operation of ADAS is distracting is thus rather clear now, and in the past few months, this has been multiple times brought under attention (e.g., IIHS, 2024; Nederend, 2024; van Ringelestijn, 2024). However, it is not often mentioned that this increased distraction within the car is a potential source for increased risk on the road, and most importantly, why this distraction can lead to less road safety.

When turning a system on or off, or by adjusting settings, the driver is likely to look away from the road. Liang et al. (2012) showed significant effects of looking away from the road on crash risk, indicating higher risk associated with looking away. According to Klauer et al. (2006), looking away from the road for more than 2 seconds can already double the chances of an accident happening compared to keeping your eyes on the road the entire time. Gershon et al. (2019) even found that the crash risk increased by 28% for every second a driver takes their eyes off the road. The duration of operating ADAS might be an indicator of how long the driver is looking away from the road and is thus important for determining the potential risk increase when operating ADAS while driving.

Distractions while driving can take various forms, including visual and cognitive distraction. Visual distraction happens when a driver has to remove their eyes from the road, while cognitive distraction occurs when the driver needs to process information to perform a certain task (Shaaban et al., 2018). As shown in the preceding study (Appendix I), and based on the multiple resources theory (Wickens, 2002), it is likely that the operation of ADAS causes both cognitive and visual distractions. While cognitive distractions tend to have a relatively smaller impact on the crash risk (Dingus et al., 2019), the combination of visual and cognitive distraction resulted in significant driver errors (Kaber et al., 2012). Further, manual distraction, including taking the hands off the steering wheel to perform an action, can also increase the likelihood of an accident (Shaaban et al., 2018). Other important factors are the mental workload that increases due to performing the distracting task (Ayoub et al., 2022; Backer-Grøndahl & Sagberg, 2011) and manual deterioration, meaning the decline in performance due to performing a distracting task (Hagl & Kouabenan, 2020). The location of operation might thus be interesting to find out if other forms of distraction are also caused by the operation of ADAS.

To assess the potential risk associated with the operation of ADAS, it is thus important to determine the scope of the operation while driving in the Netherlands. Apart from the study of the Ministerie van I&W (2024), there is not much research done on quantifying the scope of this distraction problem due to the operation of ADAS specifically. By quantifying the probability that the system is used and the probability that the system is operated, the scope of the problem in the Netherlands can be determined. The risk can then be calculated, for example, by estimating an odds ratio and by estimating the prevalence.

1.3 Current study

The previously conducted study posed the question of how many drivers in the Netherlands actually operate ADAS while driving and, subsequently, what the exact associated risk is. The literature review of that study namely revealed that the operation of ADAS while driving might be a high risk for traffic safety due to the combination of cognitive as well as visual distractions it provides. For the operation of ADAS, drivers likely have to take their eyes off the road, which can also significantly increase the crash risk. Moreover, more and more research is also indicating that this operation of ADAS potentially decreases road safety (Ministerie van I&W, 2024; Nederend, 2024; van Ringelestijn, 2024). The interviews performed in the preceding study show that people are likely to operate the systems while driving, however, a rather small sample was included in those interviews. Thus, more research is needed to quantify this operation of ADAS while driving in the Netherlands.

Currently, there is only limited research performed regarding the operation of ADAS while driving, and the risk of it is therefore not yet clear. It now becomes more and more clear that the design of ADAS within cars might be problematic (Nederend, 2024), however, it remains rather unclear what the viewpoint of the users of ADAS exactly is, and to which extent they interact with those systems. It is also not clear what the exact associated risk of ADAS usage is in numbers. Hence, this current study aims to quantify the operation of ADAS in the Netherlands and to assess the potential risk of this operation while driving. Additionally, the aim is to indicate which ADAS might be a potential source of distraction (and why), which can potentially serve as a basis for future research into this area. Using the outcomes of this study, a gap in human factor research regarding ADAS can be addressed, as this research focuses on one of the forms of interaction between the driver and ADAS which is not researched yet. More specifically, the results can help in providing advice on policy guidelines or in coming up with design guidelines for car manufacturers. This will be done according to the following research question: *To what extent do drivers operate ADAS while driving and what is the associated risk for road safety?* To answer this question, a survey was conducted to quantify the operation of ADAS in the Netherlands, and additionally, the risk, and differences between the systems in terms of risk, were assessed by using generalized linear mixed-effects modelling. Several systems were taken into account for this study (see Table 1), and those include the systems that can be operated and are relevant for the main driving tasks. Based on the previously performed interviews, a distinction was made between the systems that were likely to be operated the most (the six main systems) and systems that were likely to be operated to a lesser extent (the other systems). An explanation of those systems can be found in Appendix I.

Table 1

ADAS used in this current study and their abbreviations

Likely to be operated the most (six main systems)	
Name of the system	**Abbreviation**
Adaptive Cruise Control	ACC
Lane Keeping Assistance	LKA
Blind Spot Warning	BSW
Forward Collision Warning	FCW
Indirect Driver Monitoring System	IDMS
Intelligent Speed Assistance	ISA
Likely to be operated to a lesser extent (other systems)	
Name of the system	**Abbreviation**
Automatic High Beams	AHB
Traffic Light Recognition	TLR
Head-Up Display	HUD
Lane Centering Assistance	LCA
Active Driving Assistance	ADA
Pedestrian Detection	PD
Automatic Emergency Braking	AEB
Lane Departure Warning	LDW
Rear Cross Traffic Warning	RCTW
Wrong-Way Driving Warning	WWDW
Automatic Emergency Steering	AES
Reverse Automatic Emergency Braking	RAEB
Direct Driver Monitoring System	DDMS
Driver Re-engagement System	DRS

2. Method

2.1 Design

In this study, a questionnaire was conducted to quantify the operation of ADAS and additionally, a statistical analysis was performed to assess the potential risk the operation of ADAS might bring. The Ethics Committee of the University of Twente gave ethical approval for this study (request number 240087). The questionnaire, which had to be filled out once by the participants, consisted of questions relevant for the prevalence data used to assess the potential risk, as well as for the quantification of the operation. Both demographic questions and questions about the different ADAS were included in one questionnaire (Appendix II). The questionnaire was distributed online with a short explanation of the study and the link to the questionnaire (Appendix II), and all participants had to fill out the same questionnaire. The data was gathered in the time span of a month.

2.2 Participants

In total, 212 participants took part in this study. Participants were recruited via non-probability sampling, including convenience sampling (e.g. asking individuals that are easily accessible) and snowball sampling (e.g. asking participants to distribute the link to the survey). Both the network of the researcher and the network of Goudappel were used to recruit participants. Restrictions for participation included being Dutch, being above 18, having a driver's license (car B) and participants had to drive at least twice a month in the same car.

Out of the participants, 122 (57.5%) identified as male, 89 (42%) as female and 1 (0.5%) chose not to say how they identified. All participants were between 18 and 67 years old, and the mean age was 39.0 (*SD* = 14.7). Participants from all twelve provinces in the Netherlands were included in the sample, and in total, 26 different car brands were included. Moreover, the mean amount of kilometers driven in the past year amongst the participants was 15440.8 km (*SD* = 16637.4). In the month preceding filling out the survey, 21% of the participants drove 0-4 times a month, 24.1% drove 5-12 times a month, 21.8% drove 13-20 times a month and 33.1% drove 21-31 times a month. Visualizations of all the demographics can be found in Appendix III (Figures 15 to 20).

2.3 Materials

2.3.1 Questionnaire

The questionnaire had to be performed online in Qualtrics and consisted of three different parts: consent, demographic questions and questions about ADAS (Appendix II). The questionnaire is based on the outcomes of the preceding study that was performed (Appendix I). The first part of the questionnaire consisted of an introduction to the study, information about the participation, time spent filling out the questionnaire, and data handling. In this part, also consent was asked from the participants to participate in the study and to use their data for this study.

The second part of the questionnaire included demographic questions, as well as questions about the car of the participants and their driving experience. Gender and age were asked as previous research showed that these factors influence crash risk (Lardelli-Claret et al., 2011; Regev et al., 2018). The province in which they live was also asked, equal to the research of MuConsult (2023). This was done to see if there might be an influence of the area in which participants live on the usage and operation of ADAS. The number of years the participant has their driving license B was asked, as Curry et al. (2015) found that the licensing age can influence crash risk as well. Then, several questions were asked about the car in which the participants most often drove, including which car brand it was, which type of this car brand and in which year the car was manufactured. For car brands, the twenty most bought car brands in 2023 (AutoWeek, n.d.) were given as choice options, and "other, namely:" was included for car brands that were not included. Those questions were asked to be able to find potential differences and similarities across car brands, types or manufacturing years regarding the usage and operation of ADAS. Lastly, in this section, questions about the driving experience were asked, including how many kilometers they drive on average per year and how long their average trip is in kilometers. Then, the driving experience of the 30 days before filling out the survey was asked, including both a question about the number of times they drove in the past month and about the number of kilometers they drove in the past month. A time period of 30 days was chosen as a short recall period is recommended to lower the effects of memory loss as much as possible (Marquis & Moore, 2010). However, since participants had to drive at least two times a month to participate, a shorter period than 30 days would not be possible. All in all, the answers to these questions can be used as predictor terms in the analyses of the possible risk, and additionally, some can also be used to quantify the operation of ADAS.

In the third part of the questionnaire, questions about the use and operation of different ADAS were asked. The selection of systems and questions asked were based on the previously performed study (Appendix I). The focus was on systems that were mentioned as being operated by three participants or more during the interviews earlier conducted, and included Adaptive Cruise Control (ACC), Lane Keeping Assistance (LKA), Blind Spot Warning (BSW), Forward Collision Warning (FCW), Indirect Driver Monitoring System (IDMS), and Intelligent Speed Assistance (ISA). For each of those systems, participants were provided with an explanation based on the descriptions provided by AAA (2022). For this research, the explanation was slightly adjusted to be able to include the perspective of actual system use and behaviour, aiming to make it as easy as possible for participants to recall whether they use the system or not. For those six main systems, it was asked whether the participants used the system in the past month, and in case they did use the system in the past month, more questions had to be filled out, including the number of times they used the system in the past month, the number of times they turned the system on or off in the past month, and the number of times they adjusted settings in the past month. For every system, examples of adjusting settings were given specifically for that system. The participants were also asked to indicate how long they believe they spend on performing an action such as turning the system on or off or adjusting settings, and lastly, they were asked to specify the location in the car where these operations typically occur.

Further, in the third part of the survey, for fourteen other systems, it was asked whether participants felt like these systems ever caused distractions while operating them. It was decided to only ask one question about these systems to reduce the time spent filling out this questionnaire. Those fourteen systems were chosen based on the study performed previously (Appendix I) and were all systems used during the actual driving task that could be operated. For this part of the survey, it was expected that participants could now indicate what was meant by distraction caused by the operation of ADAS based on the previously asked questions for the first six systems. Lastly, it was asked if participants still had remaining comments and the contact details of the researcher were provided for possible questions or concerns.

2.4 Procedure

The questionnaire was first tested by five participants to see if the questions were asked understandably and if the estimated time was correct. After this test phase, the questionnaire was distributed via several online platforms (e.g. LinkedIn, WhatsApp, etc.), and participants could access the questionnaire via a link. They first had to provide consent to participate in the study and afterwards went to a page where they had to fill out the demographic questions. Lastly, they were guided to a page where the questions about the ADAS were presented. The data collection period was from the 22nd of February 2024 until the 22nd of March 2024.

2.5 Data analysis

To quantify the operation of ADAS, the data was analyzed using descriptive statistics in RStudio. Several different plots (e.g. circle diagram, box plot, mosaic plot) were created to visualize and analyze the data. To show the quantification, tables with percentages were created, and the systems were compared against each other in the end.

Additionally, to assess the potential risk, several Bayesian generalized linear mixed models (GLMM) were fitted to the data. For the six main systems, the distraction time was first calculated by multiplying the sum of the number of times the systems were turned on/off or adjusted by the number of seconds a certain action took. This time was then divided by the total number of seconds the participant drove in the past month, which was calculated by multiplying the number of kilometers driven in the past month by the number of seconds it takes to drive 1 kilometer given an average speed of 80 km/h. Afterwards, the best-fitted model was each time determined by conducting a comparison of models using the leave-one-out cross-validation method to calculate the information criteria (IC) for each model (Schmettow, 2021). Lastly, the odds of being distracted by the system were calculated using the GLMM. Also for the systems included under "other systems" in the questionnaire, the odds of being distracted by the systems were calculated using GLMM. All odds were converted to probabilities (odds / (1 + odds)), after which it was calculated how many seconds were likely to be spent on the operation for the six main systems, or how many drivers were likely to be distracted by the operation for the fourteen other systems (1 / probabilities).

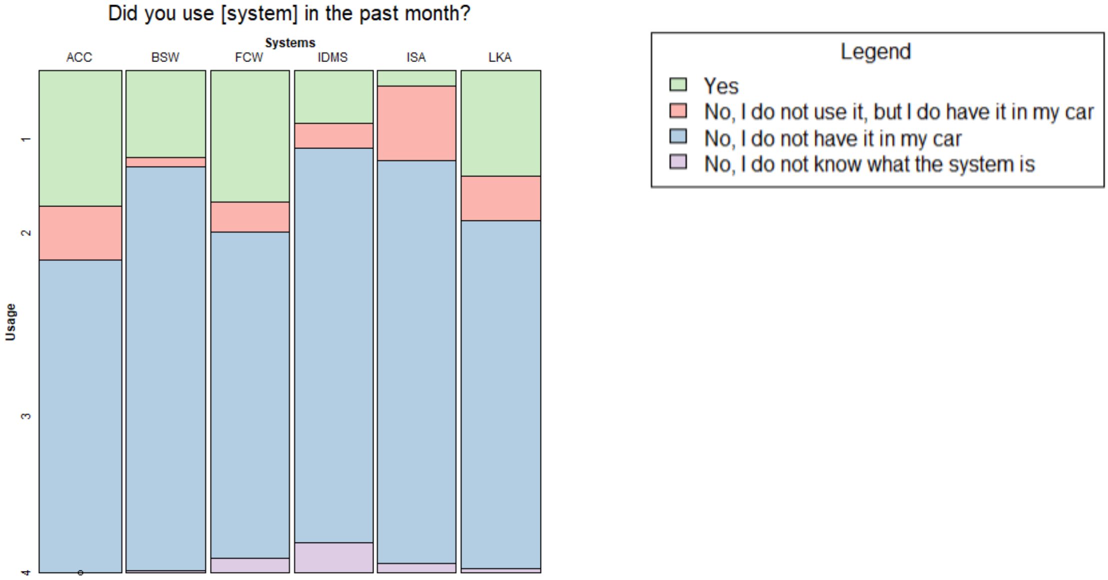
3. Results

3.1 Quantification of operation of ADAS

To quantify the data, several visualizations in the form of mosaic plots were made (Figures 1 to 10). With mosaic plots, it is possible to gain deeper insights into multivariate categorical data in an easy and ordered manner (Theus, 2012). In this case, the width of the bar shows the number of participants that provided an answer to the questions about the system mentioned above the bar. Hence, in Figures 1, 2, 4, 6, and 8, all bars have an equal width because all participants are included in those plots. In Figures 3, 5, 7, 9 and 10, where only users of the systems are included, it is visible that Adaptive Cruise Control (ACC), Forward Collision Warning (FCW) and Lane Keeping Assistance (LKA) are used more often (e.g., more participants answered those questions) than Blind Spot Warning (BSW), Indirect Driver Monitoring System (IDMS) and Intelligent Speed Assistance (ISA) based on the width of the bars. Moreover, the height of a coloured piece of the bar shows the frequency of answers in the corresponding category, meaning that the higher the piece of the bar, the more frequently someone's answer fell into the category corresponding to that colour (which is visible on the left of the bar). In the end, those visualizations make it possible to compare the different ADAS to each other on usage, frequency of usage, frequency of turning the system on or off, frequency of adjusting settings, duration of performing an operating action and the location of operation. Both plots including all answers of all participants and plots including only answers of the users of the systems are included so they can be compared as well. It has to be noted here that for some systems, participants mentioned they did use the system, however, still filled out "never" when asked about the frequency of usage. Below, the results per system will be elaborated upon. Exact numbers and percentages can be found in Appendix IV.

Figure 1

Utilization of the six main systems: ownership and past month usage among participants



Note. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option.

Figure 2

Usage frequency of the six main systems in the past month among all participants

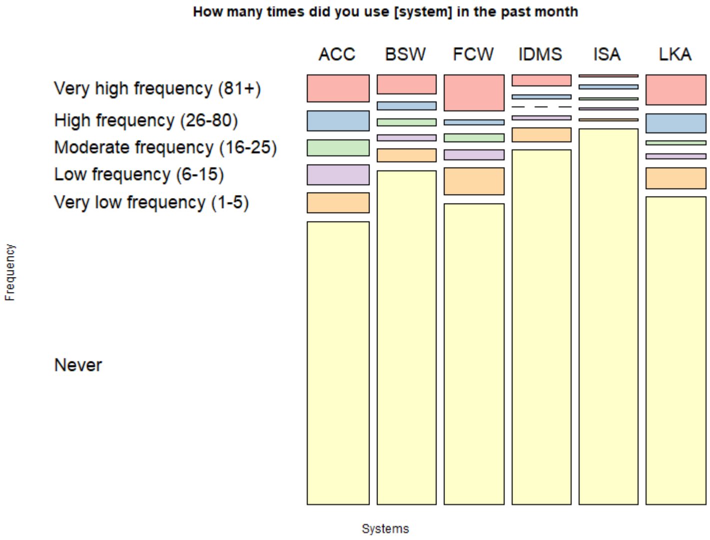
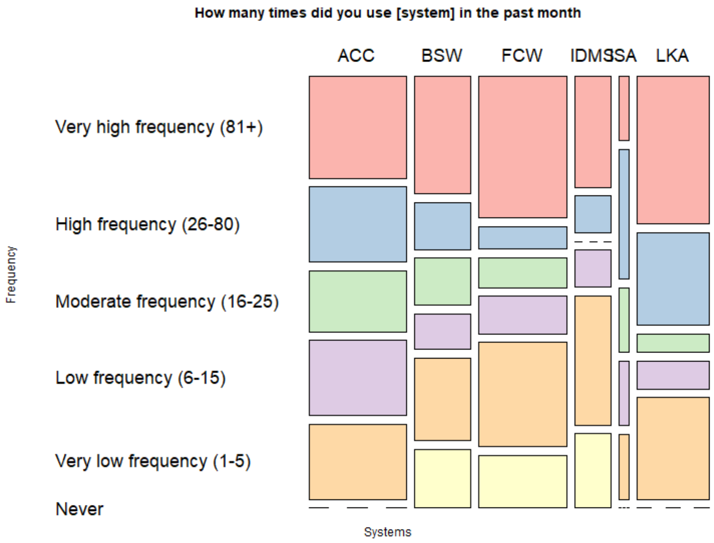


Figure 3

Usage frequency of the six main systems in the past month among users of the systems only



Note Figure 2 and 3. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side of the figures, it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option. In Figure 3, the width of the bars corresponds to the number of users for each system. A wider bar indicates a greater number of users.

Figure 4

Frequency of turning the six main systems on or off while driving in the past month among all participants

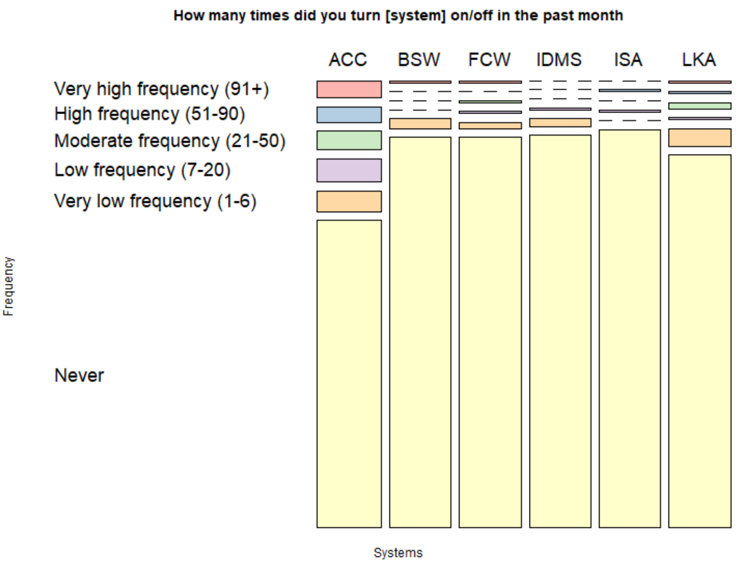
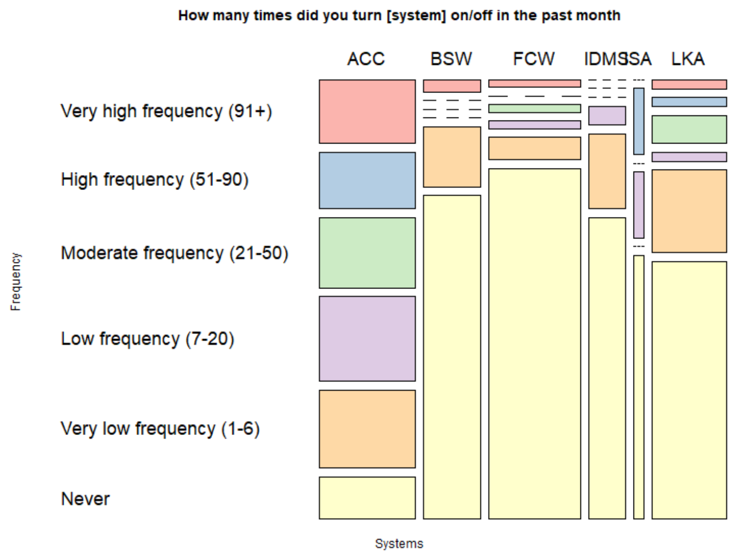


Figure 5

Frequency of turning the six main systems on or off while driving in the past month among users of the systems only



Note Figure 4 and 5. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side of the figures, it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option. In Figure 5, the width of the bars corresponds to the number of users for each system. A wider bar indicates a greater number of users.

Figure 6

Frequency of adjusting the settings of the six main systems while driving in the past month among all participants

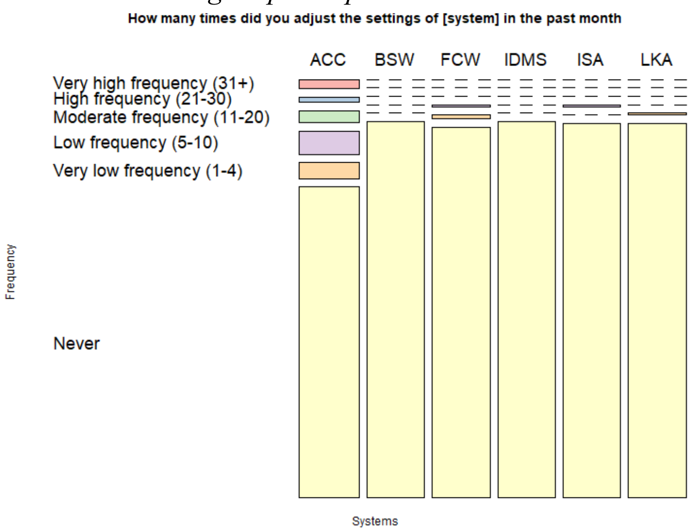
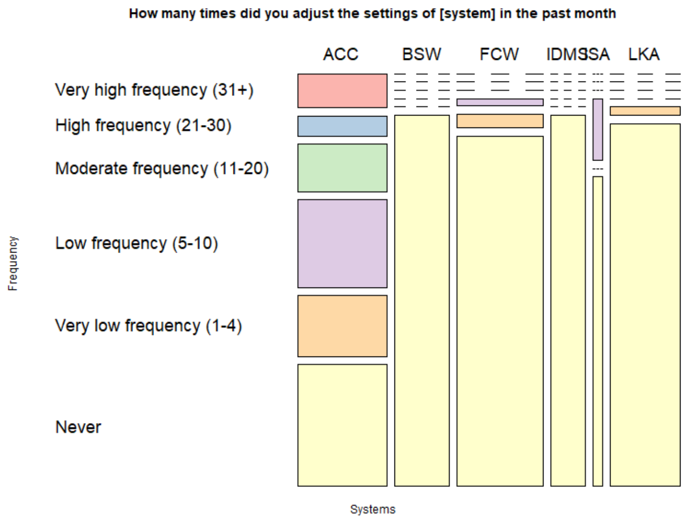


Figure 7

Frequency of adjusting the settings of the six main systems while driving in the past month among users of the systems only



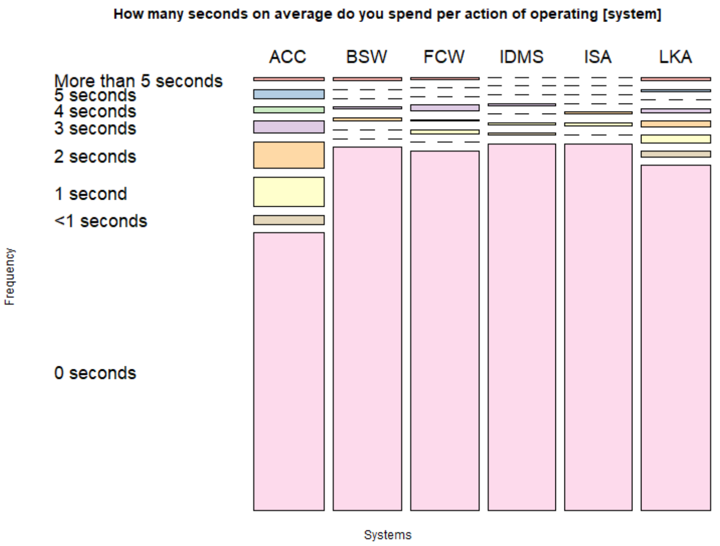
Note Figure 6 and 7. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side of the figures, it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option. In Figure 7, the width of the bars corresponds to the number of users for each system. A wider bar indicates a greater number of users.

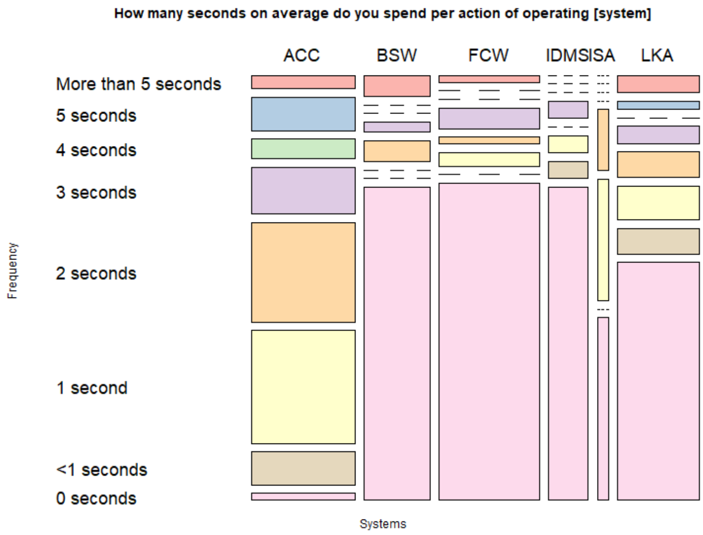
Figure 8

Duration of performing an operating action, such as turning the system on or off or adjusting settings, while driving among all participants

Figure 9

Duration of performing an operating action, such as turning the system on or off or adjusting settings, while driving among users of the systems only

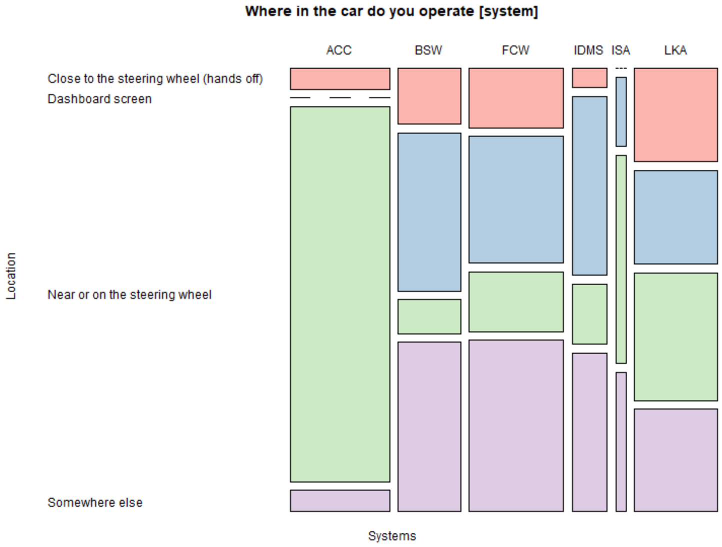




Note Figure 8 and 9. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side of the figures, it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option. In Figure 9, the width of the bars corresponds to the number of users for each system. A wider bar indicates a greater number of users.

Figure 10

Location of operation within the car for the six main systems as indicated by the participants



Note. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option.

3.1.1 Adaptive Cruise Control (ACC)

ACC is amongst the systems that are used the most and is also used quite frequently over the past month, with more than 45% of the users using it with either high or very high frequency. Nevertheless, 10% of the participants mentioned they do have it in their car but do not use it. Regarding the operation, it is visible that ACC is also turned on/off to a high extent (e.g., 30% of the users turn it on or off more than 50 times a month), and settings (e.g., setting the following distance) are adjusted the most compared to the other systems. 15% of the participants (60% of the users) mentioned that the duration of one operating action, either turning the system on or off or adjusting settings, takes them 2 seconds or more. Looking at the location where this operation happens, it is visible that almost everyone can perform those actions somewhere close to or on the steering wheel, oftentimes even without taking their hands off the steering wheel.

3.1.2 Lane Keeping Assistance (LKA)

LKA is the third most used system when comparing the six main systems, and out of the users, more than 60% indicated that they used it with (very) high frequency in the past month. Almost 9% of the participants mentioned they do have it in their car, but do not use it. Looking at the operation of LKA, it becomes visible that quite some people have the system always on (65% of the users). Nevertheless, compared to other systems, it is still operated to a rather high extent, although most often with low frequency per month. Adjusting the settings of LKA (e.g., setting alert mode or adjusting system sensitivity) is rarely done. The duration of performing an operating action for LKA is indicated to be rather high compared to the other systems, and almost 20% of the users (5% of the participants) mentioned it took them 2 seconds or longer to perform such an action. Different from Adaptive Cruise Control (ACC), the location of operation for LKA differs more amongst the participants, and although around 50% of the participants can operate LKA close to or near the steering wheel, more than 20% has to do this on the dashboard screen.

3.1.3 Blind Spot Warning (BSW)

17% of the participants is a user of BSW, and only 2% of the participants mentioned they do have it in their car but do not use it. The frequency of usage in the past month shows that most participants do use it to a high extent. Regarding the operation of BSW, it can be seen that most participants do not turn the system on or off, meaning that the system is likely to be always on in most cars. The participants who do turn the system on or off, do this most often to a low extent, and only 3% of the users (0.5% of the participants) mentioned they do this with high frequency. No one of the participants did adjust settings, including for example adjusting the volume or other functions. Although the operating actions do not happen often, they take at least 2 seconds when performed according to the participants. The location of operation differs, and more than 20% indicated they have to do this near or on the steering wheel, while almost 40% mentioned they have to do this on the dashboard screen.

3.1.4 Forward Collision Warning (FCW)

FCW is the second most used system among the participants, with 26% of them indicating they use it. 6% indicated they do have the system but do not use it. Also for FCW, the frequency of usage in the past month shows that most people do use it to a high extent. Looking at the operation, it is visible that FCW is operated to a lesser extent than LKA and ACC. Somewhat more than 10% of the users (3% of the participants) indicated that they turn FCW on or off, and only 6% of users (2.5% of the participants) mentioned they adjust settings (e.g., adjusting the sensitivity or the type of notification) in the past month. Most of the participants indicated that when performing an operating action, it takes them at least 2 seconds, however, some also indicated it only took 1 second to perform such actions. Regarding the location where this operation happens, it can be seen that this happens almost equally close to or on the steering wheel as it happens on the dashboard screen.

3.1.5 Indirect Driver Monitoring System (IDMS)

IDMS is used to a lesser extent, namely by a bit more than 10% of the participants. 5% of the participants mentioned they do have the system in their car but do not use it. The people who do use it do this almost equally to a high or low extent. The system is often not turned on or off, indicating that it is often automatically on, and when it is turned on or off, it only happens with low frequency (almost 25% of the users, and 2.5% of the participants). Nobody indicated that they adjust settings, for example adjusting the sensitivity or the volume. The time it takes to perform an operating action is rather low compared to the other systems according to the participants, as only 5% of the users indicated it took them longer than 2 seconds (0.5% of all participants). The operation of IDMS happens most often on the dashboard screen, and not even 20% of the users indicated that they perform this action near or on the steering wheel.

3.1.6 Intelligent Speed Assistance (ISA)

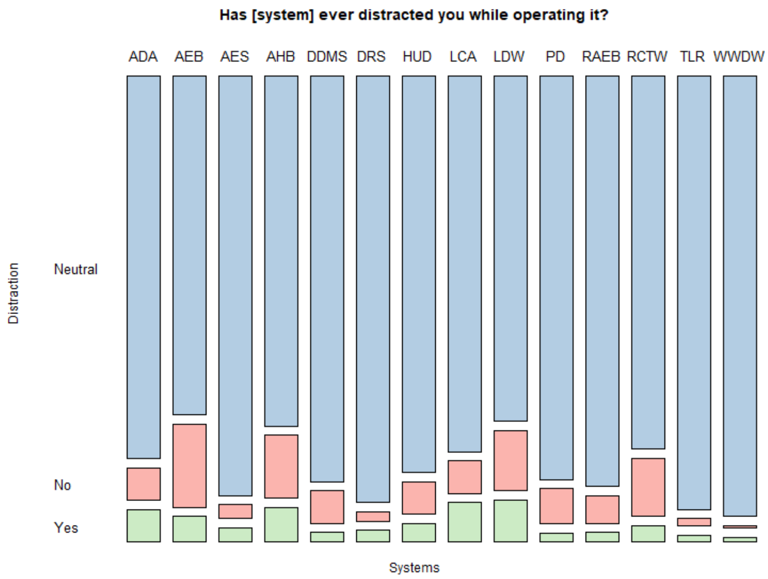
ISA is used the least out of the six main systems, as only six participants mentioned they use it (3.0%). Almost 15% of the participants did mention they do not use the system although they have it in their cars. The frequency of usage in the past month among the users differs, although slightly more users use it with high frequency. Almost 70% of the users mentioned they do not turn ISA on or off, and out of the participants that do perform this action, it is almost equally turned on or off with high or low frequency. The settings (e.g. setting the speed) are rarely adjusted, and when adjusted, the participants indicated this happened to a low extent. Similar to IDMS, the duration of performing an operating action for ISA is rather low compared to the other systems, as not even 20% mentioned it took 2 seconds, and the remaining users mentioned it took less than 2 seconds. The location of operation is mentioned to be mostly near the steering wheel and sometimes on the dashboard screen.

3.1.7 Other systems

Looking at the distraction caused by the operation of the other fourteen systems (see Figure 11), it becomes visible that there are quite some differences between them in terms of potentially being a source of distraction or not.

Figure 11

Distraction caused by operating the other systems or not



Note. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option. The answer option "neutral" indicates that the participant is not a user of the system.

Lane Departure Warning (LDW), Lane Centering Assistance (LCA), Automatic High Beams (AHB) and Active Driving Assistance (ADA) are the four systems where around 7-10% of the participants indicated they were at least sometimes distracted by the operation of these systems. Those systems also had a rather high percentage of participants being distracted by the operation when looking only at users of the systems; for ADA and LCA 50% or more, while for AHB and LDW, this was around 40% or slightly less. Then, for Automatic Emergency Braking (AEB), Head-Up Display (HUD), Rear Cross Traffic Warning (RCTW) and Automatic Emergency Steering (AES), 3-6% of the participants mentioned they were at least sometimes distracted by the operation of those systems. However, looking at only users of the systems, for AES this is 50%, for HUD almost 40% and for AEB and RCTW around 20%. Further, for Driver Re-engagement System (DRS), Reverse Automatic Emergency Braking (RAEB), Direct Driver Monitoring System (DDMS) and Pedestrian Detection (PD), between 2 and 3% of the participants indicated that they were at least sometimes distracted by the operation of those systems. When looking at the users only, 50% of the users of DRS mentioned being at least sometimes distracted, while for the other three systems (RAEB, DDMS and PD), this was around 20-25%. Lastly, Traffic Light Recognition (TLR) and Wrong-Way Driving Warning (WWDW) are the systems for which only 1-2% of the participants indicated they were at least sometimes distracted by the operation of the system, however, for both systems, 50% or more of the users indicated that it could be distracting to operate the systems.

3.2 Assessment of the potential risk

To assess the potential risk of operating ADAS, statistical models were created. More specifically, several generalized linear mixed models (GLMM) were created, which were based on known theoretical insights and were tested with model comparison using leave-one-out cross validation information criterion (LOO-IC) (Schmettow, 2021).

Gender was included in the models as a fixed effect because it has been found multiple times that gender influences attitudes towards technology use (Cai et al., 2017). Also, specifically for ADAS acceptance, gender differences were found (Son et al., 2015). However, the effect of gender on technology use and acceptance is not always found (Cai et al., 2017), and therefore, there is also a model included without the effect of gender. Age was included as a fixed effect as well because it was found that age has an influence on technology usage (Tarhini et al., 2016) and Son et al. (2015) also found age differences for ADAS acceptance specifically. Some models include a polynomial effect of age, as a linear effect might not capture the complexity of the relationship between age and distraction. It is namely often found that at a higher age, there is a negative relationship between age and perceived ease of use of technologies, due to difficulties with processing abilities and coordinating different activities at the same time (Hauk et al., 2018). Hence, some models include both a linear and quadratic relationship for age (polynomial effect) to capture this complexity.

Further, systems was included as random effect in the model as the quantification in Chapter 3.1 shows that there are likely differences in distraction caused by operating the different ADAS. Although it is not expected that effects are found between gender and the different levels of systems, this interaction is still included to check if that is indeed not the case. It is also not expected that there is an interaction effect between age and gender, however, to be sure of this, the interaction effect is included in some models. Lastly, other demographical variables are not taken into account for the models, as the answers to those questions were either not distributed well (e.g. province) or were beyond the ultimate scope of this study.

To check which model would predict distraction the best, the forecasting accuracy was evaluated by using leave-one-out cross validation information criterion (LOO-IC) (Schmettow, 2021). Using this method, observation i is removed from the dataset, after which a model is estimated. With this model, observation i is predicted, and for this observation, the predictive accuracy is then measured. Those steps are repeated until every observation is left out and forecasted once. Since several different models have to be compared, information criteria are used, which are efficient approximations of forecasting accuracy, taking into consideration both the adequacy of fit and the trade-off with model intricacy (Schmettow, 2021). A comparison table was produced to compare the models and select the most fitting one. The results of the model comparison and the GLMMs are presented below, and an overview of all models used can be found in Appendix V.

3.2.1 Potential risk of operating the six main systems

Before the statistical models could be compared, the distraction time needed to be calculated for the six main systems as it was not directly asked whether the operation of those systems caused distractions or not. This was done by adding up the number of times someone mentioned they turned the system on/off and adjusted the settings, then multiplying this by the number of seconds one action took as reported by the participant. This distraction time was then divided by the total time driven (based on an average speed of 80 km/h). The first statistical models included only the users of the systems, thus not all participants, meaning that the results show the odds of distraction in case everyone on the road has Adaptive Cruise Control (ACC), Lane Keeping Assistance (LKA), Blind Spot Warning (BSW), Forward Collision Warning (FCW), Indirect Driver Monitoring System (IDMS), and Intelligent Speed Assistance (ISA) in their car.

Five models were created based on the possible effects of gender, age and systems mentioned in Chapter 3.2. For those models, a gamma regression was used, and the created models look like this:

Model 1: including a polynomial effect of age, a fixed effect of gender and a random effect of systems:

Distraction = poly(norm_age, 2) + Gender + (1 | Systems)

Model 2: including a polynomial effect of age, a fixed effect of gender, an interaction effect of gender and age, a random effect of systems and an interaction effect of gender and systems:

Distraction = poly(norm_age, 2) * Gender + (1 + Gender | Systems

Model 3: including a polynomial effect of age, a fixed effect of gender, an interaction effect of gender and age, and a random effect of systems:

Distraction = poly(norm_age, 2) * Gender + (1 | Systems)

Model 4: including a polynomial effect of age, no effect of gender, and a random effect of systems:

Distraction = poly(norm_age, 2) + (1 | Systems)

Model 5: including a fixed effect of age, no effect of gender, and a random effect of systems:

Distraction = norm_age + (1 | Systems)

The model comparison performed using LOO-IC (see Appendix VI, Table 14) showed that the best-fitted model was Model 4. Table 15 in Appendix VI shows the outcomes of the model. However, the quadratic effect of age shows highly unrealistic values, possibly indicating oversaturation. Hence, it was decided to use a fixed effect of age rather than a polynomial effect of age. To see if it would still be best to not include gender in the model, Model 6 was created as shown below.

Model 6: including a fixed effect of age and gender, and a random effect of systems:

Distraction = norm_age + Gender + (1 | Systems)

Comparing Models 5 and 6, the best-fitted model was shown to be Model 5 (table 16, Appendix VI), only indicating an effect of age on distraction. Table 2 shows the outcomes of this model. The intercept indicates an 18-year-old driver, and the odds that an 18-year-old driver is distracted are 0.00091 (95% CI [0.00020, 0.0045]). In other words, for an 18-year-old driver, 1 out of 1097 seconds are spent on the distracting task of operating any of the six main systems. Due to uncertainty, this might also be more than 4.5 times lower (1 out of 5010 sec.) or almost 5 times higher (1 out of 221 sec.). As the age increases with one year, the odds for distraction decrease by a factor of 0.96 (95% CI [0.92, 0.99]). This means that, for instance, for a 19-year-old driver, the odds of being distracted are 0.96*0.00091 = 0.00087 (1 out of 1147 sec.), and for a 40-year-old driver, the odds of being distracted are 0.96^{22}*0.00091 = 0.00035 (1 out of 2886 sec.).

Table 2

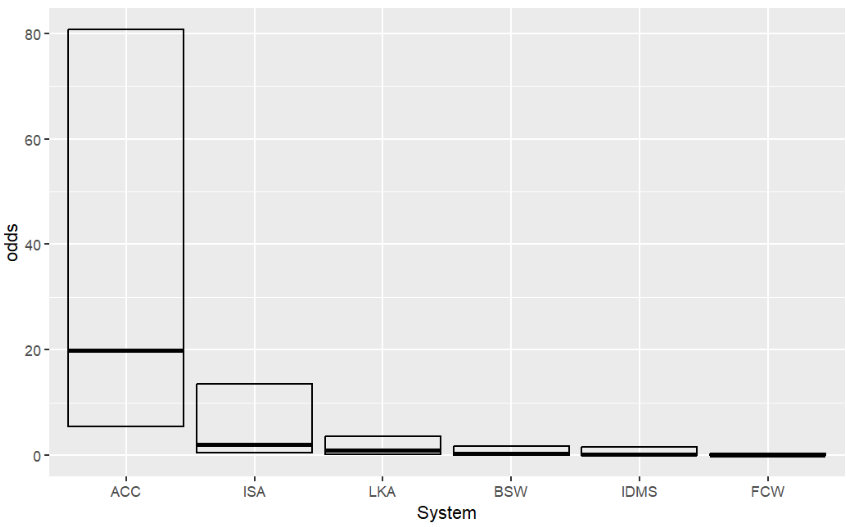
Model 5: Coefficient estimates in odds with 95% credibility for the fixed effects

fixef	center	lower	upper
Intercept	0.000912	0.0001997	0.0045440
Norm_age	0.9569782	0.9227105	0.9914811

The variability in distraction across the different systems is shown by the standard deviation (SD) of 3.05. This variability is also visible in Figure 12, and a table with the estimated random effects can be found in Appendix VI (Table 17). Adaptive Cruise Control (ACC) was associated with higher variability in distraction compared to the other systems, meaning that the impact of ACC on distraction can differ widely among different drivers or vehicles. After ACC, Intelligent Speed Assistance (ISA) is the system with the highest variability, followed by Lane Keeping Assistance (LKA). Blind Spot Warning (BSW), Indirect Driver Monitoring System (IDMS) and Forward Collision Warning (FCW) have the lowest variability, which indicates that the effect on distraction does not vary much from one observation to another for those systems.

Figure 12

Variability of the odds of distraction caused by operating the main systems



3.2.1.1 Potential risk of operating the six main systems amongst all participants. To see what the current risk is on the road in the Netherlands, the same models (Models 1-5) were also run including all participants. For this, a participant who did not use the system was given 0 seconds for distraction, as they cannot be distracted by the operation of the system.

The model comparison performed using LOO-IC (see Appendix VI, Table 18) showed that the best-fitted model was Model 2. Table 19 in Appendix VI shows the outcomes of the model. However, both the linear and quadratic effects of age show highly unrealistic values, possibly indicating oversaturation. Also, the interaction effect of age and gender shows either no effect or unrealistic values. Hence, again, it was decided to use a fixed effect of age rather than a polynomial effect of age. With this fixed effect of age, two other models were created (Models 7 and 8) to see if the interaction effect of age and gender showed a realistic effect or not when using the fixed effect of age rather than the polynomial effect of age. Gender was also included as an interaction effect with systems, similar to Model 2.

Model 7: including a fixed effect of age and gender, a random effect of systems and an interaction effect of gender and systems

Distraction = norm_age + Gender + (1 + Gender | Systems)

Model 8: including a fixed effect of age and gender, an interaction effect of age and gender, a random effect of systems and an interaction effect of gender and systems

Distraction = norm_age * Gender + (1 + Gender | Systems)

Now, Model 7 is shown to be the best-fitted model (see Table 20, Appendix VI). Table 3 shows the outcomes of this model. The intercept indicates an 18-year-old male driver, and the odds that an 18-year-old male driver is distracted are thus 0.000011 (95% CI [0.0000008, 0.00022]). In other words, for an 18-year-old male driver, 1 out of 90,910 seconds are spent on the distracting task of operating any of the six main systems. Due to uncertainty, this might also be almost 14 times lower (1 out of 1,250,001 sec.) or almost 20 times higher (1 out of 4551 sec.). For women, the odds of being distracted decrease by a factor of 0.27 (85% CI [0.017, 4.42]), and are thus 0.27*0.000011 = 0.0000029. In other words, an 18-year-old female driver spends 1 out of 341,102 seconds operating any of the six main systems. There is again great uncertainty about this effect of gender, as for females, it can also be almost 16 times lower (1 out of 5,383,442 sec.) or more than 16.5 times higher (1 out of 20,556 sec.). A one-year increase in age results in a factor 1.05 increase in odds for distraction (95% CI [1.02, 1.09]), and are thus, for instance, 1.05*0.000011 = 0.000012 for a 19-year male driver (1 out of 86,396 sec.), and 1.05^{22}*0.000011 = 0.000034 (1 out of 29,652 sec.) for a 40-year-old-driver.

Table 3

Model 7: Coefficient estimates in odds with 95% credibility for the fixed effects (all participants)

fixef	center	lower	upper
Intercept	0.0000110	0.0000008	0.0002198
Norm_age	1.0522454	1.0211288	1.0885460
Gender2	0.2665167	0.0168868	4.4227409

The variability in distraction across the different systems is indicated by an SD of 27.7 for systems and 29.7 for gender. This variability is also visible in Table 4. For both men and women, Adaptive Cruise Control (ACC) was associated with higher variability in distraction compared to the other systems, meaning that the impact of ACC on distraction can differ widely among different drivers or vehicles. For men, Blind Spot Warning (BSW) and Forward Collision Warning (FCW) are the systems with the highest variability after ACC. Intelligent Speed Assistance (ISA), Indirect Driver Monitoring System (IDMS) and Forward Collision Warning (FCW) have the lowest variability, which indicates that the effect on distraction does not vary much from one observation of a manly driver to another for those systems. For women, after ACC, Lane Keeping Assistance (LKA) is the system with the highest variability, followed by BSW and FCW. IDMS and ISA have the lowest variability, which indicates that the effect on distraction does not vary much from one observation of a female driver to another for those systems.

Table 4

Model 7: Coefficient estimates in odds with 95% credibility for the random effects

fixef	re_entity	center	lower	upper
Intercept	ACC	380.3296	20.2301902	5631.412
Gender2	ACC	0.3298518	0.0174459	6.510273
Intercept	BSW	1.255164	0.0678581	16.68572
Gender2	BSW	0.2027589	0.0108269	3.717594
Intercept	FCW	0.01086950	0.0005513	0.1570286

Gender2	FCW	23.42149	1.1109310	518.4539
Intercept	IDMS	0.0000001	0.0	0.0000007
Gender2	IDMS	204,640.3	8530.0367960	4,293,748
Intercept	ISA	0.3308876	0.0154935	4.293748
Gender2	ISA	0.0000008	0.0	0.00000173
Intercept	LKA	1.404345	0.0773932	17.69401
Gender2	LKA	0.2907228	0.0147480	5.665166

3.2.2 Potential risk of operating "other systems"

For the operation of the other systems, the question of whether the operation of the systems caused distractions was directly asked in the questionnaire. Firstly, the answers of all participants were included, so also the neutral answer options, to assess the risk there currently is on the road. For this, answer option 1, which included "yes, it has caused some form of distraction while I operated it while driving", was coded as 1 and all other answer options were coded as 0. Additionally, Models 1 to 5 (however now called Models 9 to 13) were created, and binomial regression was used as the distraction variable was coded to be binary.

The model comparison performed using LOO-IC (see Appendix VI, Table 21) showed that the best-fitted model was Model 11 (corresponding with model 3). Table 22 in Appendix VI shows the outcomes of the model. Both the effects of age show rather unrealistic values again, possibly indicating oversaturation. The interaction effects of age and gender also show unrealistic values, hence, it was decided to use a fixed effect of age rather than a polynomial effect. With this fixed effect of age, two other models were created and compared. Model 14 is similar to Model 6 previously mentioned and was created to see if it is better to leave out the interaction effect of age and gender and Model 15 was created to see if the interaction is maybe there when using a fixed effect of age:

Model 15: including a fixed effect of age and gender, an interaction effect of age and gender, and a random effect of systems:

Distraction = norm_age * Gender + (1 | Systems)

After comparing Models 14 and 15, it is shown that Model 14 is the best-fitted model (see Appendix VI, Table 23). Table 5 shows the outcomes of the model. The intercept indicates an 18-year-old male driver, and the odds that an 18-year-old male driver is distracted are 0.043 (95% CI [0.025, 0.073]). In other words, 1 out of 24 18-year-old male drivers is currently likely to get distracted by the operation of any of the other ADAS. Due to uncertainty, this might also be almost 2 times lower (1 out of 41) or more than 1.5 times higher (1 out of 15). For women, the odds of being distracted by the operation decrease by a factor of 0.58 (95% CI [0.38, 0.84]), and are thus 0.58*0.043 = 0.025. So, 1 out of 41 18-year-old woman drivers is likely to get distracted by the operation of any of the other systems. Due to uncertainty, this can also be 1.5 times lower (1 out of 61) or almost 1.5 times higher (1 out of 28). As the age increases with one year, the odds for distraction increase by a factor of 1.01 (95% CI [1.00, 1.02]), and are thus, for instance, 1.01*0.043 = 0.044 for a 19-year male driver (1 out of 24), and $1.01^{22}*0.044 = 0.049$ (1 out of 21) for a 40-year-old male driver.

Table 5

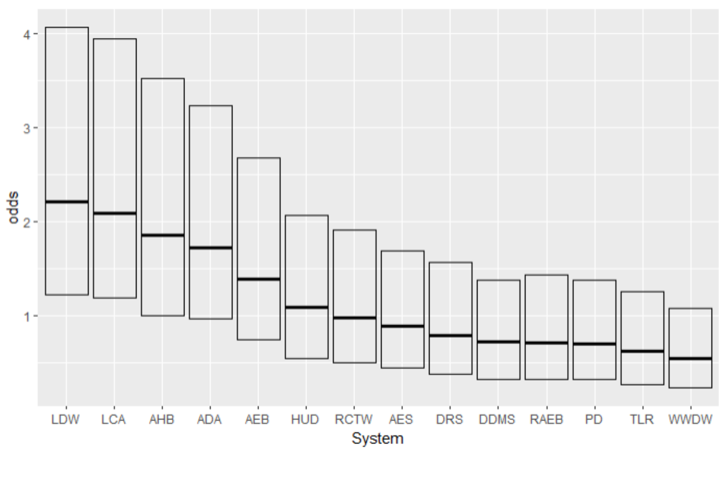
Model 14: Coefficient estimates in odds with 95% credibility for the fixed effects for all participants

fixef	center	lower	upper
Intercept	0.0434579	0.0248284	0.0725110
Norm_age	1.0054819	0.9924939	1.0185862
Gender2	0.5751909	0.3812736	0.8449454

Additionally, the variability in distraction across the different systems is shown by a SD of 1.86. This variability is also visible in Figure 13, and a table with the estimated random effects can be found in Appendix VI (Table 24). Lane Departure Warning (LDW) and Lane Centering Assistance (LCA) were associated with higher variability in distraction, meaning that the impact of LDW and LCA on distraction can differ more among different drivers or vehicles. Automatic High Beams (AHB), Active Driver Assistance (ADA), Automatic Emergency Braking (AEB) and Head-Up Display (HUD) also show high variability, whereas Traffic Light Recognition (TLR) and Wrong-Way Driving Warning (WWDW) have the lowest variability, indicating that the effect on distraction does not vary much from one observation to another for those systems.

Figure 13

Variability of the odds of distraction caused by operating the other systems amongst all participants



3.2.2.1 Potential risk of operating "other systems" amongst users. To see what the potential risk of operating those systems is when everyone would have them in their car, the same models (e.g. Model 9 to 13) were fitted to only the data from the participants who answered option 1 (Yes, it has caused some form of distraction while I operated it while driving) and option 2 (No, I do use the system but I do not experience distractions when I am operating it). So, participants who did not have the system in their car were not included in these models.

The model comparison performed using LOO-IC (see Appendix VI, Table 25) showed that the best-fitted model was Model 11 (corresponding with Model 3 above). Table 26 in Appendix VI shows the outcomes of the model. Both the effects of age show rather unrealistic values, possibly indicating oversaturation. Also, the interaction effects of age and gender show unrealistic values. Hence, again, it was decided to use a fixed effect of age rather than a polynomial effect of age. With this fixed effect of age, two other models were created and compared, similar to Models 14 and 15.

After comparing those two models, it is shown that Model 14 is the best-fitted model (see Appendix VI, Table 27). Table 6 shows the outcomes of the model. The intercept indicates an 18-year-old male driver, and the odds that an 18-year-old male driver is distracted by any of the other ADAS are 1.02 (95% CI [0.58, 1.82]). In other words, 1 out of 2 18-year-old male drivers are likely to get distracted by the operation of any of the other ADAS. However, due to uncertainty, this might also be a bit lower (1 out of 2.73), or a bit higher (2 out of 3). For women, the odds of being distracted by the operation decrease by a factor of 0.68 (95% CI [0.41, 1.14]), and are thus 0.68*1.02 = 0.69. So, 1 out of 2.44 18-year-old women drivers are likely to get distracted by the operation of any of the other systems, however, due to uncertainty, this can also be a bit lower (1 out of 3.4) or a bit higher (1 out of 2). As the age increases by one year, the odds for distraction decrease with a factor of 0.98 (95% CI [0.97, 1.00]). This means that, for instance, for a 19-year-old male driver, the odds of being distracted are 0.98*1.02 = 1.00 (1 out of 2), and for a 40-year-old male driver, the odds of being distracted are $0.98^{22}*1.02 = 0.68$ (1 out of 2.48).

Table 6

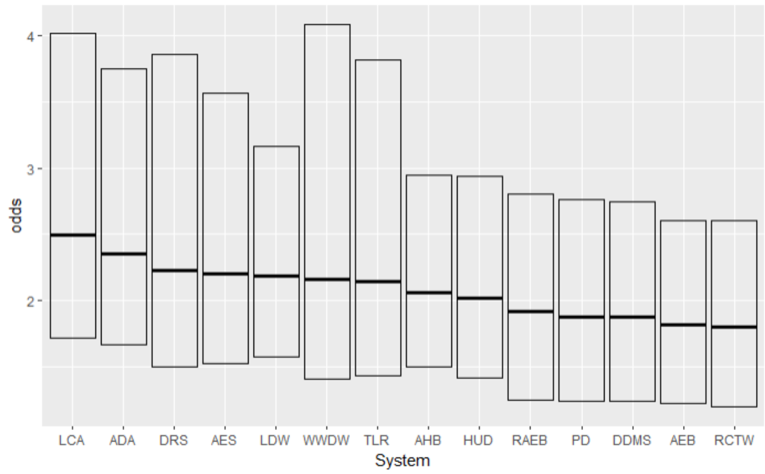
Model 14.1: Coefficient estimates in odds with 95% credibility for the fixed effects for users only

fixef	**center**	**lower**	**upper**
Intercept	1.0186229	0.5765598	1.8162582
Norm_age	0.9816621	0.9662246	0.9967646
Gender2	0.6810523	0.4050769	1.1457285

The variability in distraction across the different systems is shown by a SD of 1.44. This variability is also visible in Figure 14, and a table with the estimated random effects can be found in Appendix VI (Table 28). Lane Centering Assistance (LCA) was associated with the highest variability in distraction compared to the other systems, meaning that the impact of LCA on distraction can differ more among different drivers or vehicles. Active Driver Assistance (ADA), Driver Re-engagement System (DRS), Automatic Emergency Steering (AES), and Lane Departure Warning (LDW) also show high variability. Reverse Automatic Emergency Braking (RAEB), Pedestrian Detection (PD), Direct Driver Monitoring System (DDMS), Automatic Emergency Braking (AEB) and Rear Cross Traffic Warning (RCTW) have the lowest variability, which indicates that the effect on distraction does not vary much from one observation to another for those systems.

Figure 14

Variability of the odds of distraction caused by operating the other systems amongst users



4. Discussion

The present study aimed to explore to what extent drivers operate ADAS while driving and what the associated risk for road safety is, according to the following research question: *To what extent do drivers operate ADAS while driving and what is the associated risk for road safety?* A preceding study, as well as various other articles, revealed reasons to think that the operation of ADAS can be dangerous. The operation for example often happens on the dashboard screen, resulting in drivers having to take their eyes off the road for a rather long time, and the operation can also cause cognitive, visual, and manual distractions. Hence, it was expected that this operation poses a significant risk to road safety. To test this, a survey was conducted to quantify the operation of ADAS in the Netherlands, the potential distraction resulting from the operation were assessed, and the associated risk was analyzed using statistical models. The outcomes indicate that operating ADAS is a distractor while driving, with half of the users being likely to experience it. The time spent on operating ADAS is 0.09% of an average trip, indicating a fairly low prevalence. Mainly the design of ADAS makes it challenging to mitigate this distraction.

Before delving into the findings of this study, it is important to note that the topic of operating ADAS has gained considerable attention during the course of this research. When this research was started, minimal attention was devoted to the interaction between drivers and ADAS, rather, most research was devoted to other human factor aspects or the promising possibilities of autonomous driving. Despite the proven safety benefits of most ADAS (NHTSA, 2022), it is crucial to not neglect the human-machine interaction aspect of driving with ADAS. Although those systems are a step in the direction of autonomous driving, the driver still has a very important role in driving when using ADAS. Throughout this research, the importance of this human factor aspect has only become more prevalent in newly released articles. (News) articles, for example, indicated that the design of the technology might be a potential source of distraction (Nederend, 2024) or showed that ADAS are very easy to misuse (IIHS, 2024). The aim of this study was to take a first critical look at the downsides of ADAS, and those news articles substantially supported this aim.

4.1 Quantification of the operation of ADAS in the Netherlands

Comparing the six main systems to each other, it is easily visible that Adaptive Cruise Control (ACC) is the system that is most used as well as most operated. This operation often happens near or on the steering wheel. When looking at the systems that do not always have to be turned on or off to be used, Lane Keeping Assistance (LKA) is the system that is most used and most operated, followed by Forward Collision Warning (FCW). Drivers indicated that it takes often more than 2 seconds to operate LKA, and in almost a quarter of the cars, this has to be done on the dashboard screen. The operation of the four other systems, Intelligent Speed Assistance (ISA), Forward Collision Warning (FCW), Blind Spot Warning (BSW), and especially Indirect Driver Monitoring System (IDMS), also frequently occurs on the dashboard screen, which is contrary to the recommendation of NCAP (Nederend, 2024) to minimize operation tasks on the dashboard screen to reduce distractions. Those results are concerning, especially because nearly 35% of drivers indicated to operate ISA while driving, and between 25% and 15% interact with the other systems. Looking at the duration of operation, almost 60% of the users indicated that it takes them 2 seconds or more to perform an operating action for ACC, while this percentage is under 20% for all other systems. Nevertheless, for the other five systems, a lot of participants indicated it took them 0 seconds because they did not operate the system while driving at all, which might have influenced the results. ACC is the only system where users mentioned they adjust the settings quite frequently, indicating that it is also a possibility that the higher duration of operation is caused by adjusting the settings rather than by turning the system on or off. Another possibility is that, against the research of Nederend (2024), the high operation duration for ACC is caused by being able to operate it via buttons instead of on the dashboard screen, as it is the only system being fully operated via buttons.

It became apparent that the numbers examined in this research regarding ADAS usage are different from those in other studies. For example, whereas 38% of the drivers in this research mentioned having Adaptive Cruise Control (ACC) in their car, MuConsult (2023) reported 47% in their research. For all other systems, this research also has a lower self-reported possession of the systems than MuConsult (2023) reported. Looking at the percentage of participants who indicated having the systems in their car, the numbers are slightly lower than presented in the research of the Ministerie van I&W (2024). Noteworthy, the difference is mainly there for ACC and Intelligent Speed Assistance (ISA), where the percentage is lower in this research for both systems. Also, in this current study, more drivers mentioned to be not using the systems even though they do have it in their car than previously reported. Regarding turning the system on or off, the percentages of users who perform this action are reported to be higher than indicated by MuConsult (2023), where the biggest differences are visible for ISA and Blind Spot Warning (BSW). MuConsult did not report the frequency of turning ACC on or off, as this is a system that always has to be turned on and is never automatically on. The results of this study indicate that ACC is a system that should be considered as well, even though it is designed to be turned on and off for usage, as it is reported to take rather long to operate.

Regarding the fourteen other systems, it seems like Active Driver Assistance (ADA), Automatic Emergency Steering (AES), Driver Re-engagement System (DRS), Lane Centering Assistance (LCA), Traffic Light Recognition (TLR) and Wrong-way Driving Warning (WWDW) are the systems that cause the most distractions due to the operation of the systems among users. Systems like AES, DRS, and WWDW often operate in the background and intervene only in extreme situations, and it is thus likely that these systems are rarely operated. Therefore, it is expected that ADA, TLR, and LCA, which are systems that are more active and visible while driving, pose greater risk for road safety and require considerable attention. Looking at the other systems, Lane Departure Warning (LDW), Automatic High Beams (AHB), and Head-up Display (HUD) are systems that are recommended to be taken into consideration as well, as the percentage of users that were distracted is also rather high, and those systems are rather visible while driving. Although Direct Driver Monitoring System (DDMS) is reported to have a lower distraction percentage compared to the other systems, it might still be beneficial to look further into this system as it is comparable to Indirect Driver Monitoring System (IDMS), which is mentioned to be operated often on the dashboard screen.

4.2 Distraction and association risk

The results about the possible risk the operation of either the six main systems or the other systems can cause are not directly comparable, hence, they will be elaborated upon separately. The distraction due to the operation of the six main systems is calculated as the portion of time of a trip where the driver is performing operating actions. Often, distraction is measured using for example fixation durations (Niezgoda et al., 2015), eye movement (Yusoff et al., 2017), reaction time (Martens & Winsum, 2000) or driver errors (Shaaban, 2018), and those variables give quite some insight in the severeness of the distraction as well. It is expected the portion of a trip that someone is distracted, which is also used by Dingus et al. (2016) is a good indicator of the actual distraction and subsequently the associated risk.

The results suggest that it is possible that when everyone has the six main systems in their car, a driver is likely to spend 1 second in almost 18 minutes on the operation of either Adaptive Cruise Control (ACC), Lane Keeping Assistance (LKA), Blind Spot Warning (BSW), Forward Collision Warning (FCW), Indirect Driver Monitoring System (IDMS) or Intelligent Speed Assistance (ISA). This indicates that around 0.09% of a trip, a driver is operating ADAS. It has to be mentioned that there was high uncertainty for the results, and it is also possible that this would be either 0.02% or 0.5% of the trip. The results also suggest that the older the driver is, this time spent on operation slightly reduces, which was against expectations. A possible explanation of this decrease might be due to experience, as experience with a task is likely to lead to more automation, which can decrease the time on task (Krimsky et al., 2017). Comparing the time spent on the operation of ADAS to other distracting tasks while driving, it is found that around 6% to 9% of the trip is likely to be devoted to phone usage (SWOV, 2020). and almost 5.5% to eating or drinking (Stutts et al., 2005). Dingus et al. (2016) mentioned the operation of ADAS within the rest category in their study, and found that it was performed in less than 0.83% of the driven distance. However, the risk factor (4.6 times higher than model driving) was significantly higher for this rest category than for other distracting tasks. The operation of ADAS is an additional source of distraction that is added to the many other distractions that are there when driving. According to SWOV (2020), operating the radio can increase the accident chances by 1.5 times, and it is expected that this risk is even higher when using a dashboard screen instead of buttons (TopGear, 2022), which is the case for most ADAS. Those results indicate thus that mainly the design of the operation of ADAS raises road safety concerns.

For the other fourteen systems, the distraction number indicates how many drivers are at least sometimes distracted by the operation. When everyone has those systems in their car, 1 out of 2 male drivers is likely to get distracted by the operation of ADAS, specifically, any of the fourteen systems specified under “other systems” in this study. Due to uncertainty, this might also be either 1 out of 2.7 or 2 out of 3 male drivers. For woman drivers, this is slightly lower, although almost comparable. Emphasizing the danger of a distracted driver; in 2021, 5% of the fatal crashes involved distracted drivers, which corresponds to 3,346 distracted drivers involved in fatal crashes (NHTSA, 2023), and even more injury crashes (362,415 individuals) happen due to distracted driving. Having such a high number of drivers that is likely to be distracted by the operation is thus highly worrying. This study further suggests that the systems that are the most worrisome out of those fourteen other systems are Lane Departure Warning (LDW), Lane Centering Assistance (LCA) and Active Driver Assistance (ADA).

In assessing road safety, it is important to take into account both the prevalence data and the associated risk. Although both forms of data are related to different systems, it can be seen that a lot of people are likely to get distracted by the operation of the systems, however, they will perform this distracting task to a fairly low extent, indicating a moderate risk. Further, there is only very limited information on crashes involving distraction in the Netherlands. In the US, Dingus et al. (2016) indicated that four million crashes could be avoided annually if there was no distraction in the cars. They also mention that around 50% of the driving time is spent on any distracting task in the US. Given that 1 out of 2 drivers gets distracted by the operation of ADAS, and it happens 0.09% of the driving time, 3,600 crashes could be avoided when the operation of ADAS is not possible. Nevertheless, a direct comparison of the crashes or car owners in the US and the Netherlands is not possible due to missing data. It remains thus impossible to say how many crashes in the Netherlands could be avoided when the operation of ADAS is not possible.

Currently, on the road, those risk numbers are lower. The portion of time of a trip spent on the operation of ADAS is currently around 0.01%, and 1 out of 24 male drivers or 1 out of 41 female drivers is likely to get distracted. It has to be mentioned here that, based on the outcomes of the usage of this questionnaire, it is assumed that 65% or more of the drivers do not have the systems in their car. Nevertheless, other research already suggests that it might be that more cars on the road do have those systems (VMS Insight, 2023), and it is thus likely that the risk currently on the road is slightly higher than estimated in this research. Even if that is not the case, it is expected that the market penetration of those systems will keep increasing over the next years (MRI, 2024), and thus is the risk likely to increase in the upcoming years as well.

4.3 Limitations and future research

As with most research, some limitations can be noted. The first one is related to the high variability and uncertainty in the results of this study. Although 212 participants were included in this sample, only a small portion of them did use the systems. It was decided to include all drivers in the sample so the sample would represent the current Dutch driving population and their usage of ADAS. In the end, the number of users included in this sample does not reflect the number of drivers that are estimated to have the systems in their car according to the market penetration (VMS Insight, 2023).

This might indicate that the results are not a complete reflection of the current situation on the road. Further, due to the low number of participants using the system, there is high uncertainty about the actual risk the operation of ADAS is for road safety, hence, a recommendation for future research would be to include a larger sample that better represents the current driving population. Although there is uncertainty, those results do still suggest that the operation of ADAS seems to be rather risky, encouraging future research.

As this study made use of a questionnaire, all answers were based on self-reported numbers. For the operation of the systems, multiple participants mentioned that some systems are always on and are therefore not operated. As this was not an answer option, some participants seemed confused about what to fill out. Due to this confusion, some participants filled out 0, which explains the answer "never" for the operation of the systems. In future research, it is thus recommended to include the answer option that the system is always on and therefore not operated. Further, the numbers for the duration of the operation were also self-reported, and might therefore not be correct. It is recommended to let the researcher assess this duration of operation by for example driving along with the passenger or filming the dashboard in future research.

Moreover, the questions in the questionnaire in general might have not been as clear as previously thought. For the question about the frequency of usage, participants did fill out 0, while they indicated to make use of the system in another question. It might have been confusing to them whether this question was already related to the operation of the system or just to the usage. It was also assumed that the participants would have enough knowledge about distraction caused by the operation of the fourteen systems classified as "other systems" because they already answered the detailed questions about the six main systems. Although it is likely that when using any of the fourteen systems, this participant also would make use of at least one of the six main systems, this is not guaranteed. Also, participants who did not make use of any of the systems still had to fill out the questions related to the fourteen other systems and did not see the detailed questions about the operation. It might thus be possible that participants did misinterpret those questions, and for example gave answers related to distraction caused by sounds or intervention of the systems. For future research, it is recommended to better test the questionnaire and to find a good balance between explaining all the questions clearly while also limiting the text for questions as much as possible.

After the questionnaire was distributed, increased attention was devoted to the operation of ADAS and the possible associated risks by other researchers. With this in mind, the data analysis was slightly changed accordingly, which resulted in two different distraction measurements, one for the six main systems (portion of a trip that is devoted to the operation) and one for the fourteen other systems (number of drivers that is likely to get distracted). So, in this current study, a one-on-one comparison of the two forms of distraction risks could not be performed. Although there are individual differences per system, the number of drivers that are likely to get distracted might be the same for all ADAS. To be sure about this, future research should include the same questions for all the systems (or a selection of systems) to be able to compare the systems directly. Next to the six main systems, the most interesting systems for future research seem to be Lane Centering Assistance (LCA), Traffic Light Recognition (TLR), Active Driver Assistance (ADA), Lane Departure Warning (LDW), and Head-Up Display (HUD).

Based on the results of this study, there are several other recommendations for future research in the area of operating ADAS and distractions. To begin with, it is highly recommended to keep performing research on the operation of ADAS, as this study indicates that this operation might be worrisome for road safety. As this is one of the first studies assessing the risk of the interaction between the driver and the systems, more research is needed to better understand and assess the sources of distraction. The first recommendation would be to closely compare Adaptive Cruise Control (ACC) with Lane Keeping Assistance (LKA), to find out whether the operation being located on the dashboard screen is indeed more dangerous than with buttons (as suggested by Nederend, 2024). Those two systems can be used as they are rather close in answers to all questions except for the location of operation. Another interesting focus area for future research is the difference in operation tasks, e.g. whether turning the systems on or off or adjusting settings is most dangerous. The results of this study show that participants indicate that they take rather long to operate ACC, while this is shorter for most of the other systems. A possible explanation for this might be that adjusting settings takes longer than turning systems on or off, as only for ACC, participants indicated that they adjust the settings. Another reason could be that operating it via buttons might take longer than expected, as ACC is more often operated via buttons than the other systems. This has to be researched to verify whether those possible explanations are valid or not. A possible way of doing this is by designing tasks related to adjusting the settings of ACC (and possibly other systems), and tasks related to turning the systems on or off. Variables that can be measured include time on task or duration of eyes off the road, and those can be compared for the tasks related to adjusting the settings and turning the systems on or off, as well as between systems.

4.4 Conclusion

ADAS have great potential to increase road safety, however, the human factor side regarding the operation of this technology is often neglected till this point. In the past few months, there was an increasing awareness of the interaction between a driver and the systems, to which this study also contributed. This was one of the first studies to include prevalence data and make an assessment of the potential associated risk according to this prevalence data. This study indicated that Adaptive Cruise Control (ACC) is the system that is operated the most, followed by Lane Keeping Assistance

(LKA) and Forward Collision Warning (FCW). This study also showed that the operation of ADAS while driving is rather risky, as 1 out of 2 drivers are likely to get distracted. However, the time spent on operating ADAS is 0.09% of an average trip, indicating a fairly low prevalence. Although the overall road safety risk currently on the road is still rather low, further research is important. It is crucial to understand how the interaction between ADAS and the drivers impacts road safety. Without intervention, there is a risk that ADAS, meant to prevent accidents, could unintentionally contribute to these accidents by causing driver distraction. Limitations of this study include that a small user sample was used resulting in relatively high uncertainty, the participants might not reflect the current situation on the road, it is based on self-reported numbers, and some of the questions of the questionnaire could have been misinterpret. Still, based on the results of this study, it is not expected that the whole interaction of operation is going to be removed, however, more attention should be paid to the design of this operation. The design should make the operation as quick as possible by making the location easily accessible and by simplifying the operating options. Factors such as ease of use, intuitiveness of controls and user satisfaction should be considered more in the design of ADAS. Whether this involves moving it as much as possible to buttons instead of the dashboard screen remains questionable based on the results of this study.

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Appendix I

Previous performed study

INTERNSHIP PRODUCT

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Summary

Goudappel currently has a knowledge base in which pilot studies, academic literature, reference projects and other forms of data are included related to the effects of smart mobility. Amongst one of the categories in this knowledge base is ADAS. Goudappel is currently missing information about the effects on behaviour, which was the basis for this internship. Hence, during this internship, a literature review and interviews were conducted in order to delve deeper into the possible effects of Advanced Driver Assistance Systems (ADAS) on behaviour of drivers.

First, a literature review was conducted, which revealed that the operation of ADAS while driving can possibly cause distractions, resulting in less traffic safety. This distraction can be caused by an increase in visual or cognitive load due to sounds, vibrations or movements of the systems. Moreover, as the operation of ADAS is sometimes placed in the dashboard screen, this can cause drivers to take their eyes off the road, which is a contributor for the increase in likelihood of accidents. Generally, the findings of the literature review suggested that there is reason to think that drivers might operate ADAS during the driving task, and that this poses significant risks for the safety on the road. On the other hand, the literature review also showed that there is limited information about whether drivers operate ADAS while driving or not, and if they operate it, to which extent this happens. Hence, interviews were conducted in order to gather more information.

The interviews showed that Adaptive Cruise Control, Lane Keeping Assistance and Intelligent Speed Assistance are the systems operated the most during driving. Additionally, it was found that this operation of ADAS happens at different places in the car, depending on the car brand. Also, the systems caused several frustrations by the participants, for example when Lane Keeping Assistance applied force to stay in line while the drivers wanted to cross a line with a reason. The participants were moreover divided about whether they think the usage of ADAS makes traffic safer or not, however, most of them thought it has the potential of making it safer.

Both the literature review and the interviews helped in gaining a better understanding in behaviour patterns caused by ADAS. Additionally, the results of the conducted studies pose three research areas for possible future research. The first area relates to finding out more about the findability of the operation control or finding out whether the participants of the interviews downplayed the level of distraction by operating ADAS. The second area focuses on making systems in cars more easily operated and on specific habits of drivers, namely where they would expect operation controls to be located. Lastly, the third area is related to the different kinds of distractions that can be caused by using ADAS, for example visual or cognitive distractions.

Introduction

Currently, more and more cars have systems that support the driving task or support vehicle automation. As of now, cars with those Advanced Driver Assistance Systems (ADAS) can drive around most of the main roads in the Netherlands with little intervention of the driver. Generally, most countries want to go from automation level 0 (no automation at all) to automation level 5 (fully automated, no intervening from the driver). However, to achieve this, there are multiple steps in between those two automation levels that have to be taken. For example, there needs to be full trust in the systems that help in automating cars, and drivers need to correctly work together with those systems. Subsequently, the experiences around ADAS can either facilitate or hinder the process of going to automation level 5. Nevertheless, currently, it is rather unclear what the exact effects of ADAS are on behaviour.

ADAS is implemented in cars to make driving easier, but most of all safer. Those systems can, for example, contribute to less congestion, reduced emissions and a decrease in accidents (de Paepe et al., 2021; Goudappel, 2021). However, the use of those systems can also lead to an increase in car use, which in turn can have negative effects (Paepe et al., 2021). Moreover, it can also lead to more dangerous situations on the road due to distractions or the limitations of ADAS. Related to this, Goudappel has made a knowledge base in which pilot studies, academic literature, reference projects and other forms of data are included related to the effects of smart mobility, and amongst one of the categories is ADAS. Coming from this knowledge base, it is at this point not yet clear where the tipping point lies where the positive impacts and utility of the systems outbalances the negative effects. It also became visible that mainly the effects of ADAS on behaviour are not researched much. Therefore, it is needed to delve deeper into the negative effects of ADAS on behaviour in an attempt to overcome them. Moreover, especially because there is an increase in smart vehicles on Dutch roads, it is important to gain insights into the role the infrastructure has in increasing the positive effects of automatization (Ministerie van IenW, 2023).

As mentioned, ADAS can cause distractions, which is one of the possible negative effects of those systems. First of all, due to high trust and reliance on ADAS, individuals might get distracted, causing less attention for the driving task and a lower threshold for performing other tasks in the car. Those distractions can for example lead to lower response times in cases where the individual needs to take over driving in order to prevent an accident from happening (Zhang et al., 2019). On the other hand, ADAS itself might cause distractions while driving, for example by providing voice messages or other sounds to alert a driver. Those distractions can possibly result in less view time on the road or abrupt behaviour making the situation more dangerous (Ruscio et al., 2017; Ulrich et al., 2021). Additionally, it can lead to turning off the systems, which is (often) not the behaviour wanted. Moreover, those systems can also cause frustrations, which might result in individuals wanting to turn the system off or adjust it while driving (McDonald et al., 2018). It is expected that actions such as turning the system off also distract the driver and negatively affect the safety of driving. A quick scan in literature shows that not much research is done within those latter mentioned effects of ADAS on behaviour and subsequent distractions. Generally, ADAS systems are made to assist drivers and make driving safer, however, when causing unwanted distractions, the benefits of the technology might not outweigh the subsequent negative effects such as an increase in accidents. Also, those distractions might lead to non-use of ADAS, while in the long term, it is likely to be beneficial for drivers to use those systems and additionally this use is needed to move to automation level 5. Therefore, this research, and subsequently the Master thesis, is an attempt to delve deeper into behaviour patterns caused by ADAS, with a focus on distractions. In order to do this, a literature study followed by a small interview study were performed, of which the results are presented below.

Approach and outcomes

For this internship, first a literature study was conducted in order to get a better understanding of the already existing research in the field of Advanced Driver Assistance Systems (ADAS), behaviour and distractions. Specifically, I explored the current state of studies concerning distractions caused by ADAS. In doing this, I looked at scientific articles and (institutional) reports, and I contacted individuals working in this field of research. Hence, I first stated the current situation regarding automation levels and ADAS, followed by a summary of research on distraction caused by ADAS. Subsequently, I made a division between different forms of interaction with ADAS as I found that there were multiple sources of possible distraction caused by ADAS, which differed in terms of interaction. Lastly, I mapped the current scope regarding distractions caused by interactions from the driver to the system, e.g. turning the systems on/off or adjusting settings of the systems. A more detailed explanation can be found in the findings presented below.

After the literature study, I conducted a small interview study, in which nine interviews were performed. During these interviews, I explored the participants' viewpoints on using ADAS and gathered more detailed information on the actual usage during driving. The purpose of the exploratory interviews was to shed light on the current state regarding the operation of ADAS during driving. The interviews were used to better map out the systems that are operated while driving, at what times this often happens and how these systems are operated. Additionally, they were used to map out differences in variables such as type of car, type of trip or duration of the trip. Generally, the aim of those interviews was to further explore possible research gaps related to ADAS, behaviour and distractions. The findings of the interview can be found below.

Literature Study

Automation levels and ADAS

Cars are becoming more and more automated nowadays, and the share of driver assistance systems in new sales is increasing every year (Ministerie van IenW, 2023). When looking at the classifications of automation in cars, one of the most used categorizations is developed by The Society of Automotive Engineers (SAE). SAE defines six levels of automation, ranging from level 0 (no driving automation) to level 5 (full driving automation) (SAE International, 2021). Currently, the cars on the road have different levels of automation, which mainly include level 0 (no driving automation), 1 (driver assistance) and 2 (partial automation). Although level 3 automation cars (conditional automation) are being produced, they are only recently available on the market, and thus are to a lower extent visible on the roads. In order to move to automation level 5, current technological challenges with automated cars have to be explored and solved so we can ensure fully safe and mobile automated cars in the future (Thakurdesai & Aghav, 2021).

One of those technological advancements in cars of which it is currently shown that it brings challenges is ADAS (Christoph et al., 2019; MuConsult, 2022; Thakurdesai & Aghav, 2021). To begin, ADAS is developed to prevent driver errors from happening, thereby increasing the safety of being on the road. Hence, those systems are designed in order to reduce the number of car accidents happening due to human errors, e.g. driver inattention, fatigue, internal distractions or human performance (Cabrall et al., 2019; Kyriakidis et al., 2017; Spicer et al., 2018; Ulrich et al., 2021). It is important to distinguish between ADAS and In-Vehicle Information Systems (IVIS), whereby the main difference is that ADAS is capable of intervening, while IVIS is mostly providing information to the driver (Schmeidler, 2011). Moreover, ADAS is related to the actual driving task, thereby supporting the driver, whereas IVIS can also be related to other tasks which are not directly related to the primary driving task (e.g. radio or navigation) (Engström et al., n.d.). Whereas IVIS already exists for a longer period of time and almost all cars have several of those systems in the car, we see a growing and substantial amount of ADAS mainly in level 2 automated cars nowadays. Hence, in this report, only ADAS will be considered.

Names of those ADAS can differ amongst car manufacturers, therefore, in 2022, the American Automobile Association (AAA), together with several other parties, categorized the different types of ADAS currently available into six categories: Collision Warning, Collision Intervention, Driving Control Assistance, Parking Assistance, Driver Monitoring, and Other Driver Assistance Systems. Moreover, they have divided 23 different types of ADAS into those categories, examples of ADAS being Forward Collision Warning, Lane Keeping Assistant, Adaptive Cruise Control, Backup Camera, Direct Driver Monitoring System, and Night Vision. Additionally, more systems which are not mentioned in the overview of AAA exist nowadays. Hence, an overview of all the systems, the different names they have, and their explanations is visible in "Previous Study Attachment 1". Next to the categories, there are also different forms of ADAS. Some are for example automatically enabled when the car is started, while others have to be manually turned on by the driver. Moreover, there is a difference between active and passive ADAS, where passive systems are able to alert drivers, and active systems are actually able to intervene in order to avoid a possible collision (BasuMallick, 2022). In "Previous Study Attachment 2", it is, for a selection of the systems, indicated whether they are automatically enabled when the car is started, and whether they are active or passive. The reason for this selection is explained in the following paragraph. However, it has to be noted that it was not possible to find this information for every system, which may be due to the high variety of names and functionalities of the systems amongst different car brands. Hence, it might also be that it differs per car brand whether a system is automatically enabled or not and what the specific functionalities are.

As from July 2022 on, some systems are mandatory to implement in new manufactured cars (European Commission, 2022), meaning that more and more cars on the road will be equipped with those systems in the upcoming years. Which systems are mandatory is also visible in Attachment II. Although ADAS is developed to ensure safety on the road, those systems unfortunately also bring risks with them, which have to be lowered as soon as possible with this ongoing increase in use. It became apparent that one of the risks of ADAS is that they have potential for being a distractor (Brooks & Rakotonirainy (2005); MuConsult, 2022; SWOV, 2019). Especially during the main driving task (thus not during parking etc.), those distractions can cause great consequences for safety on the road, as the impact of a potential crash is bigger when actually driving due to higher speed for example. Since not all ADAS are relevant for the main driving task, only a specific selection of ADAS (See Previous Study Table 1) will be considered in the remainder of this study.

Previous Study Table 1

ADAS relevant for the main driving task

Blind Spot Warning
Pedestrian Detection
Forward Collision Warning
Lane Departure Warning
Lane Keeping Assistance
Lane Centering Assistance
Rear Cross Traffic Warning
Wrong-way driving warning
Automatic Emergency Braking

Automatic Emergency Steering
Reverse Automatic Emergency Braking
Adaptive Cruise Control
Active Driving Assistance
Intelligent Speed Assistance
Indirect Driver Monitoring System
Direct Driver Monitoring System
Driver Re-engagement System
Automatic High Beams
Traffic Light Recognition
Head-Up Display

Distractions (and ADAS)

Distractions during driving are rather common. A naturalistic driving research showed that drivers spend up to 50% of their driving time on distracting activities (Dingus et al., 2016). Generally, those distractions lower safety because the workload of the driver has increased. An often-used theory related to this increase in workload is the multiple resources theory (Wickens, 2002). This theory suggests that the driving task itself is already visually demanding, and adding other visual cues, such as warnings from ADAS, which also uses a certain amount of visual attention resources, can cause an overload, resulting in less attention for the actual driving task (Ruscio et al., 2017). According to the multiple resources theory, it is for example suggested that for secondary tasks, which are non-driving related tasks performed while driving, auditory or haptic cues are recommended as those resources are less used during driving (Ulrich et al., 2021). Nevertheless, visual, tactile and auditory interfaces can induce both a physical and cognitive load, therefore it is important to design systems so that they do not distract the driver in such a way that too little attention is left for the driving task that needs attention and physical load as well (Europese Unie, 2008).

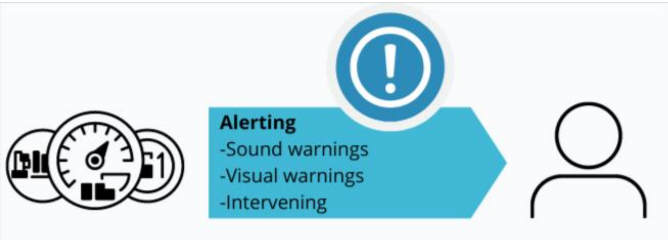
Additionally, according to the multiple resources theory, secondary tasks during driving can thus ask too much attention from the driver, resulting in insufficient attention left for the actual driving task (SWOV, 2020). Some ADAS create secondary tasks which cause the attention of the driver to be shifted away from the driving task due to distraction (Fan et al., 2018b). Furthermore, certain tasks, such as turning on cruise control, the headlights of adjusting the wipers are all seen as secondary tasks, thereby being a potential distractor for the driving task (Fan et al., 2018a). For IVIS, already multiple studies are performed that help in increasing awareness and suggesting design improvements to lower distraction due to for example operating the navigation system or radio, and guidelines for this have been compiled (European Commision, 2002; Ma et al., 2018; National Safety Council, 2020). For ADAS, those guidelines are not compiled yet, nevertheless, like IVIS, operating ADAS can be seen as a secondary task with the potential of causing distractions. Those distractions, as a result, are likely to decrease the driving performance, thus resulting in a higher chance of accidents when operating ADAS while driving. Hence, if operating ADAS is indeed a distracting secondary task, (design) guidelines are needed to improve safety on the road.

Interactions with ADAS

When having ADAS in your car, there are two main possibilities for interactions with them. The first form of interaction is from the system to the driver, including for example notifications and sounds as a warning or to alert the driver (Previous Study Figure 1). Moreover, some systems can also take over the steering wheel or adjust the speed as a form of interaction from the system to the driver. For those interactions, several studies are already performed to measure if and to which extent this causes distractions (Brooks & Rakotonirainy, 2005; Fan et al., 2018a; Langlois, 2013; Ulrich et al., 2021). Additionally, solutions for the possible distractions are proposed, e.g. by using auditory feedback instead of visual feedback or by using context-aware systems (Brooks & Rakotonirainy, 2005; Christoph et al., 2019). Further, the results of the studies concerning the interaction from system to driver make it clear that ADAS must be designed according to proper guidelines in order to make sure that the provided feedback of the systems does not become a potential origin of distraction (Europese Unie, 2008; Ulrich et al., 2021). Nevertheless, those specific guidelines remain unfound.

Previous Study Figure 1

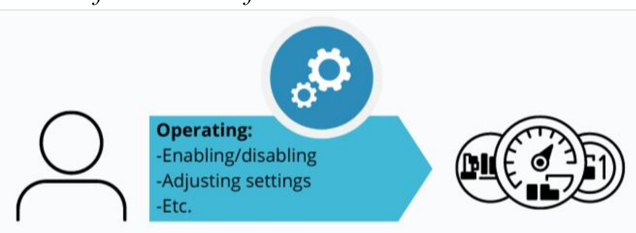
Visual of interaction from ADAS to driver



Secondly, the drivers themselves can interact with the system as well. This happens in situations in which the driver wants to turn a system on or off, or when the driver wants to adjust settings for a system (Previous Study Figure 2). An example is that adaptive cruise control might be set to the greatest distance from the car in front, however, in busier situations on the highway, it might happen that other cars always insert between the vehicle and the predecessor (Dicke-Ogenia & Olthof, 2023), resulting in the driver adjusting the following distance settings while driving. Also, several ADAS, such as (adaptive) cruise control need to actively be activated in order to use it, which might happen while driving (Harms & Dekker, 2017). Additionally, there are certain situations in which the systems have to be disabled because it otherwise causes dangerous situation due to non-proper functioning in these situations (Dicke-Ogenia & Olthof, 2023). Furthermore, for some ADAS (e.g., informative ADAS such as Intelligent Speed Assistant) it is needed that there is communication between the driver and the system, for example in order for the system to decide whether it should continue sending messages or is in need of taking over the vehicle (Fan et al., 2018a). All those tasks performed by the drivers themselves might cause distractions and consequently dangerous situations on the road, especially because they all happen while the driver is already driving. However, little to no research is focused on this type of interaction between the driver and ADAS. In the following section, a review will be given consisting of related studies to this type of interaction.

Previous Study Figure 2

Visual of interaction from driver to ADAS



Current scope

As mentioned, the interaction from the driver to ADAS is a not (much) researched topic. Nevertheless, there are several studies indicating the need to address this potential issue of distraction due to interacting with the system from the driver's side. In this section, the current scope of those studies will be elaborated upon and the need for research in this field will be addressed.

To begin with, one of the focus areas of distractions while driving is distractions caused by operating navigation systems during the driving task. Although navigation systems are not classified as ADAS, studies concerning this topic still show relevance as the operation of navigation systems might be similar to the operation of ADAS while driving (both on a touch screen). A study from MuConsult (2021), which categorized navigation systems as ADAS, showed that 20% of participants mentioned they were either highly or moderately distracted by the usage of ADAS. 45% of those distractions were caused by the operation of the navigation systems. Moreover, navigation systems are often seen to be one of the most common distractors while driving, causing significant accidents (National Center for Statistics and Analysis, 2019). Lin et al. (2019) mentioned that this high level of distraction caused by navigation systems is due to it being a visual distractor that increases both the visual and mental workload required for driving. As mentioned before, this increase in workload can cause lower levels of driving performance, resulting in higher safety concerns. Hence, guidelines suggest that it is not wise to operate the navigation while driving and it is not advised to have a small (navigation) screen that is placed far out of the driving direction and thus forces you to look away from the road for a long time (SWOV, 2019). Moreover, related to this, it was found that smaller navigation system displays had a greater potential for distraction than larger displays while driving (Yared & Patterson, 2020). As the operation of navigation systems might be similar to the operation of ADAS on a touch screen within the car, this poses the question whether operating ADAS is thus also a major factor for distraction while driving.

As mentioned, in some cars the operation functions of ADAS are placed in the menu structures of touch displays within the cars. Those touch displays are often placed in the middle of the car, thus relatively far out of the driving direction. When operating ADAS in the touch displays, it is thus (almost) impossible to do this without looking away from the road. Sometimes, drivers are searching in the menus for a rather long period of time to disable a system while they are also driving (Schenk, 2023). If those functions are deeply hidden in the menus of those touch displays, the driver is forced to take their eyes of the road for a fairly long time, causing great risks for the road safety (UDV, 2023). According to SWOV (2020), distracting activities that cause eyes to be away from the road for a long time are one of the biggest contributors for the increase in likelihood of an accident, hence, it is important that those activities are lowered as much as possible. Nevertheless, quite some traffic task-related activities are designed in such a way that they can cause distractions where the eyes are taken off the road. For example, both the operation of a navigation system while driving or searching for the control of the wipers can take eyes off the road (SWOV, 2020). Operating ADAS while driving might be an additional traffic task-related activity that potentially causes dangerous distractions where the eyes are taken off the road.

Moreover, although this emergence of touch displays is highly liked by the drivers, they unfortunately also come with a high risk of distraction in general (UDV, 2023). It has to be mentioned that every car brand or type has differences in operation, sensitivity and comfort of adjusting the systems (Dicke-Ogenia & Olthof, 2023), therefore it is not uniform where the different ADAS are adjustable within cars. Due to these differences in placement of ADAS, the different systems might potentially increase the complexity of the driver's area, and this increase in complexity is likely to increase the probability of failure on the driver's side due to for example design misconceptions (Brookhuis et al., 2001). Related to this, one of the design aims of ADAS is that the displays and control units of those systems should not distract the attention of the driver to such an extent that too little attention is left for the actual driving task (SWOV, 2019). However, it is almost impossible to design such a system that causes no distractions at all, as those systems have to demand a certain amount of focus from the driver in order to be of advantage (Brooks & Rakotonirainy, 2005). Nevertheless, these kinds of distractions are different from the distractions possibly caused by operating the systems. What also became apparent is that current guidelines available about the design and operation possibilities of ADAS are often several years old, therefore they are not up to date with the current progress of technologies (UDV, 2023). For example, multifunctional touch displays are not taken into consideration in most guidelines, thus neglecting the deep menu structures available in most cars nowadays (UDV, 2023). Those deep menu structures in the touch displays of cars are used by some manufacturers for the operation of ADAS (Schenk, 2023) and should thus be considered in guidelines to make sure that they are designed in the least distracting manner possible.

When looking at satisfaction related to ADAS, it becomes apparent that reasons for either a low or a high appreciation of those systems are often related to aspect of ease of use (MuConsult, 2021). For example, Harms and Dekker (2017) mentioned that the main reason for not using lane departure warning is that drivers find it irritating or frustrating to use. Dicke-Ogenia and Olthof (2023) also mentioned that interventions on the driving task are not always appreciated, and warning signals are sometimes perceived as irritating, with the consequence that drivers disable those systems. As some systems are only becoming visible when already driving for a while, there is a chance that drivers only start to get frustrated when already driving, increasing the chances they operate the systems during driving. Another reason for deactivating ADAS is because it is perceived as distracting, however, less than 5% of participants mentioned they actually disabled the system because of this (McDonald et al., 2018). Additionally, if multiple systems provide warnings simultaneously, drivers might get confused or frustrated, resulting in them ignoring the warning or turning the systems off (Brooks & Rakotonirainy, 2005; Fan et al., 2018b). Other research found that there is a relationship visible between high aggression levels and accidents (Kaiser et al., 2016), hence, this irritation and frustration caused by ADAS, especially the systems for which it is not possible to turn them off, might lower safety levels on the road. However, there is also a possibility that drivers only occasionally turn the systems off, as it might be that some systems stay off after turning it off once. Lijarcio et al. (2019) found, for example, that (at least) three ADAS were not used frequently as the drivers found them distracting, and those included GPS navigation, automatic parking systems and lane departure warnings. Nevertheless, for some systems it is impossible to turn them off, and some are automatically enabled when the car is started, even when disabled in a previous car ride (Schenk, 2023). Hence, it might thus be possible that drivers turn off the system or operate it while driving because of frustrations and irritations.

As above mentioned, there is reason to think that drivers might operate ADAS during the driving task, which poses significant risks for the safety on the road due to for example having the eyes off the road and increasing mental workload. However, a study by Dingus et al. (2016) showed that the operation of ADAS during driving was performed in less than 0.83% of the driven distance, as it was part of the rest category in their study. Important to note here is that this rest category had a considerable higher risk (4.6) than the operation of the air conditioning (2.3) or radio (1.9) (4.6 means that per distance driven there were 4.6 times as many accidents as average). Additionally, MuConsult (2022) performed a study in which they measured the degree of distraction by several ADAS, where they categorized the distraction levels in visual, operation, sound and processing. For most systems, the operation of ADAS contributed 10-20% towards the measured distraction. Moreover, these are one of the only studies taking the operation of ADAS into account, hence, it is needed that more research is conducted concerning the interaction of the driver with ADAS while driving to clarify the likelihood of it happening and the potential risks for road safety.

Conclusion

The above-mentioned results of the literature study show that there is a need for research regarding ADAS, behaviour and distractions. Moreover, although literature suggests that operation of ADAS during driving is likely to be distracting, it also becomes clear that there is missing information about whether drivers operate ADAS while driving or not, and if they operate it, to which extent this happens. Therefore, in order to gain a better understanding of behaviour of drivers regarding the operation of ADAS, interviews were conducted with car owners who make use of these systems. In the following section, the results of these interviews are shown.

Interviews

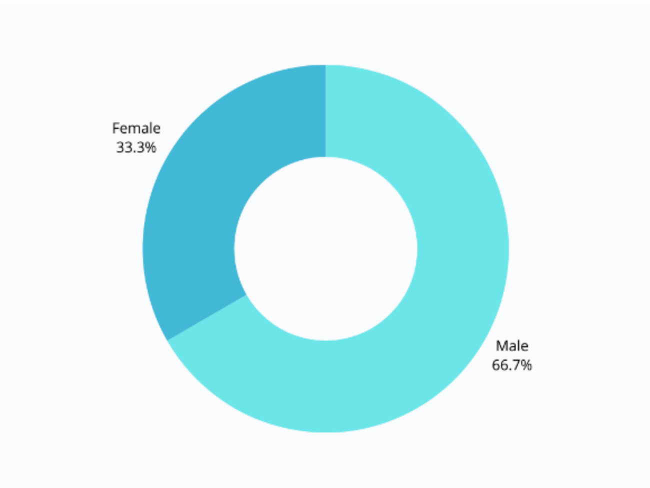
In order to gather participants, a message was sent on the Intranet page of Goudappel, as well as on my own LinkedIn page. Additionally, I asked my family to spread the message as well. This message included the aim of my research (e.g., finding out more about the operation of ADAS while driving), and in this message I asked for participants who operated these systems during driving. Furthermore, age, gender, the type of car they have, the frequency and duration of their driving and a possible moment for the interview were asked within this message. Later, participants received a table with explanations of the different systems before the interview, so they could already think about which systems they use. This table included the systems shown in Previous Study Table 1. Generally, the interviews lasted 20-30 minutes with each participant.

Demographics

In total, nine interviews were conducted, of which four participants were from inside Goudappel and five participants were from outside the company. Previous Study Figures 3, 4 and 5 show the distribution of female and male, the different age categories of the participants, and the provinces where the participants live.

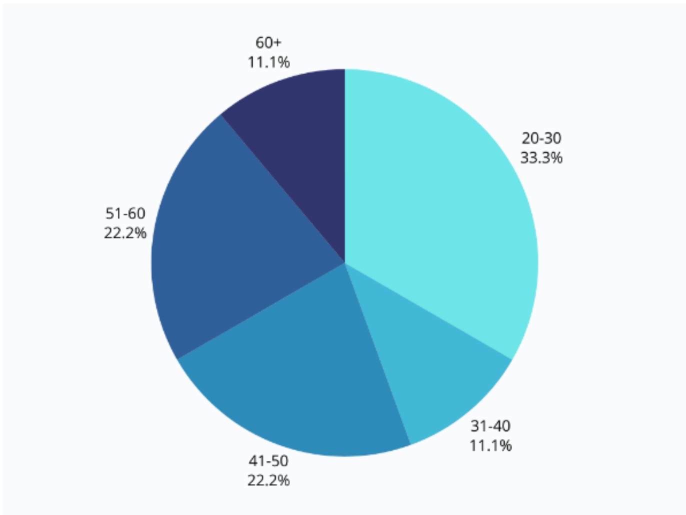
Previous Study Figure 3

Gender distribution of participants



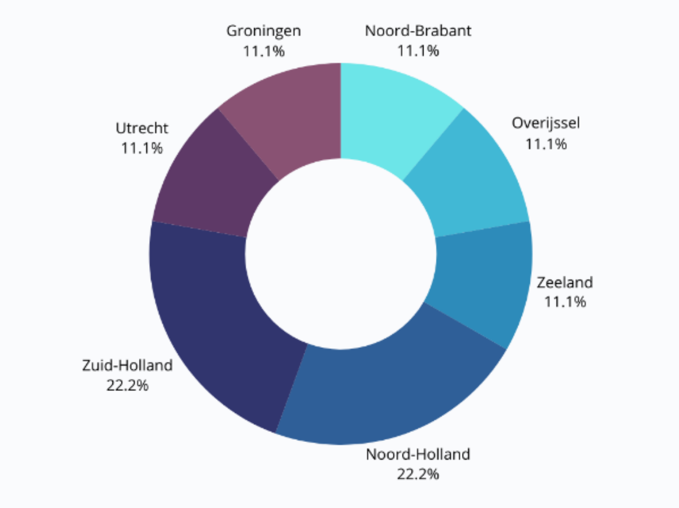
Previous Study Figure 4

Age distribution of participants



Previous Study Figure 5

Location distribution of participants



Additionally, the participants drove in several different car brands, including Volvo, Tesla, Volkswagen, Peugeot, Mercedes and Seat. Additionally, one participant drove several different car brands for his job, including Ford, Audi, BMW, Volvo, Kia, Renault, Lexus, Tesla, Skoda, Mazda, Hyundai, Mercedes, Peugeot and Ford. The duration of one trip in the car differed among the participants, ranging from 10 minutes to several hours. Furthermore, the frequency of driving in the car differed as well amongst participants, ranging from 1 day a week to 7 days a week. Additionally, two participants only used their car with ADAS for 2 or 3 months prior to the interview, while two others used it already for 10 years. Generally, most participants used their car for one to three years prior to the interview. None of the participants bought their car specifically for the ADAS available in that car, however one participant paid extra to include the systems in his car (lease car).

Use of ADAS

The participants mentioned several ADAS they used or sometimes even not used due to various reasons. An overview of the mentioned systems that were used by the participants is visible in Table 2. Adaptive Cruise Control (ACC) is the most used system amongst the participants, followed by Lane Keeping Assistance (LKA) and Blind Spot Warning (BSW). Additionally, Forward Collision Warning (FCW) and Indirect Driver Monitoring Systems (IDMS) were used amongst several participants as well. Those findings are in accordance with the smart mobility monitor of Ministerie van IenW (2023), as they mentioned that growth is expected in the use of ACC, Automatic Emergency Braking (AEB), BSW, FCW and LKA. Moreover, in a previous study, it was found that ACC, LKA, FCW, AEB, Intelligent Speed Assistance (ISA), and Lane Departure Warning (LDW) were the most used systems (van Mierlo, 2023), and half of the systems thus overlap with this study. Additionally, some systems were not mentioned by any participant (see Previous Study Table 2). It might be possible that more systems are active in the cars of the participants and thus used, however, some are sometimes not visible until a specific moment (e.g. Automatic Emergency Steering or Wrong-Way Driving Warning). Hence, it might be possible that drivers are unaware of their existence. Furthermore, it was once mentioned that a participant actively decided to not use Lane Departure Warning, three times that participants did not use LKA, once that a participant did not use ISA and once that a participant did not use Automatic High Beams. These systems were mostly not used due to irritations and frustrations during previous usage, which will be elaborated upon later.

Previous Study Table 2

Usage of ADAS mentioned by the participants

System	Usage mentioned
Blind Spot Warning	5 times
Pedestrian Detection	2 times
Forward Collision Warning	4 times
Lane Departure Warning	1 time
Lane Keeping Assistance	6 times
Lane Centering Assistance	1 time
Rear Cross Traffic Warning	/
Wrong-Way Driving Warning	/
Automatic Emergency Braking	2 times
Automatic Emergency Steering	/
Reverse Automatic Emergency Braking	/
Adaptive Cruise Control	8 times
Active Driving Assistance	2 times
Intelligent Speed Assistance	3 times
Indirect Driver Monitoring System	4 times
Direct Driver Monitoring System	/
Driver Re-engagement System	/
Automatic High Beams	2 times
Traffic Light Recognition	2 times
Head-Up Display	2 times

Participants mentioned they use ACC mostly on highways, on roads where there is speed control and on roads where you have to drive a long way in a straight line, which is in line with previous research (van Mierlo, 2023). Most participants mentioned they stop using ACC when it becomes busy on the road, although one participant mentioned she keeps using it even when it becomes busy. A reason for not using it when it becomes busy is because ACC often brakes too early while it is also possible to let the car roll out (Participant 3). Moreover, another participant mentioned he sometimes did not use ACC in curves (for example in an exit on the highway), as, in those situations, the car often has difficulties detecting the car in front. Furthermore, LKA is used on all roads where the system detects lines, and there is often not a choice to enable or disable it on roads where the driver either wants to use it or not.

Operation during driving

All participants mentioned they can operate ACC on the steering wheel (e.g. Volvo, Volkswagen) or close by the steering wheel with a handle (e.g. Peugeot, Mercedes, Seat). ACC is mostly operated to enable or disable it, to adjust the speed or to adjust the following distance. One participant did not know how to adjust the following distance and another participant mentioned that it was a bit of a hassle to adjust the following distance. Therefore, she did not operate it often as it would mean that she has to take her eyes off the road while doing it (it is operated by a handle near the steering wheel).

Further, two participants mentioned they disable LKA as soon as they start driving, which they both could do via the dashboard screen. For both cars (Mercedes and Volkswagen), LKA is automatically enabled every time they start the car. Out of those two participants, Participant 2 mentioned that operating LKA via the dashboard screen did not cause distractions for her, however, she also acknowledged that this could cause distractions if it was not such an automated task. Participant 4 mentioned that he has to perform quite some actions on the screen to disable LKA, and because the system of the car itself often takes a rather long time to be fully active, he often disabled this while already driving since he cannot operate the dashboard screen before the system is fully working. Another participant, with a Volkswagen, indeed mentioned that LKA can be operated via the dashboard screen, and also mentioned he never operated it because he has to look at the screen to do this. Moreover, Seat also automatically enables LKA when the car is started. Four other participants mentioned they could operate LKA on the steering wheel or somewhere near the steering wheel. Participant 7 (Peugeot) mentioned that, although the operation can be done close by the steering wheel, it is still required to look away from the road to operate it.

Additionally, one participant mentioned he sometimes adjusted the settings of ISA during driving. He can operate this system on the steering wheel, although it takes a few more actions than, for example, operating ACC. Therefore, he only adjusted it when it was not busy on the road. Furthermore, other ADAS mentioned were not operated during driving because they were automatically enabled, or settings could not be adjusted. This is in line with previous research in which it was also found that quite some ADAS is automatically enabled every time the car is started (van Mierlo, 2023). Moreover, this is also in line with research suggesting that for some ADAS it is not possible to be adjusted or disabled (Ministerie van IenW, 2023). An additional comment from Participant 4 indicated that he thinks it is important that it becomes possible to adjust all ADAS with a simple button rather than in the dashboard screen.

Frustrations

Several frustrations or irritations were mentioned with regards to ADAS. First of all, regarding ACC, it was mentioned that it is found annoying when the car brakes automatically during an overtaking maneuver for which you have to come closer to the car in front of you. Also, several participants found it irritating when the distance between the car in front of them and their car was big enough for other cars to insert between them, resulting in their own car braking quite abruptly. Another situation in which ACC was found to be annoying was near traffic lights, as ACC brakes quite late in those situations (Participant 8). Moreover, Participant 3 mentioned that the car sometimes brakes when it was not expected, which was also depicted as annoying. In previous research, it was found that participants found ACC especially annoying in-town (McDonald et al., 2018), however, this was not mentioned in this study. This might be due to the fact that several participants mentioned not using ACC in town.

Additionally, lane keeping was mentioned several times as an annoying ADAS, in line with the study of McDonald et al. (2018). A situation mentioned in which LKA was found to be annoying is during roadworks, as you often have to drive over a line in these situations. By doing this, the steering wheel puts quite some force to stay between the lines, and therefore it takes also quite some force from the driver to overrule this system. Participant 2 mentioned, for example, that this makes it sometimes more dangerous to use LKA than to not use it. Moreover, with LKA, you have to enable your blinkers when overtaking, otherwise the steering wheel puts quite some force to stay in the line, which was also mentioned as something raising irritation. Also, in situations where the bicycle path is separated from the road with a dashed line, LKA was mentioned to be annoying. In these situations, you often have to drive over this dashed line when there is oncoming traffic, however, the steering wheel puts force to not pass this line. As mentioned, several participants disabled this system during driving, and one participant even mentioned they disabled it permanently (Peugeot) due to these frustrations.

Furthermore, ISA was mentioned to be annoying as the system warned or braked when the speed limit was only slightly exceeded (Participant 2). Moreover, two participants mentioned the system often does not recognize the traffic signs correctly, resulting in speed adjustments that are not necessary at that point. For example, on Dutch highways, there are traffic signs saying the maximum speed is 100, with another traffic sign underneath specifying between which times this limit is 100. However, ISA does not recognize this sign underneath and thus adjusts the speed to 100 while in some situations 120 or 130 is the maximum speed allowed.

Additionally, Participant 5 mentioned that she disabled Automatic High Beams as she found it irritating in situations with bicycles. She mentioned that the lights switched too late to dim lights when approaching a cyclist, therefore the cyclist was often blinded. Lastly, IDMS was mentioned to be annoying twice due to the fact that it was not always accurate. Generally, participants wanted to disable the systems when they found it annoying, which was sometimes also done. However, some systems could not be disabled, hence, the frustrations stayed in these situations. The study of van Mierlo (2023) also indicated that the most common reason systems are de-activated is because the functionalities do not work as expected, which is in line with this research.

Traffic safety

Generally, most participants either think that ADAS enhances traffic safety or has the potential to but is currently a neutral factor for traffic safety. One participant mentioned he thinks that ADAS is a threat to traffic safety. Firstly, BSW, IDMS, EBS, ACC and LKA are mentioned as systems that enhance traffic safety, and Participant 6 mentioned that especially the systems in the background are a great addition to traffic safety. It was mentioned by participants that they think ADAS lowers the number of accidents, and someone thinks such systems work better in difficult situations than a human does, for example when there is poor sight due to bad weather. Specifically, for EBS, Participant 5 mentioned that a computer is often quicker in reacting than a human, so this is a great benefit for traffic safety. Moreover, LKA is mentioned to be a positive system for drivers who might snooze away a bit, and generally it is mentioned that participants think that for people who pay less attention those systems enhance traffic safety. With regards to ACC, it is mentioned that it can help in lowering accidents, however, it also has a potential risk for the cars behind, as they have to react quickly to a braking car in front when they are not driving with ACC themselves. Those results seem in line with previous research, where it is indicated that most of the drivers think that ADAS helps in driving more safely (Ministerie van IenW, 2023).

On the other hand, a participant mentioned that the car cannot always make a proper assessment of the traffic situation, which might make the use of ADAS a threat to traffic safety. Another reason mentioned by participants expressing their doubts about the safety of those systems is that you have to get used to these systems, therefore it might become slightly more dangerous using the systems when you are not yet used to it. Participant 5 for example mentioned that it can become more dangerous if you want to adjust something during driving when you do not know where and how this can be adjusted. Nevertheless, some cars already block this function in the dashboard screen, which in its turn enhances safety on the road. Moreover, two participants mentioned that it would only enhance safety if all cars were equipped with the systems and all drivers use them, as the human factor in driving needs to be completely gone for it to be safe according to them. Regardless, Participant 1 thinks that everyone will be forced to use it in the future or have to adjust themselves to the cars who use it, therefore it is only a matter of time before it will fully enhance safety on the road.

Several participants also mentioned that due to usage of ADAS they expect drivers to become less active and lazier. One participant mentioned he would not look at his phone himself while driving and using ADAS, however, he could understand why others would do this. Moreover, another participant mentioned that when ACC breaks, the brake lights are activated, which might cause a shock reaction for the cars behind. Therefore, it is important that everyone drives with ADAS activated according to Participant 2. The participants also expressed their doubts about the safety of LKA, as it can act quite aggressively, and it is sometimes hard to overrule it. Additionally, the irritation caused by some systems might also lower traffic safety according to Participant 4. Lastly, it was mentioned that there are currently too many situations in which the systems cannot act in the right way, for example bad weather, low sun and roadwork. Usage of ADAS in these situations can therefore lower traffic safety according to some participants.

Conclusion

The interviews show that ACC, LKA, BSW, FCW and IDMS are the most used ADAS amongst the participants. Nevertheless, it has to be noted that several ADAS are not visible for drivers until they are activated in a rather specific situation, hence, it might be that more or other systems are used more frequently than mentioned here. ADAS is mostly used on highways, long straight roads and roads with speed control. Furthermore, ACC, LKA and ISA were mentioned to be operated during driving, which happened at different places within the car (e.g., on the steering wheel, near the steering wheel or on the dashboard screen). For some ADAS, participants mentioned it was not possible to enable, disable or adjust them. Moreover, most frustrations arose when using ACC, LKA and ISA, and mainly involved situations in which the system did not function as expected. Especially for LKA, there were multiple situations in which the driver wanted to overrule it, however, quite some force was needed to be able to do this. Lastly, the participants were divided about whether they think usage of ADAS make traffic safer or not, and most participants think that either everyone needs to use the systems for it to enhance safety or the systems need to better adjust to several different situations such as bad weather and roadworks.

Conclusion and Discussion

At the start of this internship, the goal was set to delve deeper into behaviour patterns caused by ADAS, with a focus on distractions. This was done by a literature review followed by an interview study. The literature review showed that there are several reasons to think that drivers might operate ADAS while they are driving, and additionally, several reasons were found indicating that this operation of these systems while driving poses significant risk for traffic safety. Nevertheless, it remained unclear whether drivers actually operate ADAS while driving or not, and if they operate it, to which extent this happens. Therefore, interviews were conducted with nine car owners who used ADAS in order to shed light on the current state regarding the operation of ADAS during driving. All in all, I believe that both the literature study and the interviews contributed to gaining knowledge about specific behaviour related to the use of ADAS within cars, and the results of those studies pose several questions for possible future research.

First of all, it seems like BSW, LKA, ACC, ISA, and IDMS are the systems which the drivers are most aware of that they are using them, where LKA, ACC and ISA are also actually operated while driving. Regarding this operation, it became clear that especially for LKA and ISA, the ways of operating differed amongst different car brands. As indicated in both the literature review and interviews, operating LKA on the dashboard screen was seen as a potential for distraction. Moreover, it was also indicated that both LKA and ISA took more actions to operate than ACC. Regardless, something the interviews added to the literature review was the fact that some car brands already have restrictions on operating ADAS during driving by blocking these functions in the dashboard screen unless the driver stops driving. Those findings pose the question whether this operation in different places in cars from different brands lowers traffic safety in general. Can it, for example, possibly be that distraction is caused by the differences amongst car brands, as this results in more time to search for the operation buttons. Participants mentioned that being used to the operation of the systems enhances safety on the road, and also lowers the potential for the operation to be a distracting factor. Moreover, another question posed by these results and the method used is whether this self-assessment of drivers provides the correct picture. Can they for example decide for themselves what is distracting and what is not, and as some tasks are rather automated, can they recall the actions needed for operation correctly?

Secondly, as the literature suggested, LKA is mandatory in all new cars manufactured from July 2022 on as it is believed that this system enhances the safety on the road. However, the interviews suggest that this is one of the most mentioned systems that causes frustrations while using it. This frustration causes drivers to disable it, however, in some cars this is a rather hard task to perform while driving. As ACC is operated more often during driving, it is understandable that car brands made it harder to disable LKA than to disable ACC, thereby also considering LKA being a mandatory system. However, if this results in drivers being more distracted because they still want to disable LKA, it might only enhance dangerous situations on the road. Those conflicting ideas show a divide between the ideas of the manufacturers or safety regulations, and the users of the systems.

Further, as shown by the literature review and the interviews, there are several situations in which ADAS is frustrating or even dangerous to use (e.g., roadworks, highway exits). Some of these situations are rather specific for the Netherlands, for example bicycle paths on the road or an additional road sign specifying the times between which the maximum speed is 100 on a highway. This raises the question whether these systems are made for universal use or maybe for the most common roads and traffic situations. Are there maybe improvements to either the systems or the infrastructure needed for specific situations in different countries? And would this lower the frustrations mentioned by users?

Lastly, it was also mentioned by participants that ADAS might enhance traffic safety, especially for drivers who are less alert in the car. However, ADAS is not designed to fully take over the driving task, rather it is designed to assist the driver. Therefore, it is important that the driver remains alert. Participants of the interview mentioned that they were sometimes inclined to or could imagine that others would perform non-driving related activities during driving, such as looking at your phone or playing with the functionalities of ADAS. Is it needed that drivers become more aware of this assisting role rather than the take-over role, and how could you make sure that drivers stay active and alert while also using ADAS?

In conclusion, based on the previously mentioned results, there are several possible areas for future research. I will highlight three areas in which I can continue for my Master thesis, which are also relevant for Goudappel's smart mobility project about the effects of ADAS on behaviour.

- The first area is related to a limitation of interviews, namely that they are based on self-assessment. With an observation study, it would be possible to find out more about the findability of the operation controls of ADAS in cars. Also, it would be possible to figure out whether the participants of the interviews downplayed the level of distraction by operating ADAS, for example by looking at how much and how long drivers take their eyes off the road due to operating a system.

- The second area is related to making systems cars more easily operated and to habits of drivers. Nowadays, more and more systems in cars, both IVIS and ADAS, are put away in the dashboard screen. However, this can possibly make operating systems in cars more dangerous. In a future study, it would be possible to look at ways in which the operation of ADAS could be made as safe as possible. Here, it is an option to look at the current differences between cars in operating ADAS and evaluate what works best for drivers. Also, it would be possible to examine drivers' expectations on the locations at which they would expect to be able to operate ADAS.
- The third area is related to distractions caused by using ADAS. By means of an observation study, it would be possible to look at how drivers react to the interaction from the system to the driver, for example on sounds and vibrations produced by the systems, but also at interactions from the driver to the system (e.g., operation), and then mainly in situations in which the driver thinks the system is incorrect (e.g., are they getting frustrated or having another reaction). Here, it is a possibility to look at the type of distraction caused by those interactions and frustration, for example, would it induce visual distraction or maybe more cognitive distraction?

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Previous Study Attachment 1 – Overview all ADAS and their explanations

Previous Study Table 3

All ADAS and their explanations (alphabetical order)

System	Other names	Explanation
-Active Driving Assistance	-Simultaneous use of Lane Centering Assistance and Adaptive Cruise Control	Simultaneous use of Lane Centering Assistance and Adaptive Cruise Control features. The driver must constantly supervise this support feature and maintain responsibility for driving.*
-Active Parking Assistance	-Automatic Parallel Parking	Assists with steering and potentially other functions during parking maneuvers. Drivers may be required to accelerate, brake, and/or select gear position. Some systems are capable of parallel and/or perpendicular parking. The driver must constantly supervise this support feature and maintain resopnsibility for parking.*
-Adaptive Cruise Control	-Dynamic Cruise Control -Active Cruise Control	Cruise control that also assists with acceleration and/or braking to maintain a driver-selected gap to the vehicle in front. Some systems can come to a stop and continue while others cannot.*
-Anti-lock Brakes	-Anti-lock Braking System	Monitors you car's wheel speed and detects a wheel lock. Helps in preventing a lock up and helps maintain control of your vehicle.
-Automatic Emergency Braking	-Forward Collision Mitigation System -Pre-crash Warning and Braking System -Intelligent Braking	Detects potential collisions with a vehicle ahead, provides forward collision warning, and automatically brakes to avoid a collision or lessen the severity of impact. Some systems

	-Collision Mitigation Braking System -Front Automatic Braking -Autonomous Emergency Braking	also detect pedestrians or other objects.*
-Automatic Emergency Steering	-Autonomous Emergency Steering	Detects potential collisions with a vehicle ahead and automatically steers to avoid or lessen the severity of impact. Some systems also detect pedestrians or other objects.*
-Automatic High Beams	-Adaptive (LED) Headlights -Smart Headlights	Switches between high and low beam headlamps automatically based on lighting and traffic.*
-Backup Camera	-Reversing Camera -Rearview Camera	Displays the area behind the vehicle when in reverse gear.*
-Blind Spot Warning	-Side Blind Zone Alert -Lane Change Alert -Blind Spot Information System -Blind Spot Detection -Blind Spot Monitoring	Detects vehicles in the blind spot while driving and notifies the driver to their presence. Some systems provide an additional warning if the driver activates the turn signal.*
-Crosswind Stabilization	/	Detects when a car is being moved by stron gusts of wind and assist the vehicle in dealing with this strong crosswinds.
-Direct Driver Monitoring System	-Drowsiness Alert -Driver Fatigue Warning -Vermoeidheidsherkenning -Afleidingsherkenning	Detects the driver's eye and/or head movement to estimate where the driver is looking. Some systems may provide a warning to the driver and/or limit the use of other features.*
-Driver Alcohol Detection System	-Passive, vehicle-integrated alcohol impariment detection systems	Detects the drivers alcohol level and prevents or limits vehicle operation if it detects driver impairment by alcohol.
-Driver Re-engagement System	/	A series of escalating warnings and interventions attempting to engage an unresponsive driver. If the driver does not respond, the system brings the vehicle to a full stop while maintaining steering control. Some systems may steer the vehicle to the side of the road and/or make an emergency call if the driver fails to respond.*
-Electronic Stability Control	-Electronic Stability Program -Dynamic Stability Control	Helps in preventing the driver from losing control of the direction of the car due to either oversteering or

		understeering. It also reduces the risk of being in a rollover.
-Emergency Stop Signal	/	Provides warning lights (often rapidly flashing lights) in case the driver suddenly brakes hard in order to alert the drivers behind.
-Event Data Recorder	-Automotive Event Data Recorder -Accident Data Recorder	Devices that are used to record safety information related to accidents or other events (e.g. seatbelt usage or airbag deployment).
-Forward Collision Warning	-Forward Collision Avoidance System -Rear-end Crash Avoidance System -Collision Avoidance System -Forward Crash Warning	Detects a potential collision with a vehicle ahead and alerts the driver. Some systems also provide alerts for pedestrians or other objects.*
-Head-Up Display	/	Projects information relevant to driving into the driver's forward line of sight.*
-Hill Descent Control	-Hill Control Assist -Downhill Assist Control	Continually adjust braking pressure to help control slippage and maintain a constant preset speed while you are going down a steep hill.
-Hill Start Assist	-Hill-Hold Control -Hill-Start Assist Control	Automatically activates to stop your car from rolling back when you press and release the brakes on a hill by holding the brake pressure.
-Intelligent Speed Assistance	-Intelligent Speed Adaptation	Informs the driver of the applicable speed limit and, if necessary, automatically limits the vehicle's speed. As a result, the applicable speed limit is not unknwingly exceeded.
-Lane Departure Warning	/	Monitors vehicle's position within the driving lane and alerts driver as the vehicle approahces or crosses lane markers.*
-Lane Keeping Assistance	/	Provides steering support to assist the driver in keeping the vehicle in the lane. The system reacts only when the vehicle approaches or crosses a lane line or road edge.*
-Lane Centering Assistance	/	Provides steering support to assist the driver in continuously maintaining the vehicle at or near the center of the lane.*

-Night Vision	-Automotive Night Vision -Thermal Camera -Infrared Night Vision System	Improves forward visibility at night by projecting enhanced images on instrument cluster or head-up display.*
-Parking Collision Warning	-Parking Collision Avoidance -Parking Sensors	Detects objects close to the vehicle during parking meuvers and notifies the driver.*
-Pedestrian Detection	-Object Detection	Alerts the driver or brakes automatically if there is a pedestrian in the surroundings of the car.
-Rear Cross Traffic Warning	-Rear Cross Traffic Alert	Detects vehicles approahcing from the side at the rear of the vehicle while in reverse gear and alerts the driver. Some systems also warn for pedestrians or other objects.*
-Remote Parking Assistance	-Remote Smart parking Assist -Intelligent Parking Assist System -Advanced Parking Guidance System -Advanced Park Assist	Without the driver being physically present inside the vehicle, provides steering,b raking, accelerating and/or gear selection while moving a vehicle into or out of a parking space. The driver must constantly supervise this support feature and maintain responsibility for parking.*
-Reverse Automatic Emergency Braking	-Rear Automatic Braking	Detects potential collisions while in reverse gear and automatically brakes to avoid or lessen the severity of impact. Some systems also detect pedestrians or other objects.*
-Surround View Camera	-360-degree Surround View Camera -Sideview Camera -Around View Monitor -Omniview/Omidirectional Camera	Displays the immediate surroundings of some or all sides of the vehicle while stopped or during low speed maneuvres.*
-Traction Control System	/	Helps accelerating and in preventing wheel slippage (or over-spinning) when driving on slippery surfaces.
-Traffic Light Recognition	-Traffic Light Detection	Detects and analyzes traffic lights to inform the driver or respond to them independently.
-Trailer Assistance	/	Assists the driver with visual guidance while backing towards a trailer or during backing maneuvers with a trailer attached. Some systems may provide additional images while driving or backing with a trailer. Some systems may provide steering

		assistance during backing maneuvers.*
-Vehicle Communication Systems	-Vehicle Communication Network	Computer networks in which vehicles and roadside units are connected to provide eachother with information, such as safety warnings and traffic information.
-Wrong-way Driving Warning	-Wrong Way Alert	Alerts drivers that they are entering the highway in the wrong direction so they can correct themsevles before causing a collision.

**Descriptions provided by American Automobile Association (AAA), Consumer Reports, J.D. Power, National Safety Council (NSC), Partners for Automated Vehicle Education (PAVE), & SAE international (2022).*

Previous Study Attachment 2 – Characteristics of ADAS

Previous Study Table 4

All ADAS used for this research and their characteristics

System	Automatically enabled?	Mandatory?*	Driver initiated operations	Active/ passive?
Blind Spot Warning	Some are, some have to be manually enabled	No	Turning on/off	Passive
Pedestrian Detection	Unknown	No	Turning on/off	Passive/ Active
Forward Collision Warning	Most often yes	No	Turning on/off and adjusting settings	Passive
Lane Departure Warning	Some are, some have to be manually enabled	No	Turning on/off, (Sometimes also adjusting sensitivity levels and types of warnings)	Passive
Lane Keeping Assistance	Yes	Yes	Turning on/off, (Sometimes also adjusting sensitivity levels and types of warnings)	Active
Lane Centering Assistance	No	No	Turning on/off, (Sometimes also adjusting sensitivity levels)	Active
Rear Cross Traffic Warning	Yes	No	Turning on/off	Passive
Wrong Way Driving Warning	Unknown	No	Turning on/off	Passive

Automatic Emergency Braking	Yes	Yes	Turning on/off	Active
Automatic Emergency Steering	Unknown	No	Turning on/off	Active
Reverse Automatic Emergency Braking	Yes	Unknown	Turning on/off	Active
Adaptive Cruise Control	No	Yes	Turning on/off, setting the speed, setting the distance	Active
Active Driving Assistance	No	No	Turning on/off, adjusting sensitivity levels, setting the speed, setting the distance	Active
Intelligent Speed Assistance	No	Not yet, from 2024 on	Turning on/off	Active
Indirect Driver Monitoring System	Unkown, probably yes	Yes**	Unkown, probably none	Passive/ Active
Direct Driver Monitoring System	Unkown, probably yes	Yes**	Unkown, probably none	Passive/ Active
Driver Re-engagement System	Unkown, probably yes	Yes**	Unkown, probably none	Active
Automatic High Beams	Sometimes	No	Turning on/off, sometimes adjusting settings	Passive
Traffic Light Recognition	Unknown, probably yes	No	Turning on/off	Passive/ Active
Head-Up Display	Unkown	No	Turning on/off, adjusting settings	Passive

*Mandatory in new manufactured cars from 6 July 2022 on.
**Attention warning in case of driver drowsiness or distraction is mandatory.

Appendix II
Questionnaire

Invitation survey

Title: Survey for thesis research on using or not using driver assistance systems.

Currently, I am working on my graduation project at Goudappel and could really use your help! For my research, I would like to quantify how many people in the Netherlands use driver assistance systems. In case people use driver assistance systems, I am also curious about the possible operation of these systems while driving.

Do you know, or are you, someone who lives in the Netherlands, is over 18, has a driver's license (B) and drives the same car at least twice a month? If so, would you be willing to help by completing and/or forwarding the survey below? It will take around 10-15 minutes to complete the survey. **Please note! It is not necessary for you to have or use driver assistance systems in your car. If you do not have or use them, you can still complete the survey**.

Thank you in advance! If you still have questions, feel free to email (b.a.a.vandeven@student.utwente.nl) me!

Kind regards,

Britt van de Ven

Survey – quantification of the operation of ADAS while driving

Dear participant,

Thank you for wanting to participate in my research! For my Master thesis, I am conducting research on the presence and possible use of driver assistance systems. With this survey, I would like to gain more information about whether or not you use driving assistance systems, and in case you do use those systems, also about your experiences with operating the different driver assistance systems. **Please note! It is not necessary for you to have driver assistance systems in your car or use them. If you do not have them or use them, the request is still to fill out the survey**.

The survey will begin with some questions about yourself and your driving habits, followed by questions about the various driver assistance systems. *Be sure to read the information below carefully before you begin the survey!*

I would like to inform you that your participation in this study is completely voluntary. You have the right to stop the survey at any time or refuse to answer any question. In case you decide that you do not want to participate in the study after filling out the survey, please send an email to the email address below within 2 months of completion. Completing the questionnaire will take approximately 10-15 minutes.

Furthermore, your data will be treated confidentially and with care. The data collected will be used anonymously and exclusively for the current Master thesis of Britt van de Ven for the master Human Factors & Engineering Psychology.

Finally, the research has been reviewed and approved by the “BMS Ethics Committee” of the University of Twente.

If you have any questions or would like more information, you can reach me at:
b.a.a.vandeven@student.utwente.nl

Thank you in advance for your participation!

Kind regards,
Britt van de Ven

Please make your choice here:

- Yes, I voluntarily consent to participate in this study. I am aware that i may refuse to complete a question and that I may stop participating in this study at any time without having to give a reason.
- No, I do not wish to participate in this study.

Demographic questions

In this section, several demographic questions will be asked about you, your car and your driving experience. Please try to answer them as accurately as possible.

- What is your gender?
    - Man
    - Woman
    - Other
    - Prefer not to say
- What is your age?
- What province in the Netherlands do you live in?
    - Groningen
    - Friesland
    - Drenthe

  - Overijssel
  - Flevoland
  - Gelderland
  - Utrecht
  - Noord-Holland
  - Zuid-Holland
  - Zeeland
  - Noord-Brabant
  - Limburg
- For how many years do you have your driving license B? (in whole years)

Questions about the car

- As a driver, which car brand is the car you drive most often?
  - Audi
  - BMW
  - Citroën
  - Dacia
  - Ford
  - Hyundai
  - Kia
  - Mazda
  - Mercedes-Benz
  - Nissan
  - Opel
  - Peugeot
  - Renault
  - Seat
  - Skoda
  - Suzuki
  - Toyota
  - Tesla
  - Volkswagen
  - Volvo
  - Other, namely:
- Which type is the car you drive most often as a driver? *(e.g., if you drive a Toyota RAV4 most often, you fill out "RAV4").*
- What is the building year of the car you most often drive as a driver?

Questions about your driving experience

- How many kilometers do you drive on average per year as a driver? *Please estimate as accurately as possible.*
- How many kilometers is your average drive as a driver with the above-mentioned car? *Please estimate as accurately as possible.*
- In the past month, how often have you driven the above-mentioned car as a driver?
  - Less than once a month
  - 1-4 times a month
  - 5-8 times a month
  - 8-12 times a month
  - 13-16 times a month
  - 17-20 times a month
  - 21-24 times a month
  - 25-31 times a month
- In the past month, how many kilometers have you driven as a driver with the above-
- mentioned car? *Please estimate as accurately as possible.*

Questions about the driver assistance systems

The next block of questions deals with the various driver assistance systems and the possible operation of those systems by you. Different systems will be covered, for which the most common name for the system is used. It could be that in your car the name of the system differs from the name mentioned here. Therefore, please read the description of the system carefully before answering the questions about the system. These questions involve the car you named earlier in the survey.

Did you use Adaptive Cruise Control in the past month?

Adaptive Cruise Control can self-regulate the speed and distance to the car in front, so you do not have to accelerate or brake. It automatically adjusts speed if you get too close to the car in front to avoid a collision, and some systems can also bring the car to a complete stop if necessary.

- Yes
- No, I do not use it, but I do have it in my car
- No, I do not have it in my car
- No, I do not know what this system is

In case the answer is yes, the following questions will show up:

The following questions are about the operation of **Adaptive Cruise Control** while driving. In case you do not know the exact number, try to estimate it as accurately as possible.

1. **While driving, how many times did you use Adaptive Cruise Control in the past month?** *This may be several times per trip if you have disabled the system during the trip.*

2. **While driving, how many times did you turn <u>Adaptive Cruise Control</u> on or off in the <u>past month</u>?** *E.g., in case you turned it on once and turned it off once, you fill out "2".*
3. **While driving, how many times did you adjust the settings of <u>Adaptive Cruise Control</u> in the <u>past month?</u>** *This means, for example, setting the following distance. So, turning the system on or off does not count as an action here.*
4. **While driving, how many <u>seconds</u> on average do you spend per action of operating <u>Adaptive Cruise Control?</u>** *Examples of actions are turning it on/off or adjusting the settings.*
5. **Where in the car do you operate <u>Adaptive Cruise Control</u>?** *Multiple answers possible in case turning it on or off and adjusting settings is performed in different places*
    1. Near the steering wheel, I do not need to take my hands off the wheel to do this.
    2. Near the steering wheel, I do need to take one hand off the wheel to operate it.
    3. On the dashboard screen (the screen that is placed in the middle of your car on the dashboard)
    4. Somewhere else, namely:

Did you use <u>Lane Keeping Assistance</u> in the <u>past month</u>?

Lane Keeping Assistance helps in keeping the car within the lines of the lane and automatically warns and steers back into the lane if the car leaves the lane. Thus, the system responds only when the car approaches or crosses a lane or road edge.

- Yes
- No, I do not use it, but I do have it in my car
- No, I do not have it in my car
- No, I do not know what this system is

In case the answer is yes, the following questions will show up:

The following questions are about the operation of **Lane Keeping Assistance** while driving. In case you do not know the exact number, try to estimate it as accurately as possible.

1. **While driving, how many times did you use <u>Lane Keeping Assistance</u> in the <u>past month</u>?** *This may be several times per trip if you have disabled the system during the trip.*
2. **While driving, how many times did you turn <u>Lane Keeping Assistance</u> on or off in the <u>past month?</u>** *E.g., in case you turned it on once and turned it off once, you fill out "2".*
3. **While driving, how many times did you adjust the settings of <u>Lane Keeping Assistance</u> in the <u>past month?</u>** *This includes, for example, setting alert mode or adjusting system sensitivity. So, turning the system on or off does not count as an action here.*
4. **While driving, how many <u>seconds</u> on average do you spend per action of operating <u>Lane Keeping Assistance</u>?** *Examples of actions are turning it on/off or adjusting the settings.*

5. **Where in the car do you operate <u>Lane Keeping Assistance</u>?** *Multiple answers possible in case turning it on or off and adjusting settings is performed in different places*
    1. Near the steering wheel, I do not need to take my hands off the wheel to do this.
    2. Near the steering wheel, I do need to take one hand off the wheel to operate it.
    3. On the dashboard screen (the screen that is placed in the middle of your car on the dashboard)
    4. Somewhere else, namely:

Did you use <u>Blind Spot Warning</u> in the <u>past month</u>?
Blind Spot Warning detects vehicles in the blind spot while driving and warns if there is a vehicle in the blind spot. Some systems provide an additional warning when the turn signal is turned on.

- Yes
- No, I do not use it, but I do have it in my car
- No, I do not have it in my car
- No, I do not know what this system is

In case the answer is yes, the following questions will show up:
The following questions are about the operation of **Blind Spot Warning** while driving. In case you do not know the exact number, try to estimate it as accurately as possible.

1. **While driving, how many times did you use <u>Blind Spot Warning</u> in the <u>past month</u>?** *This may be several times per trip if you have disabled the system during the trip.*
2. **While driving, how many times did you turn <u>Blind Spot Warning</u> on or off in the <u>past month</u>?** *E.g., in case you turned it on once and turned it off once, you fill out "2".*
3. **While driving, how many times did you adjust the settings of <u>Blind Spot Warning</u> in the <u>past month?</u>** *This includes, for example, adjusting the volume or other functions. So, turning the system on or off does not count as an action here.*
4. **While driving, how many <u>seconds</u> on average do you spend per action of operating <u>Blind Spot Warning?</u>** *Examples of actions are turning it on/off or adjusting the settings.*
5. **Where in the car do you operate <u>Blind Spot Warning</u>?** *Multiple answers possible in case turning it on or off and adjusting settings is performed in different places*
    1. Near the steering wheel, I do not need to take my hands off the wheel to do this.
    2. Near the steering wheel, I do need to take one hand off the wheel to operate it.
    3. On the dashboard screen (the screen that is placed in the middle of your car on the dashboard)
    4. Somewhere else, namely:

Did you use <u>Forward Collision Warning</u> in the <u>past month</u>?

Forward Collision Warning detects a potential collision with a vehicle in front and wanrs if a head-on collision is imminent so you can intervene in time. Some systems also warns when pedestrians or other objects are detected.

- Yes
- No, I do not use it, but I do have it in my car
- No, I do not have it in my car
- No, I do not know what this system is

In case the answer is yes, the following questions will show up:

The following questions are about the operation of **Forward Collision Warning** while driving. In case you do not know the exact number, try to estimate it as accurately as possible.

1. **While driving, how many times did you use <u>Forward Collision Warning</u> in the <u>past month</u>?** *This may be several times per trip if you have disabled the system during the trip.*
2. **While driving, how many times did you turn <u>Forward Collision Warning</u> on or off in the <u>past month?</u>** *E.g., in case you turned it on once and turned it off once, you fill out "2".*
3. **While driving, how many times did you adjust the settings of <u>Forward Collision Warning</u> in the <u>past month?</u>** *This includes, for example, adjusting the sensitivity or the type of notification. So, turning the system on or off does not count as an action here.*
4. **While driving, how many <u>seconds</u> on average do you spend per action of operating <u>Forward Collision Warning</u>?** *Examples of actions are turning it on/off or adjusting the settings.*
5. **Where in the car do you operate <u>Forward Collision Warning</u>?** *Multiple answers possible in case turning it on or off and adjusting settings is performed in different places*
    1. Near the steering wheel, I do not need to take my hands off the wheel to do this.
    2. Near the steering wheel, I do need to take one hand off the wheel to operate it.
    3. On the dashboard screen (the screen that is placed in the middle of your car on the dashboard)
    4. Somewhere else, namely:

Did you use <u>Indirect Driver Monitoring System</u> in the <u>past month</u>?

Indirect Driver Monitoring System observes various elements, such as the state of the car, movements and how you perform as a driver to see if there may be any distraction, inattention or misuse on your part as a driver. For example, the degree of swerving within the lane or the touching or not touching of the steering wheel can be observed. Some systems can then also alert you if the system thinks you may be distracted or not paying attention.

- Yes

- No, I do not use it, but I do have it in my car
- No, I do not have it in my car
- No, I do not know what this system is

In case the answer is yes, the following questions will show up:

The following questions are about the operation of **Indirect Driver Monitoring System** while driving. In case you do not know the exact number, try to estimate it as accurately as possible.

1. **While driving, how many times did you use Indirect Driver Monitoring System in the past month?** *This may be several times per trip if you have disabled the system during the trip.*
2. **While driving, how many times did you turn Indirect Driver Monitoring System on or off in the past month?** *E.g., in case you turned it on once and turned it off once, you fill out "2".*
3. **While driving, how many times did you adjust the settings of Indirect Driver Monitoring System in the past month?** *This includes, for example, adjusting the sensitivity or the volume. So, turning the system on or off does not count as an action here.*
4. **While driving, how many seconds on average do you spend per action of operating Indirect Driver Monitoring System?** *Examples of actions are turning it on/off or adjusting the settings.*
5. **Where in the car do you operate Indirect Driver Monitoring System?** *Multiple answers possible in case turning it on or off and adjusting settings is performed in different places*
    1. Near the steering wheel, I do not need to take my hands off the wheel to do this.
    2. Near the steering wheel, I do need to take one hand off the wheel to operate it.
    3. On the dashboard screen (the screen that is placed in the middle of your car on the dashboard)
    4. Somewhere else, namely:

Did you use Intelligent Speed Assistance in the past month?

Intelligent Speed Assistance informs the driver of the applicable speed limit and, if necessary, automatically brakes so that the maximum speed is not exceeded. It also limits the option to exceed the speed limit by not allowing you to accelerate more.

- Yes
- No, I do not use it, but I do have it in my car
- No, I do not have it in my car
- No, I do not know what this system is

In case the answer is yes, the following questions will show up:

The following questions are about the operation of **Intelligent Speed Assistance** while driving. In case you do not know the exact number, try to estimate it as accurately as possible.

1. **While driving, how many times did you use Intelligent Speed Assistance in the past month?** *This may be several times per trip if you have disabled the system during the trip.*
2. **While driving, how many times did you turn Intelligent Speed Assistance on or off in the past month?** *E.g., in case you turned it on once and turned it off once, you fill out "2".*
3. **While driving, how many times did you adjust the settings of Intelligent Speed Assistance in the past month?** *This includes, for example, setting the speed. So, turning the system on or off does not count as an action here.*
4. **While driving, how many seconds on average do you spend per action of operating Intelligent Speed Assistance?** *Examples of actions are turning it on/off or adjusting the settings.*
5. **Where in the car do you operate Intelligent Speed Assistance?** *Multiple answers possible in case turning it on or off and adjusting settings is performed in different places*
    1. Near the steering wheel, I do not need to take my hands off the wheel to do this.
    2. Near the steering wheel, I do need to take one hand off the wheel to operate it.
    3. On the dashboard screen (the screen that is placed in the middle of your car on the dashboard)
    4. Somewhere else, namely:

Other systems

For the other driver assistance systems, please indicate whether they have ever caused distraction due to the operation of the system while driving. This refers to distraction caused by turning the driver assistance system on or off, or by adjusting settings. *Before completing these questions, think back to for example the questions asked earlier about the other driver assistance systems, so that you can make the best possible assessment regarding the requested form of distraction.*

While you were driving, did Automatic High Beams ever cause distraction due to the operation of it?

Automatic High Beams automatically switches between high and low beam headlamps based on the lighting of the environment and other traffic.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Traffic Light Recognition ever cause distraction due to the operation of it?

Traffic Light Recognition detects and analyzes traffic lights and informs you of the color of the traffic light or, in some cases, can respond to traffic lights independently by stopping at a red light and/or accelerating at a green light.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Head-Up Display ever cause distraction due to the operation of it?

Head-Up Display projects information relevant to driving (e.g., the speed limit) into the driver's forward line of sight (e.g. in the window or on the road).

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Lane Centering Assistance ever cause distraction due to the operation of it?

Lane Centering Assistance helps to keep the car continuously in or close to the center of the lane by, for example, supporting the steering wheel.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Active Driving Assistance ever cause distraction due to the operation of it?

Active Driving Assistance is the simultaneous use of Lane Centering Assistance and Adaptive Cruise Control features.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it

- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Pedestrian Detection ever cause distraction due to the operation of it?

Pedestrian Detection automatically warns you or brakes if it detects a pedestrian in the surroundings of the car, so you can take this pedestrian into account.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Automatic Emergency Braking ever cause distraction due to the operation of it?

Automatic Emergency Braking detects potential collisions with a vehicle ahead, provides forward collision warning, and automatically brakes to avoid a collision or lessen the severity of impact. Some systems might also detect pedestrians or other objects.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Lane Departure Warning ever cause distraction due to the operation of it?

Lane Departure Warning monitors the car's position in the lane and alerts you when the car approaches or crosses the lines of the lane.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Rear Cross Traffic Warning ever cause distraction due to the operation of it?

Rear Cross Traffic Warning detects vehicles near the car as you reverse and warns if there is a car coming from the side. Some systems also warn of pedestrians or other objects.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Wrong-Way Driving Warning ever cause distraction due to the operation of it?

Wrong-Way Driving Warning alerts you if you enter the highway in the wrong direction, so you can still correct yourself before a collision occurs.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Automatic Emergency Steering ever cause distraction due to the operation of it?

Automatic Emergency Steering detects potential collisions with a vehicle ahead and automatically steers to avoid or lessen the severity of impact. Some systems also detect pedestrians or other objects.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Reverse Automatic Emergency Braking ever cause distraction due to the operation of it?

Reverse Automatic Emergency Braking detects potential collision while you are driving in reverse gear and automatically brakes to avoid or lessen the severity of impact. Some systems also detect pedestrians or other objects.

- Yes, it has caused some form of distraction while I operated it while driving

- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Direct Driver Monitoring System ever cause distraction due to the operation of it?

Direct Driver Monitoring Systems detect your eye and/or head movement to estimate where you are looking. Some systems may provide a warning to the driver and/or limit the use of other features when it thinks that you are tired or distracted.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

While you were driving, did Driver Re-engagement System ever cause distraction due to the operation of it?

Driver Re-engagement Systems provide a series of escalating warnings and interventions attempting to engage you when you are not responsive. If you do not respond, the system brings the car to a full stop while maintaining steering control. Some systems may steer the car to the side of the road and/or make an emergency call if you fail to respond.

- Yes, it has caused some form of distraction while I operated it while driving
- No, I do use the system but I do not experience distractions when I am operating it
- No, because I do not use it (but I do have it in my car)
- No, because I do not have it in my car
- No, I do not know what this system is

Possible remarks?

- Do you have any additional remarks?

End of survey

These were all questions, thank you very much for filling out my survey and helping me graduate with my Master's degree. If you have any questions/comments, you can reach me at b.a.a.vandeven@student.utwente.nl

You can close the survey now.

Appendix III

Visualizations of demographics

Figure 15

Gender distribution among the participants

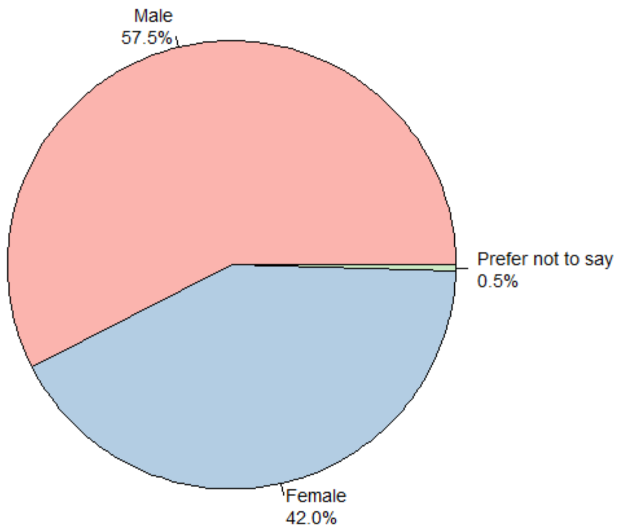


Figure 16

Age distribution among the participants

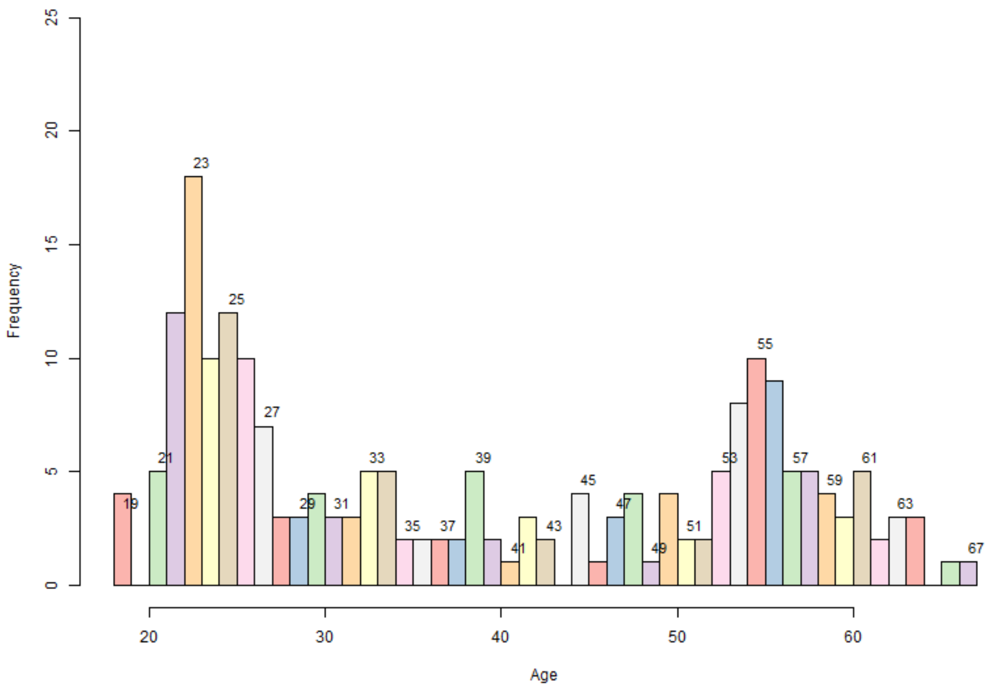


Figure 17

Distribution of respondents by province

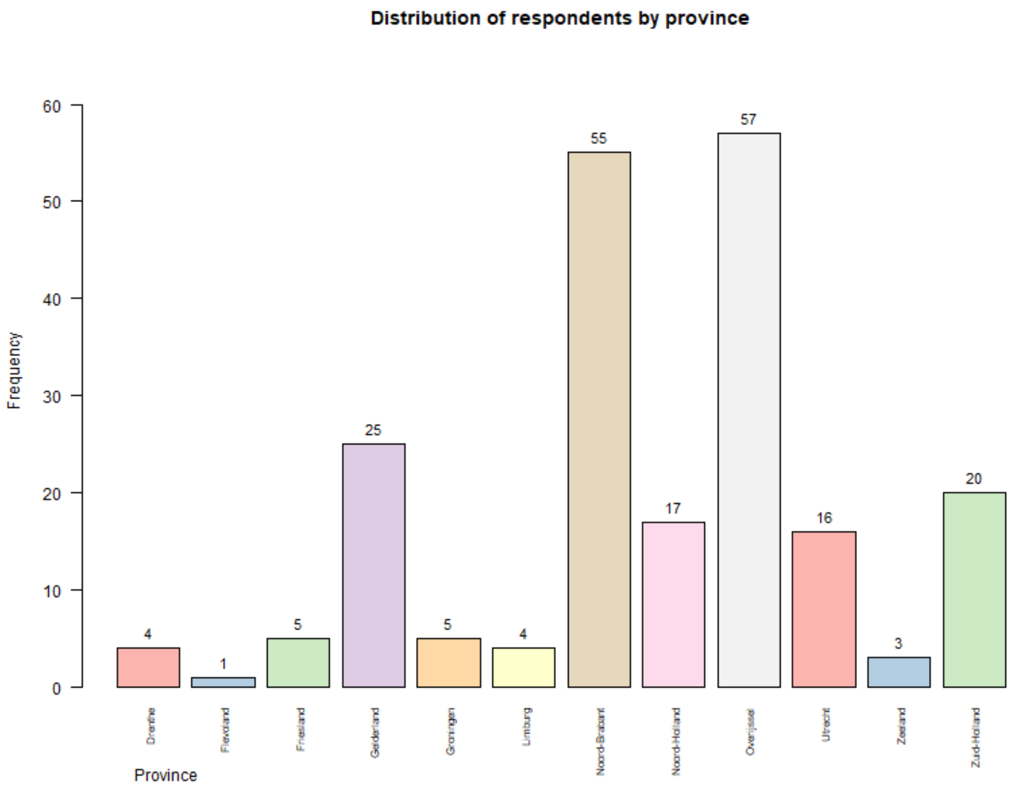


Figure 18

Distribution of car brands among the participants

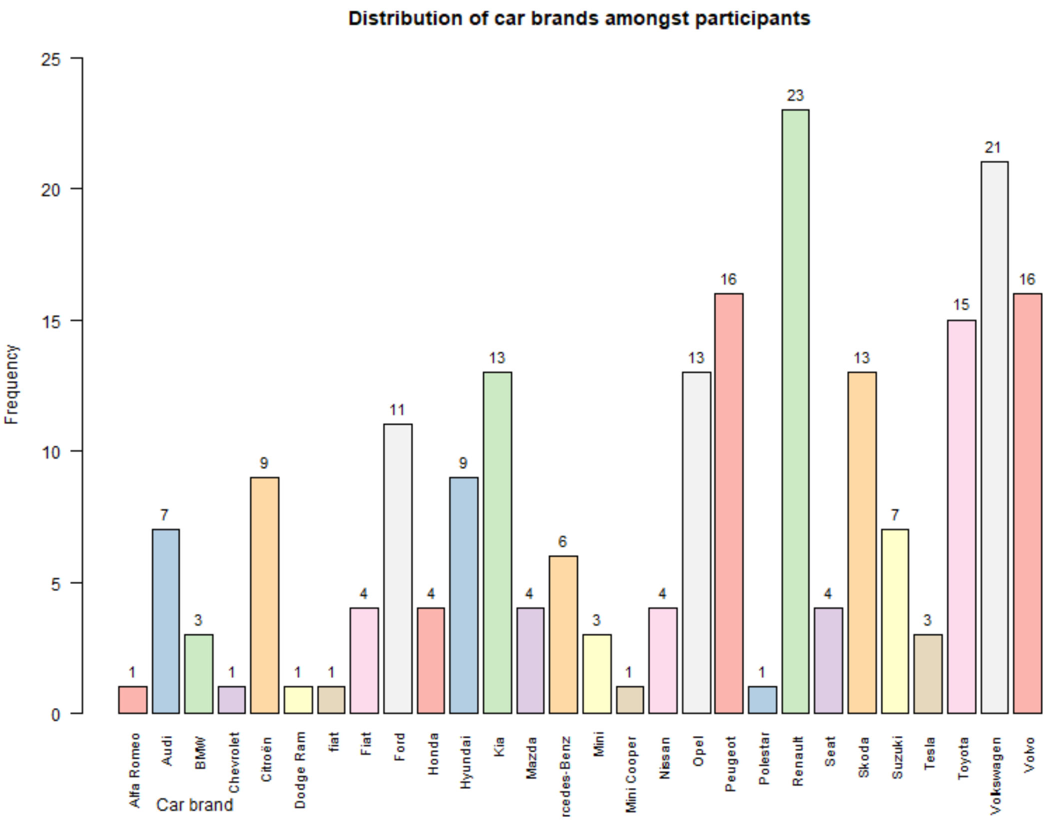


Figure 19

Distribution of driver experience (in KM driven per year) among the participants

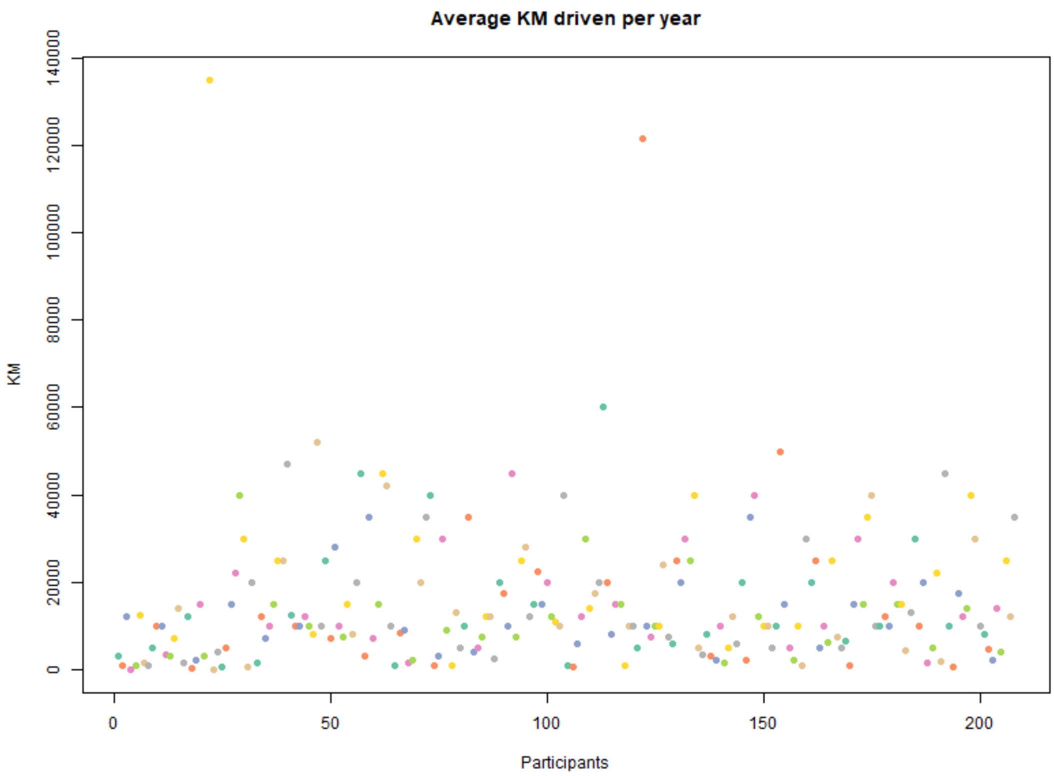
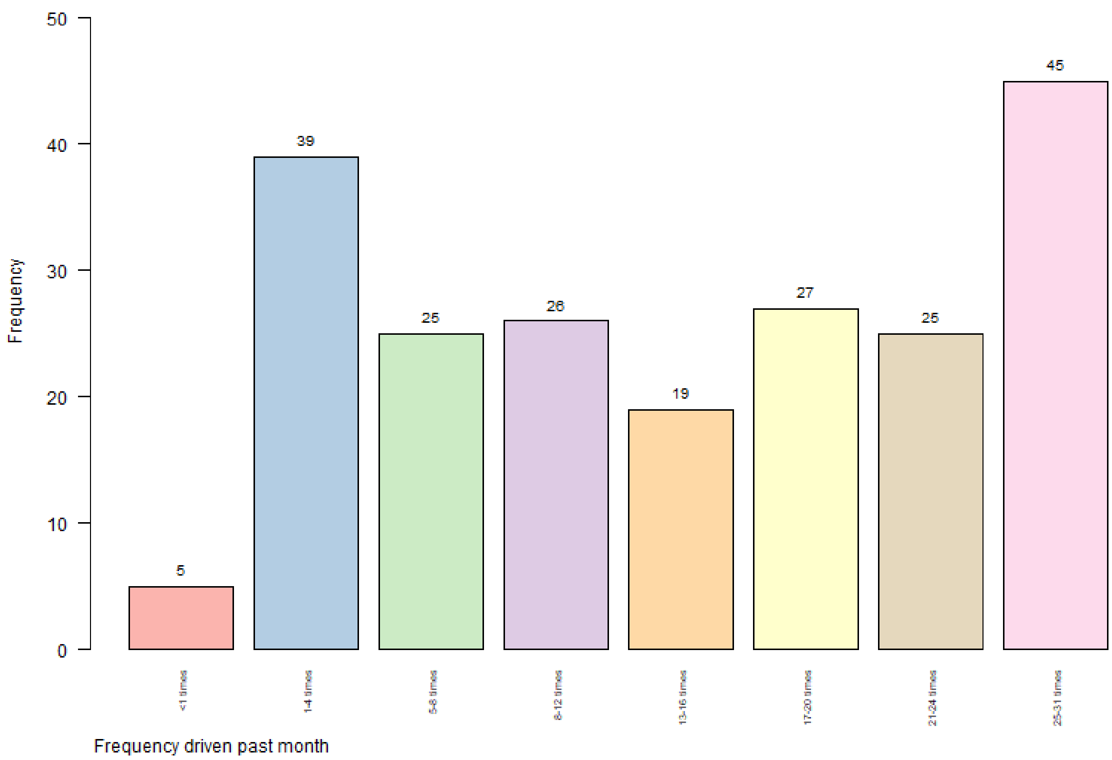


Figure 20

Distribution of the number of times driven in the past month



Appendix IV
Tables and figures quantification

Table 7

Usage of the six main systems

System	Answer option	Percentage
ACC	Yes, I do use it	26.9%
	No, I do not use it, but I do have it in my car	10.8%
	No, I do not have it in my car	62.3%
	No, I do not know what this system is	0%
LKA	Yes, I do use it	21.0%
	No, I do not use it, but I do have it in my car	8.8%
	No, I do not have it in my car	69.2%
	No, I do not know what this system is	1.0%
BSW	Yes, I do use it	17.1%
	No, I do not use it, but I do have it in my car	2.0%
	No, I do not have it in my car	80.4%
	No, I do not know what this system is	0.5%
FCW	Yes, I do use it	26.1%
	No, I do not use it, but I do have it in my car	5.9%
	No, I do not have it in my car	65.0%
	No, I do not know what this system is	3.0%
IDMS	Yes, I do use it	10.4%
	No, I do not use it, but I do have it in my car	5.0%
	No, I do not have it in my car	78.7%
	No, I do not know what this system is	5.9%
ISA	Yes, I do use it	3.0%
	No, I do not use it, but I do have it in my car	14.9%
	No, I do not have it in my car	80.1%
	No, I do not know what this system is	2.0%

Table 8

Frequency of usage of the six main systems in the past month

System	Answer option	% out of all participants	n (all participants)	% out of users only	n (users only)
ACC	Very high frequency (81+)	7.1%	15	26.3%	15
	High frequency (26-80)	5.2%	11	19.3%	11
	Moderate frequency (16-25)	4.2%	9	15.8%	9
	Low frequency (6-15)	5.2%	11	19.3%	11
	Very low frequency (1-5)	5.2%	11	19.3%	11
	Never	73.1%	155	0%	0
			Total:212		*Total: 57*
LKA	Very high frequency (81+)	7.8%	16	38.1%	16
	High frequency (26-80)	4.9%	10	23.8%	10
	Moderate frequency (16-25)	1.0%	2	4.8%	2
	Low frequency (6-15)	1.4%	3	7.1%	3
	Very low frequency (1-5)	5.4%	11	26.2%	11
	Never	79.5%	163	0%	0
			Total:205		*Total: 42*
BSW	Very high frequency (81+)	4.9%	10	30.3%	10
	High frequency (26-80)	2.0%	4	12.1%	4
	Moderate frequency (16-25)	2.0%	4	12.1%	4
	Low frequency (6-15)	1.4%	3	9.1%	3
	Very low frequency (1-5)	3.4%	7	21.2%	7
	Never	86.3%	176	15.2%	5
			Total:204		*Total: 33*
FCW	Very high frequency (81+)	9.3%	19	36.5%	19
	High frequency (26-80)	1.5%	3	5.8%	3
	Moderate frequency (16-25)	2.0%	4	7.7%	4
	Low frequency (6-15)	2.5%	5	9.6%	5
	Very low frequency (1-5)	6.9%	14	26.9%	14
	Never	77.8%	158	13.5%	7
			Total:203		*Total: 52*
IDMS	Very high frequency (81+)	3.0%	6	28.6%	6
	High frequency (26-80)	1.0%	2	9.5%	2
	Moderate frequency (16-25)	0%	0	0%	0

	Low frequency (6-15)	1.0%	2	9.5%	2
	Very low frequency (1-5)	3.4%	7	33.3%	7
	Never	91.6%	185	19.1%	4
			Total:202		*Total: 21*
ISA	Very high frequency (81+)	0.5%	1	16.7%	1
	High frequency (26-80)	1.0%	2	33.2%	2
	Moderate frequency (16-25)	0.5%	1	16.7%	1
	Low frequency (6-15)	0.5%	1	16.7%	1
	Very low frequency (1-5)	0.5%	1	16.7%	1
	Never	97.0%	195	0%	0
			Total:201		*Total: 6*

Table 9

Frequency of turning the six main systems on or off in the past month

System	Answer option	% out of all participants	n (all participants)	% out of users only	n (users only)
ACC	Very high frequency (91+)	4.2%	9	16.1%	9
	High frequency (51-90)	3.8%	8	14.3%	8
	Moderate frequency (21-50)	4.7%	10	17.9%	10
	Low frequency (7-20)	5.7%	12	21.4%	12
	Very low frequency (1-6)	5.2%	11	19.6%	11
	Never	76.4%	162	10.7%	6
			Total:212		*Total: 56*
LKA	Very high frequency (91+)	0.5%	1	2.3%	1
	High frequency (51-90)	0.5%	1	2.3%	1
	Moderate frequency (21-50)	1.4%	3	7.0%	3
	Low frequency (7-20)	0.5%	1	2.3%	1
	Very low frequency (1-6)	4.4%	9	21.0%	9
	Never	92.7%	190	65.1%	28
			Total:205		*Total: 43*
BSW	Very high frequency (91+)	0.5%	1	3.0%	1
	High frequency (51-90)	0%	0	0%	0
	Moderate frequency (21-50)	0%	0	0%	0

	Low frequency (7-20)	0%	0	0%	0
	Very low frequency (1-6)	2.6%	5	15.2%	5
	Never	96.9%	190	81.8%	27
			Total:196		*Total: 33*
FCW	Very high frequency (91+)	0.5%	1	1.9%	1
	High frequency (51-90)	0%	0	0%	0
	Moderate frequency (21-50)	0.5%	1	1.9%	1
	Low frequency (7-20)	0.5%	1	1.9%	1
	Very low frequency (1-6)	1.5%	3	5.6%	3
	Never	97.0%	197	88.7%	47
			Total:203		*Total: 53*
IDMS	Very high frequency (91+)	0%	0	0%	0
	High frequency (51-90)	0%	0	0%	0
	Moderate frequency (21-50)	0%	0	0%	0
	Low frequency (7-20)	0.5%	1	4.8%	1
	Very low frequency (1-6)	2.0%	4	19.0%	4
	Never	97.5%	197	76.2%	16
			Total:202		*Total: 21*
ISA	Very high frequency (91+)	0%	0	0%	0
	High frequency (51-90)	0.5%	1	16.7%	1
	Moderate frequency (21-50)	0%	0	0%	0
	Low frequency (7-20)	0.5%	1	16.7%	1
	Very low frequency (1-6)	0%	0	0%	0
	Never	99.0%	199	66.6%	4
			Total:201		*Total: 6*

Table 10

Frequency of adjusting the settings of the six main systems in the past month

System	Answer option	% out of all participants	n (all participants)	% out of users only	n (users only)
ACC	Very high frequency (31+)	2.4%	5	9.1%	5
	High frequency (21-30)	1.4%	3	5.5%	3
	Moderate frequency (11-20)	3.3%	7	12.7%	7
	Low frequency (5-10)	6.1%	13	23.6%	13

	Very low frequency (1-4)	4.3%	9	16.4%	9
	Never	82.5%	175	32.7%	18
			Total:212		*Total: 55*
LKA	Very high frequency (31+)	0%	0	0%	0
	High frequency (21-30)	0%	0	0%	0
	Moderate frequency (11-20)	0%	0	0%	0
	Low frequency (5-10)	0%	0	0%	0
	Very low frequency (1-4)	0.5%	1	2.3%	1
	Never	99.5%	204	97.7%	42
			Total:205		*Total: 43*
BSW	Very high frequency (31+)	0%	0	0%	0
	High frequency (21-30)	0%	0	0%	0
	Moderate frequency (11-20)	0%	0	0%	0
	Low frequency (5-10)	0%	0	0%	0
	Very low frequency (1-4)	0%	0	0%	0
	Never	100%	204	100%	34
			Total:204		*Total: 34*
FCW	Very high frequency (31+)	0%	0	0%	0
	High frequency (21-30)	0%	0	0%	0
	Moderate frequency (11-20)	0%	0	0%	0
	Low frequency (5-10)	0.5%	1	1.9%	1
	Very low frequency (1-4)	1.0%	2	3.8%	2
	Never	98.5%	200	94.3%	50
			Total:203		*Total: 53*
IDMS	Very high frequency (31+)	0%	0	0%	0
	High frequency (21-30)	0%	0	0%	0
	Moderate frequency (11-20)	0%	0	0%	0
	Low frequency (5-10)	0%	0	0%	0
	Very low frequency (1-4)	0%	0	0%	0
	Never	100%	202	100%	21
			Total:202		*Total: 21*
ISA	Very high frequency (31+)	0%	0	0%	0
	High frequency (21-30)	0%	0	0%	0
	Moderate frequency (11-20)	0%	0	0%	0
	Low frequency (5-10)	0.5%	1	16.7%	1
	Very low frequency (1-4)	0%	0	0%	0

	Never	99.5%	200	83.3%	5
			Total:201		*Total: 6*

Table 11

Duration of performing an operating action such as turning it on or off or adjusting settings

System	Answer option	% out of all participants	n (all participants)	% out of users only	n (users only)
ACC	0 seconds	74.5%	158	1.8%	1
	<1 seconds	2.4%	5	9.1%	5
	1 second	8.0%	17	30.9%	17
	2 seconds	7.1%	15	27.3%	15
	3 seconds	3.3%	7	12.7%	7
	4 seconds	1.4%	3	5.5%	3
	5 seconds	2.4%	5	9.1%	5
	More than 5 seconds	0.9%	2	3.6%	2
			Total:212		*Total: 55*
LKA	0 seconds	92.7%	190	65.1%	28
	<1 seconds	1.4%	3	7.0%	3
	1 second	2.0%	4	9.3%	4
	2 seconds	1.4%	3	7.0%	3
	3 seconds	1.0%	2	4.7%	2
	4 seconds	0%	0	0%	0
	5 seconds	0.5%	1	2.2%	1
	More than 5 seconds	1.0%	2	4.7%	2
			Total:205		*Total: 43*
BSW	0 seconds	97.5%	199	85.7%	30
	<1 seconds	0%	0	0%	0
	1 second	0%	0	0%	0
	2 seconds	1.0%	2	5.7%	2
	3 seconds	0.5%	1	2.9%	1
	4 seconds	0%	0	0%	0
	5 seconds	0%	0	0%	0
	More than 5 seconds	1.0%	2	5.7%	2
			Total:204		*Total: 35*

FCW	0 seconds	96.5%	196	86.8%	46
	<1 seconds	0%	0	0%	0
	1 second	1.0%	2	3.8%	2
	2 seconds	0.5%	1	1.9%	1
	3 seconds	1.5%	3	5.6%	3
	4 seconds	0%	0	0%	0
	5 seconds	0%	0	0%	0
	More than 5 seconds	0.5%	1	1.9%	1
			Total:203		*Total: 53*
IDMS	0 seconds	98.5%	199	85.6%	18
	<1 seconds	0.5%	1	4.8%	1
	1 second	0.5%	1	4.8%	1
	2 seconds	0%	0	0%	0
	3 seconds	0.5%	1	4.8%	1
	4 seconds	0%	0	0%	0
	5 seconds	0%	0	0%	0
	More than 5 seconds	0%	0	0%	0
			Total:202		*Total: 21*
ISA	0 seconds	98.5%	198	50%	3
	<1 seconds	0%	0	0%	0
	1 second	1.0%	2	33.3%	2
	2 seconds	0.5%	1	16.7%	1
	3 seconds	0%	0	0%	0
	4 seconds	0%	0	0%	0
	5 seconds	0%	0	0%	0
	More than 5 seconds	0%	0	0%	0
			Total:201		*Total: 6*

Table 12

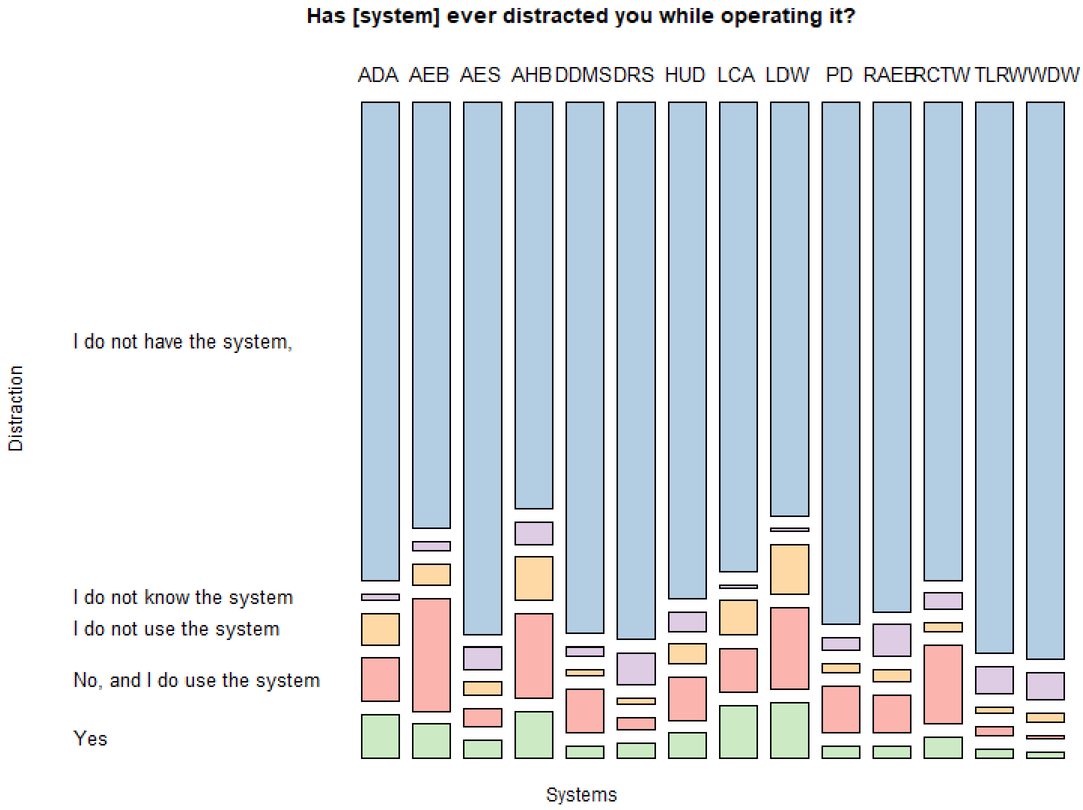
Location of operation of the six main systems

System	Location	Percentage	n
ACC	Near or on the steering wheel	89.8%	53
	Close to the steering wheel (hands off)	5.1%	3
	On the dashboard screen	0%	0

	Somewhere else	5.1%	3
LKA	Near or on the steering wheel	30.6%	15
	Close to the steering wheel (hands off)	22.4%	11
	On the dashboard screen	22.4%	11
	Somewhere else	24.6%	12
BSW	Near or on the steering wheel	8.1%	3
	Close to the steering wheel (hands off)	13.5%	5
	On the dashboard screen	37.8%	14
	Somewhere else	40.6%	15
FCW	Near or on the steering wheel	14.3%	8
	Close to the steering wheel (hands off)	14.3%	8
	On the dashboard screen	30.3%	17
	Somewhere else	41.1%	23
IDMS	Near or on the steering wheel	14.3%	3
	Close to the steering wheel (hands off)	4.8%	1
	On the dashboard screen	42.8%	9
	Somewhere else	38.1%	8
ISA	Near or on the steering wheel	50.0%	3
	Close to the steering wheel (hands off)	0%	0
	On the dashboard screen	16.7%	1
	Somewhere else	33.3%	2

Figure 21

Mosaic plot with all answer options for the other systems



Note. Each coloured segment of the bar represents the percentage of participants who selected that particular answer option. On the left side it is visible which answer option corresponds to each colour. A larger coloured segment indicates that more participants chose that specific answer option. The answer option "neutral" indicates that the participant is not a user of the system.

Table 13

Distraction caused by the operation of the other systems

System	Answer option	Percentage	n	% distracted out of users only
ADA	Yes, it has caused some form of	7.3%	14	50.0%
	distraction	7.3%	14	
	No, I do use the system but I do not			
	experience distractions	5.2%	10	
	No, because I do not use it but I have it in			
	my car	79.2%	153	
	No, because I do not have it	1.0%	2	
	No, I don't know what this system is		*Total:193*	
AEB	Yes, it has caused some form of	5.7%	11	23.4%
	distraction	18.7%	36	
	No, I do use the system but I do not			
	experience distractions	3.6%	7	
	No, because I do not use it but I have it in			
	my car	70.5%	136	
	No, because I do not have it	1.5%	3	
	No, I don't know what this system is		*Total:193*	
AES	Yes, it has caused some form of	3.1%	6	50.0%
	distraction	3.1%	6	
	No, I do use the system but I do not			
	experience distractions	2.1%	4	
	No, because I do not use it but I have it in			
	my car	88.1%	170	
	No, because I do not have it	3.6%	7	
	No, I don't know what this system is		*Total:193*	
AHB	Yes, it has caused some form of	7.8%	15	35.7%
	distraction	14.0%	27	

	No, I do use the system but I do not	7.2%	14	
	experience distractions			
	No, because I do not use it but I have it in	67.4%	130	
	my car	3.6%	7	
	No, because I do not have it		*Total:193*	
	No, I don't know what this system is			
DDMS	Yes, it has caused some form of	2.1%	4	22.2%
	distraction	7.3%	14	
	No, I do use the system but I do not			
	experience distractions	1.0%	2	
	No, because I do not use it but I have it in			
	my car	88.0%	169	
	No, because I do not have it	1.6%	3	
	No, I don't know what this system is		*Total:192*	
DRS	Yes, it has caused some form of	2.6%	5	55.6%
	distraction	2.1%	4	
	No, I do use the system but I do not			
	experience distractions	1.0%	2	
	No, because I do not use it but I have it in			
	my car	89.1%	171	
	No, because I do not have it	5.2%	10	
	No, I don't know what this system is		*Total:192*	
HUD	Yes, it has caused some form of	4.2%	8	36.4%
	distraction			
	No, I do use the system but I do not	7.3%	14	
	experience distractions			
	No, because I do not use it but I have it in	3.1%	6	
	my car			
	No, because I do not have it	82.3%	158	
	No, I don't know what this system is	3.1%	6	
			Total:192	
LCA	Yes, it has caused some form of	8.8%	17	54.8%
	distraction	7.3%	14	
	No, I do use the system but I do not			
	experience distractions	5.7%	11	

	No, because I do not use it but I have it in	77.7%	150	
	my car	0.5%	1	
	No, because I do not have it		*Total:193*	
	No, I don't know what this system is			
LDW	Yes, it has caused some form of	9.3%	18	40.9%
	distraction	13.5%	26	
	No, I do use the system but I do not			
	experience distractions	8.3%	16	
	No, because I do not use it but I have it in			
	my car	68.4%	132	
	No, because I do not have it	0.5%	1	
	No, I don't know what this system is		*Total:193*	
PD	Yes, it has caused some form of	2.1%	4	21.1%
	distraction	7.8%	15	
	No, I do use the system but I do not			
	experience distractions	1.5%	3	
	No, because I do not use it but I have it in			
	my car	86.5%	167	
	No, because I do not have it	2.1%	4	
	No, I don't know what this system is		*Total:193*	
RAEB	Yes, it has caused some form of	2.1%	4	25%
	distraction	6.2%	12	
	No, I do use the system but I do not			
	experience distractions	2.1%	4	
	No, because I do not use it but I have it in			
	my car	84.4%	162	
	No, because I do not have it	5.2%	10	
	No, I don't know what this system is		*Total:192*	
RCTW	Yes, it has caused some form of	3.6%	7	21.9%
	distraction	13.0%	25	
	No, I do use the system but I do not			
	experience distractions	1.6%	3	
	No, because I do not use it but I have it in			
	my car	79.2%	152	
	No, because I do not have it	2.6%	5	
	No, I don't know what this system is		*Total:192*	

TLR	Yes, it has caused some form of	1.6%	3	50.0%
	distraction	1.6%	3	
	No, I do use the system but I do not			
	experience distractions	1.0%	2	
	No, because I do not use it but I have it in			
	my car	91.2%	176	
	No, because I do not have it	4.6%	9	
	No, I don't know what this system is		*Total:193*	
WWDW	Yes, it has caused some form of	1.0%	2	66.7%
	distraction	0.5%	1	
	No, I do use the system but I do not			
	experience distractions	1.6%	3	
	No, because I do not use it but I have it in			
	my car	92.2%	177	
	No, because I do not have it	4.7%	9	
	No, I don't know what this system is		*Total:192*	

Appendix V
Models

Model 1 (gamma regression): Distraction = poly(norm_age, 2) + Gender + (1 | Systems)

Model 2 (gamma regression): Distraction = poly(norm_age, 2) * Gender + (1 + Gender | Systems

Model 3 (gamma regression): Distraction = poly(norm_age, 2) * Gender + (1 | Systems)

Model 4 (gamma regression): Distraction = poly(norm_age, 2) + (1 | Systems)

Model 5 (gamma regression): Distraction = norm_age + (1 | Systems)

Model 6 (gamma regression): Distraction = norm_age + Gender + (1 | Systems)

Model 7 (gamma regression): Distraction = norm_age + Gender + (1 + Gender | Systems)

Model 8 (gamma regression): Distraction = norm_age * Gender + (1 + Gender | Systems)

Model 9 (binary regression): Distraction = poly(norm_age, 2) + Gender + (1 | Systems)

Model 10 (binary regression): Distraction = poly(norm_age, 2) * Gender + (1 + Gender | Systems

Model 11 (binary regression): Distraction = poly(norm_age, 2) * Gender + (1 | Systems)

Model 12 (binary regression): Distraction = poly(norm_age, 2) + (1 | Systems)

Model 13 (binary regression): Distraction = norm_age + (1 | Systems)

Model 14 (binary regression): Distraction = norm_age + Gender + (1 | Systems)

Model 15 (binary regression): Distraction = norm_age * Gender + (1 | Systems)

Appendix VI
Tables statistical models

Table 14

Comparison of IC for LOO cross validation for models 1 to 5

Model	IC	Estimate	SE	diff_IC
M_4	looic	-7162.193	271.2244	0.0
M_5	looic	-7161.400	271.9363	0.7930278
M_2	looic	-7114.675	269.7186	47.5177988
M_3	looic	-7111.280	269.4778	50.9126599
M_1	looic	-7106.531	269.8762	55.6616813

Table 15

Model 4: Coefficient estimates in odds with 95% credibility for the fixed effects

fixef	center	lower	upper
Intercept	0.0003965	0.0001134	0.0013941
Poly(norm_age, 2)1	0.0	0.0	0.0000313
Poly(norm_age, 2)2	$3.694271 * 10^{14}$	22.4522654	$2.641067 * 10^{28}$

Table 16

Comparison of IC for LOO cross validation for models 5 and 6

Model	IC	Estimate	SE	diff_IC
M_5	looic	-7161.691	271.8803	0.0
M_6	looic	-7109.082	270.0785	52.60832

Table 17

Model 5: Coefficient estimates in odds with 95% credibility for the random effects

re_entity	center	lower	upper
ACC	19.9765847	5.5486486	80.6439940
BSW	0.3970604	0.0837537	1.8167827
FCW	0.0676226	0.0132527	0.3855466
IDMS	0.1827068	0.0140282	1.5859193

ISA	2.0503635	0.4510055	13.5534861
LKA	0.9007313	0.2371268	3.5472361

Table 18

Comparison of IC for LOO cross validation for models 1.1 to 5.1

Model	IC	Estimate	SE	diff_IC
M_2.1	looic	-57497.61	356.5725	0.0
M_4.1	looic	-57391.97	361.7565	105.6385
M_5.1	looic	-57391.50	362.2087	106.1081
M_3.1	looic	-57242.15	356.8594	255.4544
M_1.1	looic	-57153.21	356.9101	344.3990

Table 19

Model 2.1: Coefficient estimates in odds with 95% credibility for the fixed effects

fixef	center	lower	upper
Intercept	0.0000292	0.0000023	0.000459
Poly(norm_age, 2)1	$2.753467 * 10^{18}$	$5.025091 * 10^{4}$	$3.679096 * 10^{35}$
Poly(norm_age, 2)2	$2.596906 * 10^{22}$	$2.132513 * 10^{10}$	$1.350170 * 10^{34}$
Gender2	0.2832076	0.0165079	4.701909
Poly(norm_age, 2)1:Gender2	0.0191981	0.0	$6.020874 * 10^{20}$
Poly(norm_age, 2)2:Gender2	0.0	0.0	0.0

Table 20

Comparison of IC for LOO cross validation for models 7 and 8

Model	IC	Estimate	SE	diff_IC
M_7	looic	-57496.07	355.7624	0.0
M_8	looic	-57484.23	357.3776	11.84508

Table 21

Comparison of IC for LOO cross validation for models 9 to 13

Model	IC	Estimate	SE	diff_IC
M_11	looic	928.1934	63.32050	0.0
M_10	looic	930.1022	63.53177	1.908812
M_9	looic	935.3533	63.55836	7.159950
M_12	looic	942.4312	63.98132	14.237797
M_13	looic	946.7992	64.40345	18.605854

Table 22

Model 11: Coefficient estimates in odds with 95% credibility for the fixed effects

fixef	center	lower	upper
Intercept	0.0475474	0.0304169	0.0714887
Poly(norm_age, 2)1	449.0637	0.0020342	$1.813545 * 10^{8}$
Poly(norm_age, 2)2	10.79579	0.000063	$1.697532 * 10^{6}$
Gender2	0.4287076	0.2564387	0.6833071
Poly(norm_age, 2)1:Gender2	0.0060567	0.0	$4.577104 * 10^{6}$
Poly(norm_age, 2)2:Gender2	$2.239941 * 10^{16}$	$7.225815 * 10^{6}$	$1.570729 * 10^{26}$

Table 23

Comparison of IC for LOO cross validation for models 14 and 15

Model	IC	Estimate	SE	diff_IC
M_14	looic	940.5028	64.14704	0.0
M_15	looic	942.3892	64.33662	1.886403

Table 24

Model 14: Coefficient estimates in odds with 95% credibility for the random effects

re_entity	center	lower	upper
ADA	1.6799597	0.9124845	3.197706
AEB	1.3481922	0.6886144	2.639443
AES	0.8373516	0.3932182	1.643505

AHB	1.7998907	0.9418684	3.486501
DDMS	0.6738499	0.2735677	1.338436
DRS	0.7486217	0.3300486	1.535996
HUD	1.0392076	0.4939316	2.026273
LCA	2.0390201	1.1440145	3.912621
LDW	2.1603066	1.1750542	4.034148
PD	0.6594499	0.2681788	1.340548
RAEB	0.6658826	0.2710259	1.392245
RCTW	0.9336472	0.4493585	1.862973
TLR	0.5786312	0.2145791	1.215368
WWDW	0.4956333	0.1822975	1.033177

Table 25

Comparison of IC for LOO cross validation for models 9.1 to 14.1

Model	IC	Estimate	SE	diff_IC
M_11.1	looic	421.0701	13.33701	0.0
M_10.1	looic	421.8089	13.40761	0.7388277
M_9.1	looic	424.3192	12.24425	3.2491046
M_12.1	looic	426.1707	12.08630	5.1005989
M_13.1	looic	426.8355	11.64446	57653609

Table 26

Model 11.1: Coefficient estimates in odds with 95% credibility for the fixed effects

fixef	center	lower	upper
Intercept	0.6707919	0.4452697	1.008591
Poly(norm_age, 2)1	0.0000167	0.0	290.7668
Poly(norm_age, 2)2	0.1912040	0.0000002	$1.230222 * 10^{5}$
Gender2	0.5397175	0.3000794	0.9426654
Poly(norm_age, 2)1:Gender2	0.0	0.0	3231.98
Poly(norm_age, 2)2:Gender2	$9.671590 * 10^{14}$	$5.129121 * 10^{4}$	$8.850214 * 10^{25}$

Table 27

Comparison of IC for LOO cross validation for models 14.1 and 15.1

Model	IC	Estimate	SE	diff_IC
M_14.1	looic	425.4065	11.95045	0.0
M_15.1	looic	427.0077	12.20686	1.601208

Table 28

Model 14.1: Coefficient estimates in odds with 95% credibility for the random effects

re_entity	center	lower	upper
ADA	1.2711716	0.7921437	2.619398
AEB	0.7714673	0.3756741	1.228100
AES	1.1009278	0.6343430	2.459890
AHB	1.0011792	0.5828577	1.679455
DDMS	0.8337541	0.3488553	1.368486
DRS	1.1342811	0.6309189	2.721531
HUD	0.9702588	0.5150171	1.716211
LCA	1.3773104	0.8726675	2.947217
LDW	1.1010200	0.6877494	1.983150
PD	0.8385851	0.3672150	1.418223
RAEB	0.8793204	0.3772234	1.526366
RCTW	0.7612005	0.3484436	1.209441
TLR	1.0648894	0.5563519	2.587063
WWDW	1.0698400	0.5461219	2.991279

Appendix VII
RStudio scripts

The complete R-scripts and data files can be accessed using the link provided here:

https://drive.google.com/drive/folders/10AA9ry1i5NBG1oZTxquxWG5ON7gLD75P?usp=sharing

<u>*Explanation:*</u>

- *The documents called "Visualization" provide the code for all the visualizations that are created and displayed within this report.*
- *The documents called "Quantification" provide the code for all the numbers and percentages that are calculated and displayed within this report.*
- *The documents called "Statistical model" provide the code for the statistical models that are created and fitted to the data.*