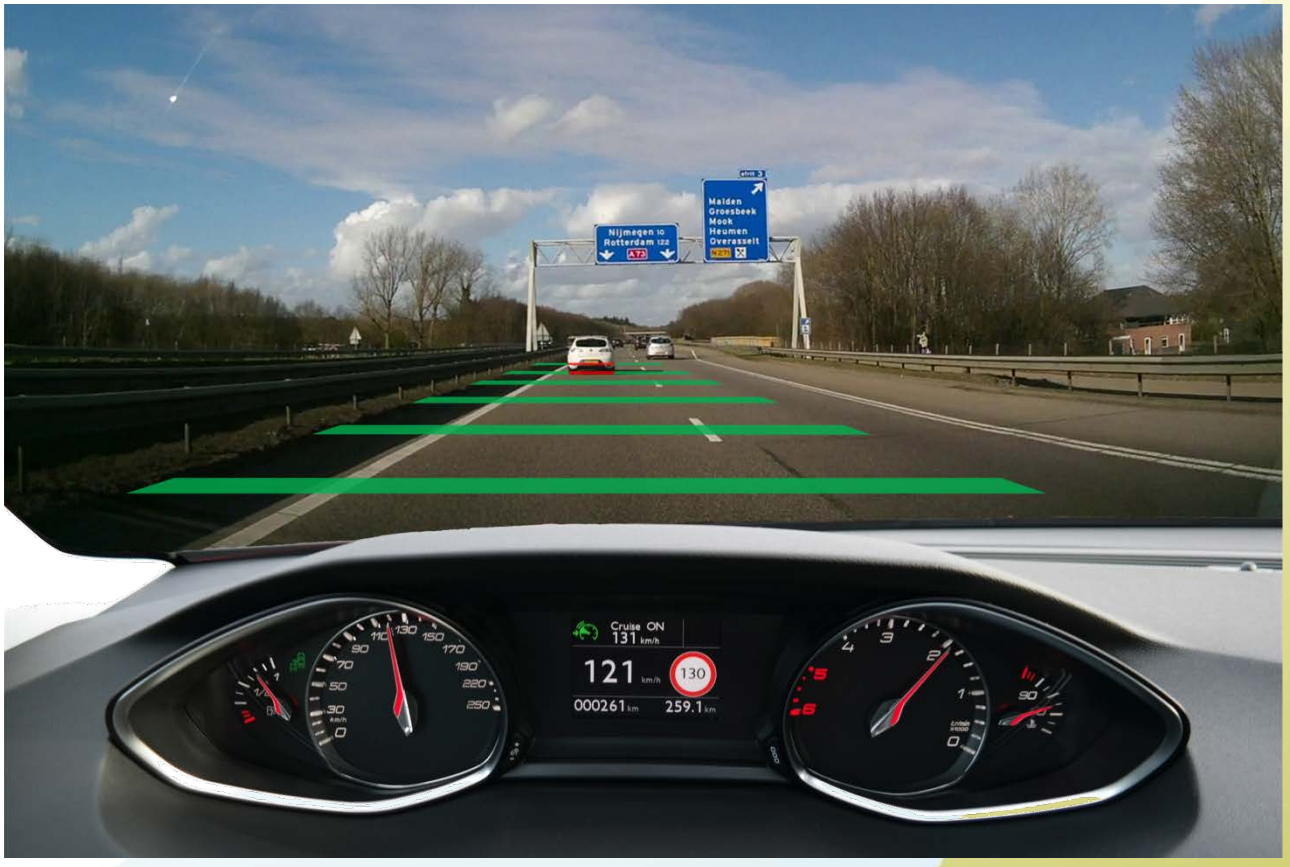
Royal HaskoningDHV
Enhancing Society Together

TU Delft Delft University of Technology



Adaptive Cruise Control in Practice

A Field Study and Questionnaire into its influence on Driver, Traffic Flows and Safety

Final Report

Thesis MSc Civil Engineering

Mark Gorter

October 2015

Adaptive Cruise Control in Practice

A Field Study and Questionnaire into its influence on Driver, Traffic Flows and Safety

Final Report - October 2015

Thesis MSc Civil Engineering
Delft University of Technology - Faculty of Civil Engineering and Geosciences - Department Transport & Planning

Mark Gorter
Student Number 4087267
mark.gorter@rhdhv.com

Graduation Committee:

Prof.dr.ir. B. Van Arem *Chair*
Delft University of Technology - Faculty of Civil Engineering and Geosciences - Department Transport & Planning

Ing. P.G. Prins *Daily Supervisor Royal HaskoningDHV*
Royal HaskoningDHV - Business Line Infrastructure - Advisory Group Transport NL

Dr.ir. W.J. Schakel *Daily Supervisor TU Delft*
Delft University of Technology - Faculty of Civil Engineering and Geosciences - Department Transport & Planning

Dr.ir. J.C.F. De Winter *External Supervisor*
Delft University of Technology - Faculty of Mechanical, Maritime and Materials Engineering - Department BioMechanical Engineering

Ir. P.B.L. Wiggenraad *Graduation Coordinator*
Delft University of Technology - Faculty of Civil Engineering and Geosciences - Department Transport & Planning

PREFACE

PREFACE

Currently you are reading the result of almost 10 months of researching, car driving, questionnaire designing, watching camera images, watching even more camera images, statistical research and writing. This research is my graduation project as part of the MSc program Civil Engineering at the Delft University of Technology. It is executed in cooperation with Royal HaskoningDHV.

I did not know that a subject as specific as Adaptive Cruise Control was so interesting. I really enjoyed designing the field test and the questionnaire to find out what the influence is of ACC on the behavior of the driver, on the flows on the road and the safety. This research is really interdisciplinary, which resulted in me finding myself for example conducting research into the psychology of a car driver. This research really pushed my boundaries and I am glad I got the chance to do this.

This research is executed under the passionate supervision of my graduation committee presided by Bart van Arem. Bart, but also Joost de Winter, Wouter Schakel en Paul Wiggenraad possessed the ideal balance of enthusiasm and criticism to really motivate me to do this as good as possible. Thank you for your cooperation!

Also I am very grateful to my colleagues at Royal HaskoningDHV. Pieter Prins and Evert Klem in particular coached me a lot. Not only to execute this research as good as possible, but also how to be a good traffic advisor in general. All my colleagues at the department Transport NL in Amersfoort gave me a lot of insight in their work and I learned a lot of them. I really look forward to stay as a junior advisor at this department and keep learning for the time to come, and I am very thankful to get this opportunity.

This research would not have been possible without my Royal HaskoningDHV colleagues who leased an ACC-equipped car. They gave me their car to be packed with cameras and recording devices, and they allowed me to watch them drive on the roads and analyzing their performance. Thank you for allowing me to virtually travel with you for several weeks, and thank you for the trust you gave me.

Also the people at the Dutch motorists' organization ANWB helped me a lot. They gave me the chance to use their network of car drivers to distribute my questionnaire to. This was very important, because the 200 respondents they gave me provided a unique insight in the motives and opinions of ACC drivers. Chris Hottentot, thank you!

Finally I would like to thank my family, my friends and my amazing girlfriend Jorien for supporting me, not only throughout this process, but also through my whole period of study and basically life in general.

Amersfoort, October 2015,

Mark Gorter

Executive Summary

Background

Adaptive Cruise Control (ACC) is a driver assistance system present on several car models. It enables the car to autonomously maintain a certain speed. On top of that, a radar or laser is onboard which detects the predecessor. Based on the location and the speed of the predecessor, the speed of the ACC-equipped vehicle is changed. This can be done by actively braking or by releasing the throttle, and accelerating again when necessary.

ACC takes over a part of the driving task of the driver of the car. This means that it influences the behavior of the driver, but also the impact of the car on traffic flows and safety. An increasing number of car models currently on the road is equipped with Adaptive Cruise Control systems. Now that ACC is available and used on the Dutch road network for a while, it is possible to reflect on the performance of ACC in practice. This research is meant to determine the influence of ACC on the behavior of the driver, and on flows and safety on the road.

The last evaluation of the influence of ACC on the Dutch roads is almost ten years ago (*Alkim et al., 2007*). And research into the impact of ACC and other ADAS systems becomes more important as long as the development of these systems goes on. ACC is considered to be one of the early examples of the trend of systems which assist the driver, and eventually take over (several of) his driving tasks. This implies that evaluation of ACC is necessary.

Research Method

The research question of this research is: 'What is the influence of Adaptive Cruise Control on driver behavior, traffic flows and safety, and how can this influence be optimized?' This research question is answered using a framework as shown in Figure 1.

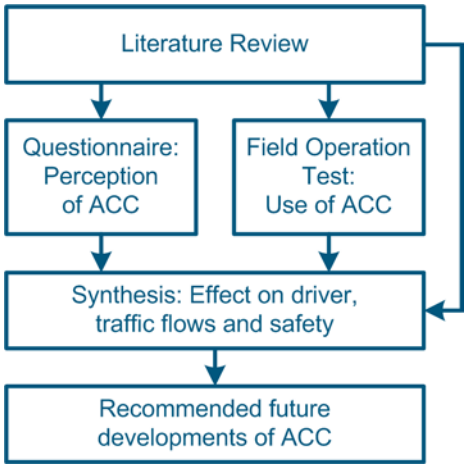


Figure 1 - Research Framework

Visible is that three databases are used. First a literature review is executed. Based on this literature review two data sources are determined: a questionnaire to analyze the perception of ACC by its users, and a Field Operation Test to analyze the use of ACC in practice.

The questionnaire, containing 56 questions, was distributed among as many ACC users as possible. This was done mainly with help of the Dutch Motorists' Organization ANWB. A news article was shown on their website with a link to the questionnaire, and in the two-weekly electronic newsletter of the ANWB, a reference to this news article was made. Additionally, social media accounts of the TU Delft University and Royal HaskoningDHV were used to distribute the questionnaire. In total 200 valid responses were collected from users with Adaptive Cruise Control experience, and 25 responses from a reference group without ACC experience.

The field test consisted of eight participants, all Royal HaskoningDHV employees. These participants already had at least three months of ACC experience before the test started. Their driving behavior was analyzed during normal use of their leased ACC-equipped car on the highway, for at least four weeks. In total these eight drivers provided 48 hours of driving data. The largest part of this data was collected on weekdays, during peak hours. The most important variables recorded during this test were the Adaptive Cruise Control settings (On or Stand-by/off), speed, spacing, location on the highway and lane changes. The recording was done by two cameras: one facing the road in front of the vehicle, and one facing the dashboard to record the ACC settings. Also a data logger was installed in the OBD-II port of the cars, recording speeds.

The results of the field test and the questionnaire together are used to execute a synthesis of the results, together with the literature review: an overall analysis of the influence of ACC on the driver, on traffic flows and on safety. This synthesis leads to conclusions and a view into the future: recommendations are made about the implementation of ACC.

Results

In this section all results of the research will be described. They are separated in four areas: ACC driver and car characteristics, the influence of ACC on driver behavior, its influence on traffic flows and on safety.

This executive summary gives a very brief insight in the results of this research. For every conclusion the paragraph numbers this conclusion is based on are included between square brackets. This enables the reader to further analyze the way the conclusions are gained.

ACC Driver and Car Characteristics

96% of all respondents of the questionnaire is male, and 93% of all respondents is at least 40 years old. 90% of all respondents owns a drivers license for 20 years or more, and 67% of all respondents drives more than 20.000 kilometers per year. This means that the respondents of the questionnaire are mainly male drivers which are older than 40 years, and have a lot of driving experience. Different car brands are present, but mainly Volvos (18% of all respondents), Toyotas (14% of all respondents) and Volkswagens (14% of all respondents) have ACC on board. The average time users use ACC at the moment they answered the questionnaire was quite short: a third of all respondents only used ACC for less than 6 months, and another third for between 6 and 24 months. This probably is because ACC is installed on newer cars. The respondents of the questionnaire mainly bought or leased the ACC-equipped car themselves (94% of all respondents), a smaller part used someone else's car (5% of all respondents), or bought a used car with ACC pre-installed (1% of all respondents) [§2.3.1, §0, §3.2.4].

A difference is visible between the average ACC driver and the reference group in terms of driving style: ACC drivers more often think of themselves as 'fast' drivers. They indicate to more often drive faster than permitted compared to the reference group and receive more traffic fines. Also they indicate they perform more secondary tasks. They are however tolerant drivers, which keep larger distances to their predecessors while driving [§2.3.2].

The last two characteristics, more secondary tasks and a larger headway, are both known to be related to ACC. ACC could indeed lead to more secondary activities, and also it turns out that ACC usage leads to a larger headway on average. This could lead to the conclusion that ACC usage influences the driving style of its users. Regarding the amount of secondary activities, this can cause safety hazards.

The driving style of the user also influences his appreciation of ACC. Drivers who say that they are more decisive and careful and who tend to have a larger headway rate ACC higher, compared to users who are more indecisive, careless and who tend to have a smaller headway. Here a two way relation is present as well: ACC leads to larger headways, and drivers who themselves tend to have a larger headway compared to other drivers appreciate ACC more [§0].

Influence of ACC on Driver Behavior

According to the manufacturers, a primary purpose of ACC is to make driving more comfortable and relieve the driving task. Also safety is a reason of opting for ACC; drivers are convinced it reduces the risk on head-tail collisions [§2.3.7].

According to the results of the questionnaire, the driving task is indeed relieved when ACC is activated. The largest part of the drivers indicates that this decrease of driving task does not have any influence on their level of alertness (64% disagreed with the statement "With ACC activated, I don't need to watch traffic as much"). They stay alert so that they can interfere as soon as the situation requires that. This is something which is specifically stated by the car manufacturers in the manuals. The driver stays responsible, and must always be able to immediately take over control [§2.3.6].

29% of all respondents admits that his attention level decreases after he activates ACC. Approximately half of this group, 13% of all respondents, uses the decrease in driving task to perform more secondary activities. The answers on the questions about losing attention and performing secondary activities can be socially biased. Therefore the part of drivers who loses attention can in reality be expected to be even bigger than this 30%. This will have a negative impact on traffic safety [§2.3.6].

The questionnaire shows a strong relation exists between this group of ‘irresponsible’ drivers, and the amount of instructions they got when they started using ACC, either by reading the owner’s manual or by receiving instructions from an experienced user. The less instructions a driver received, the more likely he is to perform more secondary activities or loose attention. 45% of the drivers using ACC receives instructions extensively, and 31% does slightly receive instructions before ACC usage. Obviously this percentage is highest for users who opt for ACC themselves. The users who received instructions, indicate that they are more aware of the risks. This can also be proven by the fact that ACC does less often behave unexpectedly for this group, for example by deactivating itself or by suddenly braking or accelerating [§2.3.6].

22% of all respondents states that they did not get any instructions. Of that group, almost everyone indicates that they, despite the lack of preparation, do know what the risks of using ACC are. This can mean two different things: either they overestimate their own knowledge of the system, or they have learnt to use ACC and handle with the risks of it by practice. Either way, this might imply a safety hazard. Users who overestimate themselves are undoubtedly a risk, but users who only learn by practice might also be a risk because the system can behave in an unforeseen way, because the users do not know exactly what could happen when using ACC [§0].

A large part of the drivers learns ACC by using it in practice. This is visible for example in the appreciation of ACC: the longer users use ACC, the more they appreciate it. Also the group of users which is prepared before using ACC is more positive. This means that preparation makes the driver better understand and appreciate ACC. Another relation is present here as well: the users who opt for ACC themselves are more likely to get instructions before using it, and this group is per definition more positive about ACC [§0].

Although ACC systems are available that do not have a lower limit, so which theoretically could be deployed on urban or rural roads, the appreciation of ACC on these roads is not very high. It is very high on highways and expressways. Especially in quiet traffic conditions, ACC is highly appreciated. The systems without a lower limit are also rated very positive in congested conditions on the highway. This means that ACC is a system which fits best on the highways, and users use it on these roads in particular. Users are much more positive about the ACC-systems which are active at all speeds, compared to systems with a lower limit. In general, users rate their ACC-system with an 8,03 out of 10 points [§0].

Influence of ACC on Traffic Flows

The headway increases when users activate ACC. This is a significant increase, for all traffic conditions, and visible with all participants of the field test. The headway (from the front of the car with ACC to the back of the predecessor) increases with 16,7% in free flow conditions, and with 25,8% in capacity conditions. The spacing in congested conditions (also from the front of the car with ACC to the back of the predecessor) increases with 16,8%. This means that the capacity of the road decreases significantly, which has a negative influence on flows, especially in capacity conditions. Users also notice this, but this does not lead to lower ACC ratings. This means users are willing to accept this characteristic. Also most drivers do not manually decrease the headway [§2.3.8, §3.3.2].

The headways do however become more constant. Very small headways become rare. The standard deviation of the headways and the spacing decreases significantly. In free flow conditions the standard deviation of the headway decreases with 17,9%, and in capacity conditions with 23,3%. The standard deviation of the spacing in congested conditions decreases with 12,2%. This means that traffic with ACC activated will be better able to prevent and eliminate shockwaves and risks on head-tail collisions [§3.3.2].

ACC is a speed maintaining system, so activating ACC leads to more constant speeds. In free flow conditions but also in capacity conditions, when intensities on the road are higher, the standard deviation of the speeds decreases significantly. In free flow conditions the standard deviation of the speeds decreases with 12,9%, in capacity conditions with 32,0% and in congested conditions with 0,7% [§3.3.3].

Respondents of the questionnaire analyze these effects of ACC as well. They state that ACC leads to more steady and smooth driving behavior [§2.3.8].

This smooth driving behavior is also visible in the amount of strong braking actions: they occur less in capacity and congested situations. In free flow conditions they increase, probably due to merging traffic in front of the car. Also accelerations are less strong compared to when ACC is not activated [§3.3.3].

ACC has two effects on the position on the highway. A group of users is present who more often decides to follow another car, instead of overtaking. This car-following behavior leads to an increase of use of the right lane. Another group is present who often does choose to overtake other cars, and this group needs a very large headway to return to the right lane, because otherwise their ACC will immediately start braking again. Therefore they more often decide to stay in the left lane. This results in more use of the left lane. It differs per driver which effect is visible. Not only the field test shows this behavior, but also the questionnaire indicates that two different kinds of users exist regarding the position on the highway [§2.3.8, §3.3.5].

Both the questionnaire and the field test show a strong decrease in amount of lane changes when ACC becomes active, especially in free flow- or capacity conditions (decrease of respectively 16,6% and 30,7%). Apparently more car-following behavior is shown by drivers when activating ACC [§2.3.8, §3.3.6].

An example of these influences of ACC on flows is visible in Figure 2. Here two fragments from one trip, made by the same driver, are shown. The upper part of the picture shows the speed, position and the spacing when ACC is not activated, and the lower part shows the same parameters when ACC is activated. Visible is that the speeds and the spacing become more constant, and the amount of lane changes decreases.

Figure 2 - Speed, Position on the Highway and Spacing Class for one driver and trip, without ACC activated (Upper) and with ACC Activated (Lower)

Influence of ACC on Traffic Safety

According to ACC users, the risk of getting a head-tail collision reduces when using ACC. This makes them indicate that ACC leads to safer traffic conditions. However some threats are present: ACC sometimes leads to strong braking when another car merges in front of the vehicle with ACC. This is also detected in the field test: in free flow conditions the amount of strong braking actions increases when ACC is activated [§2.3.7, §3.3.3].

Activating Adaptive Cruise Control makes users more aware of the speed limits. They deliberately adapt the set speed of ACC to this limit. This leads to less speed limit violations. Both the questionnaire and the field test showed this [§2.3.7, §3.3.4].

CONCLUSIONS

ACC leads to larger headways, but also to more constant speeds and headways, less lane changes and more car-following driving behavior. This results in more homogeneous traffic. These characteristics enable ACC to prevent shockwaves and head-tail collisions.

ACC leads to more relaxed driving and a relief of the driving task. Two third of the drivers indicates that this does not lead to a decrease of attention level, but another third does indicate they lose attention when driving with ACC. Half of this group uses this opportunity to perform more secondary activities.

Preparation before using ACC is very important, since prepared users do encounter unexpected situations when using ACC less often. Also they use ACC more prudent: they do perform less secondary activities and stay alert.

22% of the respondents of the questionnaire did not receive any instructions at all. They learn to operate ACC by using it in practice. They show less insight in the risks of using ACC. This means this group might use ACC in an unsafe way.

ACC systems which are active at all speeds are rated more positive compared to systems with a lower limit. Despite that, all systems, regardless of their range, are barely used on rural and urban roads. ACC is a system most fitted to be used on highways.

Users tend to get used to ACC quite quickly and are willing to accept the working of ACC, despite it not always performing well. They seem to easily adapt to using ACC. This is hopeful for the further development of improved ACC systems and other ADAS-systems.

ACC is less intelligent: it only looks to one predecessor. Therefore its driving style is sometimes too defensive (it brakes much too early) and sometimes too offensive (it breaks too late). Other safety risks are in the lack of preparation of some users, resulting in an invalid assessment of the risks of using ACC.

RECOMMENDATIONS

Preparation before using ACC is important to guarantee safe usage, and a proper assessment of the risks by the user. Therefore instructing drivers beforehand increases safety. Also systems which detect whether the driver is alert enough are helpful to ensure the driver uses the system safely.

ACC has a positive influence on traffic stability, but the headways increase very much. By designing an ACC system which looks further ahead than only one predecessor, and which even looks to the right and the left side of the car, the average headway can safely be decreased. The car will be able to anticipate on its predecessors and the surrounding traffic much better. Even better is Cooperative ACC, where communication exists between different cars, which leads to even more stable driving behavior. Also ACC could be expanded with a road-analyzing functionality, which enables the car to adapt its behavior to the road layout.

MANAGEMENT-SAMENVATTING

ACHTERGROND

Adaptive Cruise Control (ACC) is een assistentiesysteem voor de bestuurder, dat aanwezig is op verschillende automodellen. Het stelt de wagen in staat zelfstandig een vastgestelde snelheid te handhaven. Daarbij is een radar of laser aan boord, die de auto vóór de met ACC uitgeruste auto detecteert. Op basis van de locatie en de snelheid van deze voorloper wordt de snelheid van het met ACC uitgeruste voertuig aangepast. Dit kan door actief te remmen of door het laten uitrollen van de auto, en weer op te trekken als dat nodig is.

ACC neemt een deel van de rijtaak over van de bestuurder van de auto. Dit betekent dat het invloed uitoefent op het gedrag van de bestuurder, maar ook op de invloed van de auto op de doorstroming en de veiligheid. Een toenemend aantal automodellen dat nu op de weg rijdt, is uitgerust met Adaptive Cruise Control. Nu ACC beschikbaar is en al een tijd gebruikt wordt op het Nederlandse wegennet is het mogelijk om te reflecteren op de prestaties van ACC in de praktijk. Dit onderzoek is bedoeld om de invloed van ACC te bepalen op het gedrag van de bestuurder, op de doorstroming en op de verkeersveiligheid.

De laatste evaluatie van de invloed van ACC op de Nederlandse wegen is bijna tien jaar geleden (*Alkim et al., 2007*). En onderzoek naar de effecten van ACC en andere ADAS-systemen wordt steeds belangrijker naarmate de ontwikkeling van deze systemen verder gaat. ACC wordt beschouwd als een van de eerste voorbeelden van de ontwikkeling van systemen die de bestuurder helpen, en uiteindelijk (verschillende van) diens rijtaken overnemen. Dit betekent dat de evaluatie van ACC noodzakelijk is.

ONDERZOEKSMETHODE

De hoofdvraag van dit onderzoek is: 'Wat is de invloed van Adaptive Cruise Control op het gedrag van de bestuurder, doorstroming en veiligheid, en hoe kan deze invloed geoptimaliseerd worden?' Deze onderzoeksvraag is beantwoord met behulp van een onderzoekskader zoals aangegeven in Figure 3.

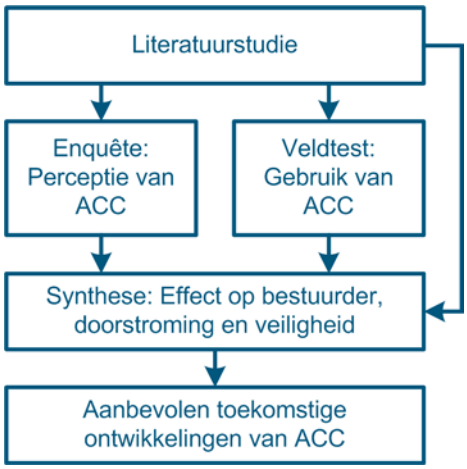


Figure 3 - Opzet van het Onderzoek

Zichtbaar is dat drie databases gebruikt zijn. Eerst is een literatuuronderzoek uitgevoerd. Gebaseerd op dit literatuuronderzoek zijn twee databases gedefinieerd: een enquête om de perceptie van ACC door de gebruikers te analyseren, en een veldtest om het gebruik van ACC in de praktijk te analyseren.

De enquête, bestaande uit 56 vragen, is verspreid onder zo veel mogelijk ACC gebruikers. Dit is voornamelijk gedaan met behulp van de ANWB. Een nieuwsartikel is weergegeven op de website met een link daar de enquête, en in de tweewekelijkse e-mailnieuwsbrief van de ANWB is een verwijzing naar dit artikel gemaakt. Daarbij zijn sociale media-accounts van de TU Delft en van Royal HaskoningDHV gebruikt om de enquête te verspreiden. In totaal zijn 200 geldige reacties verzameld van gebruikers met Adaptive Cruise Control-ervaring, en 25 reacties van een referentiegroep zonder ACC-ervaring.

De veldtest bestond uit acht deelnemers, allen medewerkers van Royal HaskoningDHV. Deze deelnemers hadden al minstens drie maanden ACC-ervaring voor de test startte. Hun rijgedrag werd geanalyseerd tijdens het normale gebruik van hun geleasete, met ACC uitgeruste auto op de snelweg, gedurende tenminste vier weken. In totaal is van deze acht bestuurders 48 uur aan data verzameld. Het grootste deel van deze data werd verzameld op werkdagen tijdens de spits. De belangrijkste variabelen opgenomen tijdens deze test waren de Adaptive Cruise Control-instelling (Aan of Uit/Stand-by), snelheid, afstand tot de voorganger, locatie op de snelweg en veranderingen van rijstrook. Het registreren werd gedaan door twee camera's: één gericht op de weg voor het voertuig, en één gericht op het dashboard om de ACC-instellingen op te nemen. Ook werd een datalogger geïnstalleerd in de OBD-II-poort van de auto's, voor het registreren van snelheden.

De resultaten van de veldtest en de enquête samen worden gebruikt om de synthese van de resultaten uit te voeren, samen met het literatuuronderzoek: een complete analyse van de invloed van ACC op de bestuurder, doorstroming en veiligheid. Deze synthese leidt tot conclusies en tot een blik in de toekomst: aanbevelingen worden gedaan over de implementatie van ACC.

RESULTATEN

Hier zullen alle resultaten van het onderzoek beschreven worden. Ze zijn verdeeld in vier gebieden: specificaties van ACC-rijders en –auto’s, de invloed van ACC op het rijgedrag, zijn invloed op de doorstroming en op de veiligheid.

De management-samenvatting geeft bondig inzicht in de resultaten van dit onderzoek. Voor elke conclusie de paragraafnummers waar deze conclusie op gebaseerd is zijn toegevoegd tussen blokhaken. Dit stelt de lezer in staat om de manier waarop de conclusies gevonden zijn verder te analyseren.

SPECIFICATIES VAN ACC-RIJDERS EN –AUTO’S

96% van alle respondenten is mannelijk, en 93% van alle respondenten is minstens 40 jaar oud. 90% van alle respondenten heeft al 20 jaar of meer een rijbewijs, en 67% van alle respondenten rijdt meer dan 20.000 kilometer per jaar. Dit betekent dat de respondenten van de enquête vooral mannelijke bestuurders zijn, ouder dan 40 jaar, met veel rijervaring. Verschillende automerken zijn aanwezig, maar vooral Volvo's (18% van alle respondenten), Toyota’s (14% van alle respondenten) en Volkswagens (14% van alle respondenten) hebben ACC aan boord. Gebruikers gebruikten ACC op het moment dat ze de enquête beantwoordden nog maar vrij kort: een derde van alle respondenten gebruikte ACC minder dan 6 maanden lang, en nog een derde gebruikte het tussen de 6 en 24 maanden lang. Dit is waarschijnlijk omdat ACC wordt geïnstalleerd op nieuwere auto’s. De respondenten van de enquête kochten of leaseten de met ACC uitgeruste auto voornamelijk zelf (94% van alle respondenten). Een kleiner deel gebruikt de auto van iemand anders (5% van alle respondenten), of kocht een gebruikte auto waarin ACC al was geïnstalleerd (1 % van alle respondenten) [§2.3.1, §0, §0].

Er is een verschil tussen de gemiddelde ACC bestuurder en de referentiegroep qua rijstijl: ACC bestuurders zien zichzelf vaker als 'snelle' rijders. Ze geven aan dat ze vaker sneller rijden dan is toegestaan ten opzichte van de referentiegroep,

en ze ontvangen meer verkeersboetes. Ook geven ze aan dat ze meer secundaire taken uitvoeren achter het stuur. Ze zijn echter tolerante bestuurders, die grotere afstanden houden tot hun voorgangers tijdens het rijden [§2.3.2].

Van de laatste twee kenmerken, meer secundaire taken en een grotere volgtijd, is beide bekend dat ze gerelateerd zijn aan ACC. ACC zou leiden tot meer nevenactiviteiten, en ook blijkt dat ACC-gebruik leidt tot een grotere gemiddelde volgtijd. Dit zou kunnen leiden tot de conclusie dat ACC-gebruik invloed heeft op de rijstijl van zijn gebruikers. Wat betreft de hoeveelheid nevenactiviteiten, kan dit veiligheidsrisico's veroorzaken.

De rijstijl van de gebruiker heeft ook invloed op zijn waardering voor ACC. Bestuurders die zeggen dat ze beslister en zorgvuldiger zijn en gemiddeld een grotere volgtijd aanhouden tot de voorganger, waarderen ACC hoger in vergelijking met bestuurders die besluitelozer en zorgelozer zijn, en die gemiddeld een kleinere volgtijd hebben. Hier is ook sprake van een relatie in twee richtingen: ACC leidt tot grotere volgafstanden, en gebruikers die aangeven van zichzelf een grotere volgafstand aan te houden in vergelijking met andere bestuurders, waarderen ACC meer [§0].

Invloed van ACC op het rijgedrag

Volgens de fabrikanten is een primair doel van ACC om het rijden comfortabeler te maken en de rijtaak te verlichten. Ook veiligheid is een reden om te kiezen voor ACC; bestuurders zijn ervan overtuigd dat het het risico op kop-staartbotsingen vermindert [§2.3.7].

Volgens de resultaten van de enquête wordt de rijtaak inderdaad verlicht als ACC wordt geactiveerd. Het grootste deel van de bestuurders geeft aan dat deze daling van de rijtaak geen invloed heeft op het niveau van hun alertheid (64% is het oneens met de stelling "Als ACC geactiveerd is, hoef ik minder op het verkeer te letten"). Ze blijven alert, zodat ze, zodra de situatie dat vereist, kunnen ingrijpen. Dit is iets dat duidelijk door autofabrikanten in de handleidingen wordt vermeld. De bestuurder blijft verantwoordelijk, en hij moet altijd in staat zijn om direct de controle over te nemen [§2.3.6].

29% van alle respondenten geeft toe dat zijn aandacht daalt tijdens het rijden nadat hij ACC activeert. De helft van deze groep, 13% van alle respondenten, maakt gebruik van de daling van de rijtaak om meer nevenactiviteiten uit te voeren. De antwoorden op de vragen over de afname van de alertheid en het uitvoeren van nevenactiviteiten kunnen sociaal beïnvloed zijn. Dat betekent dat verwacht kan worden dat het deel van de bestuurders dat zijn aandacht verliest in werkelijkheid zelfs groter dan deze 30% is. Dit zal een negatief effect hebben op de verkeersveiligheid [§2.3.6].

De enquête toont aan dat er een sterk verband bestaat tussen deze groep van 'onverantwoordelijke' rijders, en de hoeveelheid instructies ze kregen toen ze begonnen met het gebruik van ACC, hetzij door het lezen van de handleiding of door het ontvangen van instructies van een ervaren gebruiker. Hoe minder instructies een bestuurder gekregen heeft, hoe groter de kans dat zijn alertheid afneemt of hij meer nevenactiviteiten uit gaat voeren. 45% van de gebruikers heeft uitgebreid instructies ontvangen voor het gebruik van ACC, en 31% heeft een beetje instructies ontvangen voor ACC-gebruik. Uiteraard is dit percentage het hoogst voor gebruikers die zelf gekozen hebben voor ACC. De gebruikers die instructies ontvangen hebben, geven aan dat ze zich meer bewust zijn van de risico's. Dit kan worden onderstreept door het feit dat ACC zich minder vaak onvoorspelbaar gedraagt voor deze groep, bijvoorbeeld door zichzelf te deactiveren of door plotseling te remmen of versnellen [§2.3.6].

22% van alle respondenten zegt dat hij geen enkele instructie heeft ontvangen. Van die groep geeft bijna iedereen aan dat hij, ondanks het gebrek aan voorbereiding, weet wat de risico's van het gebruik van ACC zijn. Dit kan twee verschillende betekenissen hebben: óf ze overschatten hun eigen kennis van het systeem, óf ze hebben in de praktijk geleerd ACC te gebruiken en de risico’s te beheersen. In beide gevallen zou dit een veiligheidsrisico in kunnen houden. Gebruikers die zichzelf overschatten zijn ongetwijfeld een risico, maar gebruikers die alleen maar leren uit de praktijk kunnen ook een risico zijn, omdat het systeem zich op een onverwachte manier kan gedragen, omdat de gebruikers niet precies weten wat er kan gebeuren bij het gebruik van ACC [§0].

Een groot deel van de bestuurders leert ACC door het te gebruiken in de praktijk. Dit is zichtbaar in bijvoorbeeld de waardering van ACC: hoe langer bestuurders ACC gebruiken, hoe meer ze het waarderen. Ook de groep gebruikers die

voorbereid is voor het gebruik van ACC is positiever. Dit betekent dat de voorbereiding ervoor zorgt dat de bestuurder ACC beter begrijpt en waardeert. Er is hier ook sprake van een andere relatie: de gebruikers die zelf kiezen voor ACC hebben meer kans om instructies te krijgen alvorens het te gebruiken, en deze groep is per definitie positiever over ACC [§0].

Hoewel er ACC-systemen zijn die niet beschikken over een ondergrens, zodat die in principe zouden kunnen worden ingezet op stedelijke of regionale wegen, is de waardering van ACC op deze wegen niet erg hoog. Deze is zeer hoog voor snelwegen en autowegen. Vooral in rustig verkeer wordt ACC zeer gewaardeerd. De systemen zonder een ondergrens worden ook zeer positief beoordeeld in drukker verkeer op de snelweg. Dit betekent dat ACC een systeem is dat het beste past op snelwegen en de gebruikers gebruiken het ook vooral op deze wegen. Gebruikers zijn veel positiever over de ACC-systemen die bij alle snelheden actief zijn, in vergelijking met systemen met een ondergrens. In het algemeen waarderen gebruikers hun ACC-systeem met een 8,03 op een schaal van 1 tot 10 [§0].

Invloed van ACC op de doorstroming

De volgtijd wordt groter wanneer gebruikers ACC activeren. Deze toename is aanzienlijk voor alle verkeersomstandigheden en is zichtbaar bij alle deelnemers van de veldtest. De volgtijd (vanaf de voorkant van de auto met ACC tot de achterkant van het voertuig ervoor) neemt toe met 16,7% in rustig verkeer en met 25,8% in capaciteitsomstandigheden. De volgafstand (ook vanaf de voorkant van de auto met ACC tot de achterkant van het voertuig ervoor) neemt in filesituaties toe met 16,8%. Dit betekent dat de capaciteit van de weg aanzienlijk afneemt, wat een negatieve invloed op de doorstroming heeft, vooral in capaciteitscondities. Gebruikers merken dit ook, maar dit leidt niet tot een lagere waardering van ACC. Dit betekent dat gebruikers bereid zijn om deze eigenschap te accepteren. Ook de meeste rijders verlagen niet handmatig de volgtijd [§2.3.8, §3.3.2].

Wel worden de volgtijden constanter. Zeer kleine volgtijden worden zeldzaam. De standaarddeviatie van de volgtijd en volgafstand neemt aanzienlijk af. In rustig verkeer neemt de standaarddeviatie van de volgtijd af met 17,9% en onder capaciteitsomstandigheden met 23,3%. De standaarddeviatie van de volgafstand in de file neemt af met 12,2%. Dit betekent dat het verkeer als ACC geactiveerd is beter in staat zal zijn schokgolven en risico's op kop-staartbotsingen te voorkomen en uit te dempen [§3.3.2].

De ACC is een systeem dat de snelheid constant houdt, dus het activeren van ACC leidt tot constantere snelheden. In rustig verkeer, maar ook in capaciteitsomstandigheden, als intensiteiten op de weg hoger zijn, neemt de standaarddeviatie van de snelheden significant af. In rustig verkeer neemt de standaarddeviatie van de snelheid af met 12,9%, onder capaciteitsomstandigheden met 32,0% en in file met 0,7% [§3.3.3].

De respondenten van de enquête zien deze effecten van ACC ook. Zij geven aan dat ACC leidt tot stabieler en vloeiender rijgedrag [§2.3.8].

Dit vloeiende rijgedrag is ook zichtbaar in de hoeveelheid sterke remacties: die komen minder vaak voor in capaciteitscondities en in congestie. In rustiger verkeer nemen ze echter toe, waarschijnlijk als gevolg van het invoegen van verkeer vóór de auto met ACC. Ook accelleraties zijn minder sterk dan wanneer ACC niet is geactiveerd [§3.3.3].

ACC heeft twee effecten van de positie op de weg. Er is een groep gebruikers die vaker beslist een andere auto te volgen, in plaats van in te halen. Dit auto-volggedrag leidt tot een toename van het gebruik van de rechterrijstrook. Er is een andere groep die vaak wel kiest voor het inhalen van andere auto’s, en deze groep heeft een heel groot gat tussen twee auto’s op de rechterrijstrook nodig om na het in te halen weer naar rechts te gaan, omdat ACC anders meteen weer begint te remmen. Daarom kiezen ze vaker ervoor om links te blijven rijden. Dit resulteert in meer gebruik van de linkerrijbaan. Het verschilt per bestuurder welk van deze effecten zichtbaar is. Niet alleen uit de veldtest blijkt dit gedrag, maar ook de enquête geeft aan dat er twee verschillende soorten gebruikers zijn met betrekking tot de positie op de weg [§2.3.8, §3.3.5].

Zowel de enquête als de veldtest laat een sterke afname zien van het aantal rijstrookwisselingen wanneer ACC actief is, vooral in rustig verkeer (afname van 16,6%) en in capaciteitsomstandigheden (afname van 30,7%). Blijkbaar wordt meer auto-volggedrag vertoond door de bestuurders als ACC geactiveerd is [§2.3.8, §3.3.6].

Een voorbeeld van deze invloeden van ACC op de doorstroming zijn zichtbaar in Figure 4. Hier worden twee fragmenten getoond, uit één rit gemaakt door dezelfde bestuurder. Het bovenste deel van de afbeelding toont de snelheid, positie op de weg en de volgafstand wanneer ACC niet is geactiveerd, en het onderste deel geeft dezelfde parameters als ACC wel is geactiveerd. Zichtbaar is dat de snelheid en de volgafstand constanter worden en de hoeveelheid rijstrookwisselingen afneemt.

Figure 4 - Snelheid, Positie op de Snelweg en Volgafstand-klasse voor één bestuurder en rit, zonder ACC geactiveerd (Boven), en met ACC geactiveerd (Onder)

INVLOED VAN ACC OP DE VEILIGHEID

Volgens ACC-gebruikers reduceert het risico op een kop-staartbotsing bij gebruik van ACC. Ze geven om deze reden aan dat ACC leidt tot een veiligere verkeerssituatie. Er zijn echter enkele bedreigingen voor de veiligheid: ACC leidt soms tot sterk afremmen als er een andere auto invoegt voor het voertuig met ACC. Dit is ook waargenomen in de

veldtest: in rustige verkeersomstandigheden neemt de hoeveelheid sterke remacties toe wanneer ACC is ingeschakeld [§2.3.7, §3.3.3].

Het activeren van Adaptive Cruise Control zorgt ervoor dat gebruikers meer bewust zijn van de snelheidslimiet. Ze passen bewust de ingestelde snelheid van hun ACC aan deze limiet aan. Dit leidt tot minder snelheidsovertredingen. Dit bleek uit zowel de enquête als de veldtest [§2.3.7, §3.3.4].

CONCLUSIES

ACC leidt tot grotere volgtijden, maar ook tot meer constante snelheden en volgtijden, minder rijstrookwisselingen en meer auto-volggedrag. Dit resulteert in meer homogeen verkeer. Deze eigenschappen stellen ACC in staat schokgolven en kop-staartbotsingen te voorkomen.

ACC leidt tot meer ontspannen rijden en een verlichting van de rijtaak. Twee derde van de bestuurders geeft aan dat dit niet leidt tot een afname van het attentieniveau, maar het resterende derde deel geeft wel aan dat hun aandacht afneemt bij het rijden met ACC. De helft van deze groep maakt gebruik van deze gelegenheid om meer nevenactiviteiten uit te voeren.

Voorbereiding voorafgaand aan het gebruik van ACC is erg belangrijk, aangezien voorbereide gebruikers minder vaak in onverwachte situaties terechtkomen bij het gebruik van ACC. Ook gebruiken ze ACC verstandiger: ze ondernemen minder nevenactiviteiten en blijven beter alert.

22% van de respondenten van de enquête geeft aan geen enkele instructies te ontvangen. Ze leren ACC bedienen door het te gebruiken in de praktijk. Ze tonen minder inzicht in de risico's van het gebruik van ACC. Dit betekent dat deze groep ACC op een onveilige manier zou kunnen gebruiken.

ACC-systemen die actief zijn bij alle snelheden worden positiever beoordeeld in vergelijking met systemen met een ondergrens. Ondanks dat worden alle systemen, ongeacht hun range, nauwelijks gebruikt op regionale en stedelijke wegen. ACC is een systeem dat meest geschikt is voor gebruik op snelwegen.

Gebruikers wennen vrij snel aan ACC en zijn bereid om de werking van ACC te accepteren, ondanks dat het niet altijd goed presteert. Ze lijken zich gemakkelijk aan te passen aan het gebruik van ACC. Dit geeft hoop voor de verdere ontwikkeling van verbeterde ACC-systemen en andere ADAS-systemen.

ACC is minder intelligent: het detecteert slechts één voorganger. Daarom is zijn rijstijl soms te defensief (het remt veel te vroeg) en soms te agressief (het remt te laat). Andere veiligheidsrisico’s zitten in het gebrek aan voorbereiding van sommige gebruikers, dat resulteert in een slechte inschatting van de risico's van ACC.

AANBEVELINGEN

Voorbereiding voor het gebruik van ACC is belangrijk om veilig gebruik en een juiste beoordeling van de risico's door de gebruiker te garanderen. Daarom verhoogt het vooraf instrueren van de bestuurders de veiligheid. Ook systemen die detecteren of de bestuurder alert genoeg is zijn nuttig om te zorgen dat de bestuurder veilig gebruikmaakt van het systeem.

ACC heeft een positieve invloed op de stabiliteit van het verkeer, maar de volgtijden nemen fors toe. Door het ontwerpen van een ACC-systeem dat verder vooruitkijkt dan één auto, en die ook rechts en links van de auto kijkt, kan de gemiddelde volgtijd veilig worden verlaagd. De auto zal veel beter in staat zijn om te anticiperen op zijn voorgangers en het omringende verkeer. Nog beter is Coöperatieve ACC, waarbij gecommuniceerd wordt tussen verschillende auto's, wat leidt tot nog stabieler rijgedrag. Ook kan ACC worden uitgebreid met een functionaliteit die de weg analyseert, waardoor de auto zijn gedrag aan kan passen aan de weginrichting.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1 INTRODUCTION

1 Introduction

1.1 INTRODUCTION

Before executing this research, it has to be clear what will be researched, why that will be researched, and how the research is designed. This will be described in this chapter.

In paragraph 1.2, some context will be explained, and why this research is executed. Then in paragraph 1.3, the main research question and the sub-questions will be described. The methodology of this research will be described in paragraph 1.4, and finally in paragraph 1.5 a literature review is shown.

1 Introduction

1.2 CONTEXT

In the next years, the way we use cars will radically change. According to the book *Reinventing the Automobile: Personal Urban Mobility for the 21st Century* (*Mitchell et al., 2010*), a paradigm shift is necessary to change the ways we look at cars. The way cars are used at the moment is a result of the developments during the previous century. At the beginning of the 20th century, the car was invented as a motorized coach without horses. From that starting point, the car has developed to what it is today. But to further develop the car so to make it fit the needs of the user in the 21st century, we cannot rely on the cars as they exist today.

A very important notice is for example the way cars are controlled. Until now, cars were driven by their drivers, manually, just like the coachmen a century ago. But more and more systems are available which support the driver in executing his task. The focus changes from a driver who is in charge and takes decisions, to a car which is more and more capable of executing tasks on its own.

The transition towards this new, 21st-century car does not take place instantly. A slow, steady transition is necessary and likely. Visible is that this transition has already started. At the moment, different stakeholders are exploring the possibilities, all in their own field of expertise. For car manufacturers for example, driver comfort and safety are very important objectives. With these criteria in mind, car manufacturers are designing new systems that are capable of performing driving tasks instead of the driver. An example of such a new system designed to assist the driver is Adaptive Cruise Control (ACC).

ACC is an expansion of the common cruise control. Cruise control maintains a constant speed, set by the driver. This means the driver does not have to keep his foot on the accelerator constantly. Cruise control is an assistance system that reduces fatigue, especially on long trips. To even further help the driver, ACC is invented. It functions the same as cruise control, but it is also capable of detecting the preceding vehicle. This means that when this vehicle brakes, the car with ACC reacts immediately by braking or coasting, dependent on the headway. No action of the driver is required, the system functions independent. When the preceding vehicle accelerates, this is also detected, and the following vehicle accelerates as well, until it reaches the maximum speed set by the driver.

An increasing number of car models currently on the road has been equipped with Adaptive Cruise Control systems. Now that ACC is available and used on the Dutch road network for a while, it is possible to reflect on the performance of ACC in practice. The system might have a large influence on the driver and his behavior. This means that research is necessary to ensure that ACC in practice performs like what the car manufacturers have designed. This implies that evaluation of ACC is necessary.

The last evaluation of the influence of ACC on the Dutch roads is almost ten years ago (*Alkim et al., 2007*). Little is known about the influence of ACC on driver behavior in the Netherlands. How does the behavior of the driver change when using ACC? Under what circumstances does the driver use ACC? These questions will be answered in this research. It is very important that these questions are answered, because the success and the positive effects of ACC will only be there when the driver accepts the system and uses it correctly. When the driver does not, the effects of ACC will more likely be less positive, or even negative.

Examples are known of users who deactivate their ACC system when faced with congestion. The reason for this is because they resent the abrupt way the system interferes. Also, the influence of ACC on the flow might be in fact negative, because the large headway setting motivates lateral movements. Due to the large headway cars on an adjacent lane are given enough space to switch lanes in front of the ACC vehicle. The consequence of this is that the ACC-vehicle brakes abruptly, since the system wants to preserve its headway. This could cause shockwaves, and causes instability in the traffic flows and an overall poorer performance.

It stands out that it is necessary to evaluate the use of ACC in the Netherlands, and the way it influences the traffic flows. When the use and influence of ACC is evaluated, the insight this has given might be of use when elaborating the implementation of Cooperative Adaptive Cruise Control (CACC), a system where different cars on the road collaborate to determine the optimum speed and headway settings.

1 Introduction

1.3 Research Objective and Questions

The objective of this research is to evaluate the performance of Adaptive Cruise Control on the Dutch highways. Three types of research will be executed. In the first place it is necessary to assess literature currently available on the subject. Secondly the opinion of the users of ACC will be investigated. In third place, insight must be gained in the performance of ACC in practice, and the way the user uses ACC. Together these three different kinds of research give insight in the performance of ACC, and its influence on driver behavior, traffic flows and safety.

The outline of the research is determined with help of a research question. The main research question is:

What is the influence of ACC on driver behavior, traffic flows and safety, and how can this influence be optimized?

The ACC systems that are reviewed are systems that can be described as adaptive or intelligent cruise control systems. These systems are cruise control systems, which means that they ensure the car maintains a certain speed. On top of that, a radar or laser is onboard which detects the predecessor. Based on the location and the speed of the predecessor, the speed of the following vehicle is changed. This can be done by actively braking or by releasing the throttle. These are the minimum specifications of the ACC systems to be reviewed in this research. Several different systems are sold and used in the Netherlands, and the development of smarter and more advanced systems is still going on. All ACC-users which are analyzed in this research use ACC for a minimum period of three months. Therefore this research goes into the ACC systems as they were available around the beginning of the year 2015.

This research focuses on the use of ACC in the Netherlands. It turns out that cultural differences are present between countries and cultures in terms of driving style (*Özkan et al., 2006*). Therefore it is not recommended to extrapolate the conclusions to other countries, but to a certain extent the results will be internationally applicable.

It is known that ACC is mainly used on roads with higher speeds, like highways, expressways, and, to a smaller extent, rural roads. The focus of this research will be on the highways. These are the roads where ACC is used the most. The field test that will be executed as part of this study will only take place on the highways. Also the largest part of the questionnaire will handle the highways as well.

This research focuses on the influence of ACC on driver behavior, traffic flows and safety. How ACC influences these three characteristics must be analyzed. Of these influences, the focus will be on traffic flows, since about the influence of ACC on traffic flows relatively little knowledge is available. Also the relation ACC - traffic safety will be elaborated.

This research is intended to give insight in the behavior of ACC in practice. Therefore it is important that all data that will be collected is as close to practice as possible. This is necessary to interpret the results correctly, and to make the outcome of this research as valid as possible.

To answer this main question, five sub-questions are formulated. These will be described in the following paragraphs.

1.3.1 Sub-question 1 - What are the technical specifications of ACC?

This research question focuses on literature. It will be discussed in paragraph 1.5. Before investigating the way users cope with the aid of ACC, research must be executed to determine what exactly ACC is, why it is implemented in several cars nowadays and how it is designed. This is necessary to provide a strong theoretical basis for this research. For this research, the available literature consists of scientific papers, articles and so on.

The outcome of the theoretical research in this chapter is a collection of hypotheses about the performance of ACC and its influence on driver behavior, traffic flows and safety. These hypotheses are based on literature research, and are as specifically as possible. Basically, these hypotheses together form the framework with which in depth conclusions can be drawn on the performance of ACC. These hypotheses are used in the synthesis in chapter 4, where the conclusions from the Field Test and the questionnaire are combined to find answers on the main research question.

1 Introduction

1.3.2 Sub-question 2 - What are driver's experiences with ACC?

This research question will be described in chapter 2. It will be the main focus of this research, along with the next sub-question. To successfully assess the use of ACC in practice, two different types of research need to be executed, namely to the objective and the subjective performance of ACC. First must be found out how the driver of the car with ACC experiences it and how he reacts on the system. And secondly insight must be gained in how exactly ACC is used in practice. The first subject is covered by this sub-question, and the second by the next question.

A questionnaire gives insight in the use of ACC in practice. To take into account the reviews of as much ACC-users as possible, a questionnaire is designed. This questionnaire will be distributed amongst as much ACC users as possible. The results can be used to investigate in which way ACC is used in practice. Furthermore, literature review will be used to answer this sub-question, and to find the theoretical basis for the outcomes of the user reviews.

1.3.3 Sub-question 3 - How is ACC used in practice?

This, together with the former sub-question, will be the main focus of the research. Not only the experiences of drivers using ACC are important in this research, but also how they behave in practice. This will be described in chapter 3.

To answer this research question, a field test is designed. This field test consists of eight participants. These participants already have ACC on board for a while. They are given as less orders as possible, so that they use ACC in a natural way. The participants use their cars like they normally do. This way, a database of different characteristics is collected for at least five weeks. The data that is collected contains approximately as much driving hours with ACC activated as without it activated. This enables the researcher to compare driving behavior and characteristics with and without ACC.

1.3.4 Sub-question 4 - What is the effect of ACC on driver, traffic flow and safety, and how can this effect be optimized?

At this stage of the research, three different data sources are used to gain information, which are literature research, questionnaires and a Field Operation Test. Now conclusions will be made, by means of the synthesis of the three different sources of data. This means that the influence of ACC on driver behavior, traffic flows and safety can be formulated.

Based on the outcome of the Field Test and the questionnaire, the hypotheses formulated in paragraph 1.5 will either be approved or rejected. Based on all these small hypotheses, an integral answer will be provided on the question what the influence is of ACC on traffic flows, safety and the driver of the car.

The research which will be done for this sub-question is described in chapter 4, and will serve as a basis on which recommendations about the implementation of ACC in the future can be done.

1 Introduction

1.3.5 Sub-question 5 - What are likely and recommended future developments of ACC and CACC?

Based on the answers provided in the previous sub-question, recommendations can be made about the implementation of ACC and other systems in the near future. A description will be given how ACC must be altered to eliminate the negative influence on driver or road conditions, and how the positive influence of ACC can be maximized.

Also other types of ACC will be analyzed, for example Connected ACC, to see whether these improved ACC variants will have a positive influence. The outcome of this research will be used to give recommendations about the implementation of CACC.

An overall wrap up of the research is done and the outcome will be discussed and its relevance and reliability will be described.

1 Introduction

1.4 RESEARCH METHODOLOGY

To answer the main question a framework has to be designed. That framework is shown in Figure 5. The answer on the main research question is found by answering the five sub-questions described in paragraph 1.3.1 to 0. These five sub-questions are mutually connected as shown in Figure 5. The numbers 1 to 5 visible in the figure correspond with the five sub-questions.

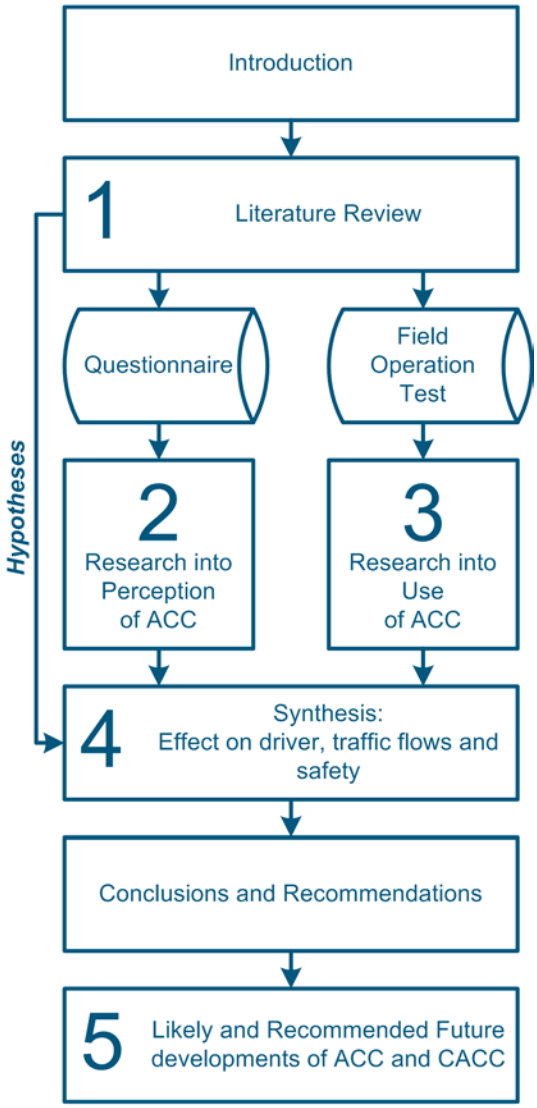


Figure 5 - Research framework and sub-questions

Visible is that this research begins with an introduction. Then the first sub-question of this research is described in the Literature Review. This literature review influences the questionnaire (sub-question 2) and the Field Test (sub-question 3), which are, parallel to each other.

1 Introduction

Besides that, in the literature review also several hypotheses are formulated, based on the literature which is analyzed. These hypotheses, indicated with the arrow on the left side of Figure 5, are the input for the synthesis of the outcome of the questionnaire and the field test, as it is described in sub-question 4. Al these hypotheses will be used to integrally determine the influence of Adaptive Cruise Control on driver, traffic flows and safety.

Then, when the current situation regarding the influence of ACC in practice is thoroughly analyzed, overall conclusions and recommendations will be described. Based on these conclusions an analysis and recommendations about future implementation will be made. This is described in sub-question 5.

1 Introduction

1.5 Literature Review

A lot is known about ACC at this moment already. It is of course useful to take this knowledge into account when conducting this research. Therefore a literature research is executed.

This literature review consists of several paragraphs. In paragraph 1.5.1 the purpose of ACC will be described from the perspective of the car manufacturers. Then the characteristics of the ACC systems of several brands will be elaborated, in paragraph 0. In 1.5.3 the context of ACC will be addressed: its role in the development of different ADAS systems which are developed now or will be in the future. Then in 1.5.4 Cooperative Adaptive Cruise Control will be described, and finally in 1.5.5 the literature which is currently available will be assessed, and based on that several hypotheses will be formulated, which will be tested later in this report.

1.5.1 Purpose of ACC

Adaptive Cruise Control and its radar technology is considered to be invented by William Chundrlik and Pamela Labuhn, employed at General Motors Corporation (*Chundrlik & Labuhn, 1991*). Mr Chundrlik states that ACC is meant to ease the driving task, but he certainly states that ACC will have a positive influence on traffic safety, and even on traffic flows. About safety he says (*Blackstone, 2012*): *"A lot of accidents occur at lower speeds with inattentive drivers and you can use this technology to -and I use this word carefully- mitigate collisions."* He foresees that ACC is one of the early technologies which will lead to an automatic vehicle. The influence of ACC on traffic flows will be positive, he says, since it will eliminate shockwaves.

It stands out that car manufacturers, the companies which have to sell ACC, are much less focused on traffic flows. When analyzing the owner's manuals of several car brands, it stands out that the main purpose of ACC is to relieve the driving task. The manual of the Volvo V40 from 2015 states (*2014*): *The adaptive cruise control (ACC – Adaptive Cruise Control) helps the driver maintain a safe distance from the vehicle ahead. Adaptive cruise control provides a more relaxing driving experience on long journeys on motorways and long straight main roads in smooth traffic flows.* And Audi says in a promotional video (*2013*): *The Adaptive Cruise Control helps control leg fatigue on long distances*. Another video, this time from Volkswagen, says (*Volkswagen, 2013*): *Safe motoring also involves keeping the right distances. The ACC provides assistances. It delivers stress-free and comfortable motoring*. Continental Automotive, a company which offers separate ACC systems, indicates that ACC is an extension for Cruise Control, which enables the user to use it also in dense traffic (*2015*): *ACC enables a new kind of mobility, not only allowing drivers to arrive more relaxed and in greater safety, but also making driving a pleasure again despite all the hectic traffic on the roads.*

Car manufacturers give driver comfort as a main reason to install ACC. For drivers themselves, this is an important reason as well, but also safety is very important (*Donker, 2014*). Safety is an issue with ACC, since almost all car brands show large disclaimers in the instruction manual. In the owner's manual of the BMW 740i from 2014, it reads (*2014*): *The system does not relieve the driver of the responsibility to adapt his or her speed, distance and driving style to the traffic conditions. Drive attentively, and react to the current traffic events. Intervene actively when necessary, e.g., by braking, steering or making an evasive maneuver, otherwise, there is danger of an accident*. Also it is clearly stated that ACC, which leads to a decrease of driving task, does not relieve the driver of the responsibility that comes with driving a car. Skoda says (*2015*): *The driver must always be ready to take over steering of the vehicle himself (accelerate or brake)*.

Car manufacturers, in summary, do want the drivers to be relaxed, but the responsibility still has to be by the driver.

1 Introduction

1.5.2 Specifications of Different ACC Versions

Adaptive Cruise Control becomes more and more implemented on the Dutch car market. Until two or three years ago, only the more luxury cars did have ACC, but now it is implemented in a large part of the available car models. Exact numbers about the implementation of ACC in the Netherlands are unknown[1], but a significant amount of cars has ACC onboard, and this amount increases every year.

A very few car models have ACC as part of the standard package, but a lot of brands offer ACC as an option. Nearly all car brands do have an ACC option. All brands have developed their own system, and the quality and customizability differs a lot. Often ACC is offered as part of a package of different driving assistance- or safety systems. Volvo for example, with its strong focus on safety, offers ACC as part of the Intellisafe package, consisting of several features like Blind Spot Information System, Hydraulic Brake Alert, Driver Alert Control, and so on. Also Audi offers ACC in the 'Tour' assistance package on the Q7 model, consisting of, amongst others, Active Lane Assist and Traffic Sign Recognition.

The car brands with ACC systems which are mostly used in the Netherlands are Audi, BMW, Peugeot, Toyota, Volkswagen and Volvo. Table 1 shows what the specifications are of the most recent ACC systems for these car brands. Several characteristics define the ACC systems of every car brand. First of all, there is the adjustable headway. Every model offers an adjustable headway. This means that the distance, most of the time expressed in time headway, can be chosen. This is a value which differs between roughly 1 and 3 seconds. Besides the headway, Audi and Volkswagen do also give a choice in sensitivity. Volkswagen offers three different options: Comfort, Normal and Sport. These options indicate the acceleration and deceleration characteristics.

Car Brand	Headways Adjustable	Sensitivity Adjustable	Range (braking)	Range (speeds - automatic gearbox)	Range (speeds - manual gearbox)
Audi	5 levels	yes	Full	All (with Stop&Go)	From 30 kph
BMW	4 levels	no	Full	All (with Stop&Go)	From 30 kph
Peugeot	4 levels	no	Only Coasting*	From 40 kph	From 40 kph
Toyota	3 levels	no	Full	From 50 kph	From 50 kph
Volkswagen	4 levels	yes	Full	All	From 30 kph**
Volvo	5 levels	no	Full	All	From 30 kph

* ACC deactivates and shows warning light and sound when braking is required
** Can only be activated at higher speeds, but does brake to a full stop. Below 30 kph only emergency stops

Table 1 - Specifications of the most recent ACC systems per car brand

All ACC systems do brake actively, with Peugeot being an exception. The Peugeot system only allows the car to only decelerate by coasting. This means that when the situation on the road requires active braking, ACC deactivates itself, and gives a visible and audible warning signal. Then the driver has to take over and brake.

Visible is that the gearbox has a huge influence on the speed range of ACC. When the car has a manual gearbox, all ACC systems have a lower limit, which is somewhere between 30 and 50 kph, partly dependent of the gear the car is in. Only Volkswagen offers an extra service at lower speeds: despite ACC can only be activated at higher speeds, the car

[1] Based on the paper of *Flemming, 2012*, the reactions on the questionnaire and the amount of cars with ACC amongst Royal HaskoningDHV lease-cars, it is estimated that approximately 1-3% of the cars in the Netherlands is equipped with Adaptive Cruise Control.

can brake autonomously to a full stop. Also the system stays active at lower speeds, but then it only interferes in an emergency situation. Then the car can autonomously make an emergency stop.

When the car has an automatic gearbox, all models except the Toyota and the Peugeot, can be active at all speeds. This means that cars also can drive in congested situations or on urban roads with ACC activated.

At the moment the development of ACC goes very fast. Several systems do not only take the predecessor into account, but also use the road map database. This database shows when steep curves are ahead, and the car itself can decelerate to safely go around the curve. Also systems which detect maximum speeds and adapt the cars speed are available.

1.5.3 Place of ACC within other ADAS Systems

As stated in the introduction, ACC is part of a development of systems that support the driver in executing his driving task, the so called ADAS-systems. The transition from manually controlled vehicles towards automated vehicles is described by SAE International. Six levels of automation are determined, from 0 to 5. The different levels of automation are shown in Figure 6.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 6 - SAE International Levels of Automated Driving (2014)

1 Introduction

ACC is a system that is located in SAE Level 1. The execution of acceleration and deceleration is done by the system, and the driver monitors. This means that the driver is responsible at all times.

Other ADAS Systems are Lane Change Assistance, Automatic Emergency Braking and Park Assist. These systems are all also located in SAE Level 1. A lot of warning systems are currently available as well. Systems for example which warn when approaching another vehicle, or when leaving a lane without using the indicator light.

Car manufacturers are the stakeholders who develop these systems. Barely any supervision by governments or research institutes is present in the development of these systems. This is not necessary, since a car with ACC can operate autonomously. This is very different compared to cooperative systems like Cooperative Cruise Control, which requires the vehicles to mutually communicate. This has to be initialized by some governing organization like a research institute or government.

The Dutch government is very clear about the implementation of automated vehicles on the road, and the pattern towards fully automated vehicles. Ambitions are to make the Netherlands one of the initiators of these systems. The Dutch minister of Infrastructure and Environment states in a letter to the Speaker of the House of Representatives (*Schultz van Haegen, 2014*):

I expect the autonomous vehicle to eventually help improve traffic flow, traffic safety and livability. (...) The automotive industry and research institutes expect that it will take many years until a safe and widespread implementation of an autonomous car can take place. The autonomous functions of vehicles will gradually be extended and should be tested in practice. This is important because of the technical availability, and because consumers need to gain acceptance and ability to deal with these applications. (...) Testing in practice is essential to monitor the use of new technology and to provide the necessary regulations.

Conclusions are that the implementation of Adaptive Cruise Control and other ADAS systems are strongly recommended by the Dutch government. Also the government acknowledges the importance of testing of these systems in practice.

1.5.4 Cooperative Adaptive Cruise Control

Adaptive Cruise Control is one of the examples of the transition of manual driving towards automatic driving. It is a system that takes over several driving tasks from the driver. Expectations are that this development towards automatic driving will go on and on for the years to come. But another development is going on as well: the transition from autonomous towards cooperative driving. This means that cars and drivers do not individually determine what the best driving strategy is, but that different cars collaborated to find the solution that is best for everyone. One of the earliest examples of this connected driving is Cooperative Adaptive Cruise Control. It is an improvement of ACC which is also able to communicate with other cars.

This means that CACC not only takes over a part of the driving task of the driver, but also determines the ideal path, speed and headway of the car, based on the information provided by other cars. This means that the behavior of the car and its influence on traffic safety and especially traffic flows can be further optimized. Theoretically, this could lead to platoons of cars driving very close to each other. This will lead to an enormous increase of road capacities. Research based on simulation shows that vehicle to vehicle communications provide more stability (*Milanés & Shladover, 2014*, *Netten et al., 2010*, *van Arem et al., 2006*). And also a Field Operation Test in the United States showed that Cooperative Adaptive Cruise Control is not only successful when high penetration grades are present, but also when smaller amounts of cars are equipped with the system. Interference between CACC cars and non CACC cars is possible (*Milanes et al., 2014*). This means that implementation of CACC can take place in the same way as ACC, where CACC equipped cars perform as ACC-cars, until they meet another CACC-equipped car. Then they can form a platoon. This approach is also suggested by *Van Arem, 2013*.

Literature shows that the vehicle to vehicle communication component which distinguishes CACC from ACC, might have a very large influence on traffic flows in the future.

1 Introduction

1.5.5 Analysis of Currently Available Literature and determination Hypotheses

The 'Assisted Driver'-project

About the implementation of Adaptive Cruise Control in the Netherlands, a research is executed by *Alkim et al., 2007*. This research, the so called 'Assisted Driver'-project, included a field test containing nineteen drivers driving a Volkswagen Passat for five months (February – June 2006). The behavior of these drivers is recorded, and also a questionnaire is made to assess the preferences of the drivers. This research is executed almost ten years ago, and therefore new research about this subject is valuable. But the 'Assisted Driver'-project has been an example about how to design this research, and the conclusions made by it are used in the literature review of this research.

Main differences between this research and the 'Assisted Driver' are the time it is executed: This research is based on the newest ACC systems while the 'Assisted Driver' is based on ACC systems which are ten years old. Also the size is a difference: The 'Assisted Driver' contained more cars and a larger test time compared to the field test in this research, but the questionnaire executed in this research is larger than the questionnaire used in the 'Assisted Driver'-project. Another difference is that the 'Assisted Driver' was based on 19 participants which did not have any experience with ACC when starting with the test. The field test carried out in this research is based on eight drivers which are already experienced users. This indicates that this research provides conclusions which are to a larger extent applicable in practice.

Overall, the 'Assisted Driver'-project and its conclusions provide very valuable input for this research. Other literature sources have to be assessed as well. Therefore a methodology is designed. This is elaborated in the next paragraph.

Methodology

This research is meant to give insight in the influence of ACC in practice, on the Dutch roads. So first a framework has to be designed how 'the situation on the road' can be described. Three important variables are present that determine almost everything that happens on a highway. These three are the humans in traffic, in this case drivers of vehicles, the safety on the road and the traffic flows. These three and the interaction between them are input for the traffic system. Everything that happens on the road can be traced back to one of more of these three variables and the relation between them. Not only are these three input, but they are output as well. That means that the traffic system is both influenced by these variables and it influences them. For example, the behavior of a car driver has influence on the flows, and the other way around, the driver adapts his behavior to the conditions on the road. The traffic system is shown in the blue square in Figure 7, and the three main variables are shown in the blue circles. The blue arrows represent the interactions between the three.

These three variables consist of a lot of parameters. The behavior of the driver for example, consists of the mood and the alertness of the driver, his comfort, his driving style, and so on. Also the traffic flows and safety consist of various parameters.

Besides the traffic system, there is ACC. Also ACC and its performance are determined by a lot of factors. The way ACC works and the driver is used to it, the level of trust the driver has in ACC, and so on. This ACC influences the traffic system. This is indicated by the yellow box and arrow in Figure 7.

1 Introduction

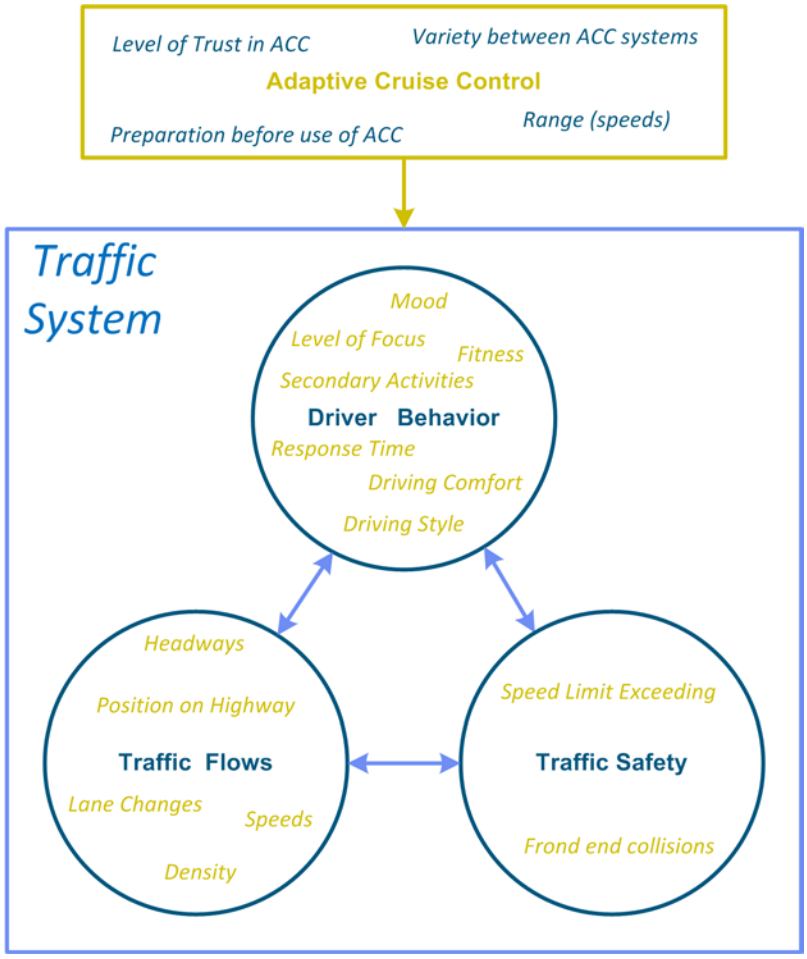


Figure 7 - The influence of ACC on the traffic system consisting of Driver Behavior, Traffic Flows and –Safety

Before analyzing literature and conducting this research, the way ACC influences the traffic system must be explained. This yellow arrow needs to be further elaborated. This is done in Figure 8.

This arrow, representing the influence of ACC on the three main factors of the traffic system, can be divided into five relations, numbered 1 to 5. The first three are direct relations between Adaptive Cruise Control and respectively traffic flows, traffic safety and driver behavior. These relations are straightforward. When ACC activated, it directly influences traffic flows (e.g. the headway increases which reduces road capacity), traffic safety (e.g. it prevents head-tail collisions) and the driver (e.g. he gets less tired because with ACC driving costs less effort).

The fourth and fifth are indirect relations, between ACC and respectively the traffic flows and traffic safety, via the behavior of the driver. This means that ACC influences the behavior of the driver, and that results in an effect on either traffic flow or safety. For example, with ACC activated, drivers tend to perform less lane changes, which results in a more stable traffic situation, or the reduction in driving task makes drivers perform more secondary activities which has a negative impact on traffic safety.

1 Introduction

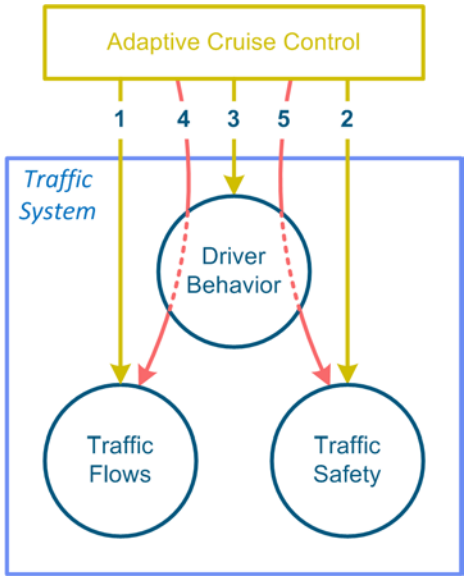


Figure 8 - The Five Types of Influence of ACC on the Traffic System

Now it is necessary for each of the five relations to analyze the available literature about that relation. This will lead to several hypotheses, which will be tested in this research. For each hypothesis will be formulated which way of testing will be used.

These hypotheses will be used in chapter 4. In that chapter, the results of the Field Test and the questionnaire will be used to determine an answer to these hypotheses.

In the following paragraphs, tables are shown with the hypotheses, based on literature review, which will be tested in this research. Also the sources are shown. When analyzing the sources it is very important to take into account the way the data is collected in these papers. The data collection is shown for every source paper. The following data collection methods are possible:

- Literature Review: A paper based on an analysis of known literature. This is as reliable as the source material.
- Simulation: A computer program is used to analyze ACC behavior. This is as reliable as the input parameters and the reliability of the simulation software. Keep in mind simulation always is theoretical: results are not always directly transferrable to the real world.
- Driving Simulator: Participants are tested in a controllable environment, in a driving simulator. This means that reproducible circumstances can be created, which is good when comparing results for different participants. Despite that, a drawback of this method is that driving behavior might not always be representative, since participants know that the simulator is not real.
- Field Test: Data is collected using a Field Operation Test. This means that the situation in practice can be investigated. This is a very reliable source for research. But results are heavily related to the characteristics of the participants, and conditions are not so well controllable.
- Questionnaire: Participants are asked to fill in a questionnaire. Quite reliable, but results are subjective. This shows only the opinion and the perception of the participants. Results are also very dependent on the quality of the questions.

1 Introduction

- Focus Groups: Basically the same as the questionnaire, but the results are collected using a conversation instead of a list with questions. Also this means: possibly subjective and socially accepted answers.
- Test Track: Comparable to a simulator study where a single situation is imitated and tested. This is done not virtually, but in practice on a dedicated testing environment. Reality can be very well approached, but interference with other cars only happens forced by the researchers. This might mean the results are biased.

The notes shown here for every way of collecting data are important when interpreting literature.

Furthermore, for every hypothesis, the way of testing it is shown. Three possibilities are present to test the hypothesis: with help of the questionnaire, the field test, or both. In chapter 2 and 3 the questionnaire and the field test and their outcome will be discussed, and in chapter 4, an integral answer on these hypotheses will be given, based on the outcome of the questionnaire and field test.

Relation 1: ACC – Traffic Flows

Research is being done on the effects of ACC on traffic. Conclusions are that stable ACC systems are possible under certain conditions and that ACC at least does not have negative impacts on the traffic flow (*Kesting et al., 2008*; *Suzuki & Nakatsuji, 2003*; *Wang et al., 2012*; *Wang et al., 2013*). However, these researches mainly have a theoretical character. These studies use simulations which assume drivers who are fully aware of the way of operation of ACC, and who use the system in the correct way. In practice, the reality of this moment and the near future may well be more complicated.

ACC, when activated, coordinates the driving behavior of the car. This means that the way ACC functions, has influence on the traffic flows. Several parameters determine a cars influence on traffic flows.

Speed and acceleration are the most important ones. A constant speed prevents or accumulates disturbances which might lead to shockwaves. Also strong accelerations are important, when a car is accelerating after being in congestion. Then it is important that the accelerations are as high as possible. Then the congestion reduces. Several studies show that the speeds become more constant when ACC is active. This makes sense, since ACC, as well as CC, maintains a certain speed, as long as no other vehicle drives directly in front of the ACC-equipped car. The studies which state the stability of speeds increases, are based on different sources. A field test in the Netherlands, executed in 2006 (*Alkim et al., 2007*) provides data from practice, while theoretical research and a questionnaire state the same. The basis for this hypothesis is strong.

Furthermore there is headway. A larger headway means that under the same traffic conditions the density is lower. The amount of cars that fit on a highway stretch is lower. This has a negative influence on traffic flows. A lot of researches show that the headway is larger when ACC is activated. This is due to the safety margins of the system. The researches underlining this statement are many: both driving simulator tests and field tests show this in practice, and a questionnaire states that also users experience this headway increase.

But ACC leads to more car-following behavior, and thus to a more constant headway. This is found in practice by two different field tests, executed in the Netherlands. One driving simulator test, *Hoedemaeker & Brookhuis, 1998*, shows an opposite result. This test is executed 17 years ago, and the results might very well be outdated.

1 Introduction

No.	Hypothesis	Source(s)	Test Hypothesis with	
			Questionnaire	Field Test
1.1	ACC leads to more constant speeds	*Alkim et al., 2007* (Field Test); *Marsden et al., 2001* (Simulation); *van Twuijver & Pol, 2004* (Questionnaire)	X	X
1.2	ACC leads to an increase of headways	*Bianchi Piccinini et al., 2014* (Driving Simulator); *Pauwelussen & Feenstra, 2010* (Field Test); *Pauwelussen & Minderhoud, 2008* (Field Test); *van Twuijver & Pol, 2004* (Questionnaire); Rejected by *Hoedemaeker & Brookhuis, 1998* (Driving Simulator)	X	X
1.3	ACC leads to more constant headways	*Alkim et al., 2007* (Field Test); *Rakha et al., 2001* (Field Test)	X	X

Table 2 - Hypotheses, Sources and Ways of Data Collection for the relation ACC - Traffic Flows

Relation 2: ACC – Traffic Safety

One of the main reasons users opt for ACC is because it reduces the risk of head-tail collisions. This not only stated by the ACC manufacturers, but also by the questionnaire executed by *van Twuijver & Pol, 2004*. This is positive. This hypothesis will in this research again be checked by means of a questionnaire, which probably will show the same outcome. But what users indicate in a questionnaire might not be true in practice. This must be kept in mind when assessing the results.

Hoedemaeker & Brookhuis, 1998, a source based on a simulation study, shows that the amount of strong decelerations increases when using ACC. This is definitely a safety hazard. However, this source shows very different results compared to other sources on other hypotheses, and therefore the theoretical basis of this hypothesis is weak. The field test will provide an up-to-data validation or falsification of this hypothesis.

A lot of studies analyzed, based on different data sources, state that ACC leads to less speed limit exceeding. This is because users of the system deliberately adjust the ACC settings to the maximum allowed speed. Again, one source rejects this statement. This is the same source, based on a 1998 driving simulator study, which shows different results when assessing literature for the headways. Therefore this source is judged less reliable than all other sources stating the opposite.

No.	Hypothesis	Source(s)	Test Hypothesis with	
			Questionnaire	Field Test
2.1	ACC leads to a reduction of the amount of front end collisions, with the preceding vehicle as well as the vehicle behind.	*van Twuijver & Pol, 2004* (Questionnaire)	X	
2.2	ACC leads to stronger braking	*Hoedemaeker & Brookhuis, 1998* (Driving Simulator)		X
2.3	ACC leads to less speed limit exceeding	*Alkim et al., 2007* (Field Test); *van Twuijver & Pol, 2004* (Questionnaire); *Vollrath et al., 2011* (Driving Simulator); Rejected by *Hoedemaeker & Brookhuis, 1998* (Driving Simulator)	X	X

Table 3 - Hypotheses, Sources and Ways of Data Collection for the relation ACC - Traffic Safety

1 Introduction

Relation 3: ACC – Driver Behavior

As already stated, ACC is a system that is designed with the safety of the driver in mind. But a second goal is to further relieve the task of the driver, especially in congested conditions. When driving on a highway under capacity conditions, it can be very tiresome to continuously have to brake and accelerate again. When the car is able to do that autonomously, this means a relief for the driver. Literature, based on different user preference studies, states that indeed ACC reduces the workload for the driver. Whether this is positive or negative must be found out, because a decreasing workload might result in distracted drivers and more activity such as smoking and texting during driving. This will be discussed in the paragraph about the relation ACC - Driver Behavior – Safety.

Also a lot of research papers from driving simulator-,field test- or questionnaire-studies, show that drivers have to prepare before ACC, either by reading the owner's manual where the risks and safety hazards are shown, or by listening to an experienced user's explanation.

Also the characteristics of the ACC-system are assessed: one paper states that ACC is preferable when it only advises and does not brake actively. Also several researches show that the customizability of ACC is very important.

No.	Hypothesis	Source(s)	Test Hypothesis with	
			Questionnaire	Field Test
3.1	ACC leads to an increase in driving comfort	*Bianchi Piccinini et al., 2015* (Driving Simulator); *Strand et al., 2011* (Focus Groups); *van Twuijver & Pol, 2004* (Questionnaire)	X	
3.2	ACC leads to a calmer driving style	*van Twuijver & Pol, 2004* (Questionnaire)	X	X
3.3	Drivers have to learn using ACC	*Alkim et al., 2007* (Field Test); *Beggiato & Krems, 2013* (Driving Simulator); *Larsson, 2012* (Questionnaire); *Larsson et al., 2014* (Driving Simulator); *Weinberger et al., 2001* (Field Test)	X	
3.4	Preparation beforehand is necessary for users to use ACC correctly and satisfactorily	*Beggiato & Krems, 2013* (Driving Simulator); *Dickie & Boyle, 2009* (Questionnaire)	X	
3.5	ACC must be customizable because of the differences between driving styles	*van Twuijver & Pol, 2004* (Questionnaire); *Viti et al., 2008* (Field Test); *Xiong et al., 2012* (Driving Simulator)	X	

Table 4 - Hypotheses, Sources and Ways of Data Collection for the relation ACC - Driver Behavior

1 Introduction

Relation 4: ACC – Driver Behavior – Traffic Flows

The way users use ACC has a large influence on traffic flows. Already in the paragraph about the relation ACC - Traffic Flows is stated that ACC leads to more constant headways. Here, literature review states that ACC leads to less lane changes and more use of the right lane. This means that ACC leads to more car-following behavior. The less lane changes occur, the less traffic is disturbed. Furthermore the position of the car on the road is a critical parameter. In the Netherlands, it is obligatory to drive on the right side of the road when this is possible. When the right lane is occupied, then it is allowed to use the left lane. Because these are the rules, it is preferable to use the right lane as much as possible. Then the highway is used as efficiently as possible. So both the position on the highway and the amount of lane changes influence the traffic flows. The sources of this hypothesis are basically all based on the judgment of the drivers. This means that behavior in reality is not that strongly assessed. Therefore the questionnaire, but especially the field test, can be useful to check if this hypothesis is true.

User reviews and literature tend to show that headways are larger with ACC on. This feels uncomfortable for the driver, who is going to manually decrease headways. This is analyzed by one source, based on a field test. By doing this, the advantages of ACC on traffic flows and safety are eliminated. Therefore investigation whether this is true is necessary. When it is true, recommendations have to be made how to design ACC more in line with the expectations of the user.

No.	Hypothesis	Source(s)	Test Hypothesis with	
			Questionnaire	Field Test
4.1	ACC leads to less lane changes and more use of the right lane	*Strand et al., 2011* (Focus groups); *van Twuijver & Pol, 2004* (Questionnaire); Rejected by *Rudin-Brown & Parker, 2004* (Test Track);	X	X
4.2	ACC leads to more car-following behavior	*Strand et al., 2011* (Focus Groups)	X	X
4.3	Drivers tend to manually decrease the headway proposed by the ACC system	*Viti et al., 2008* (Field Test)	X	
4.4	Users tend to go to the left earlier when overtaking a car, to prevent the ACC system from braking before that car	*Alkim et al., 2007* (Field Test)	X	X

Table 5 - Hypotheses, Sources and Ways of Data Collection for the relation ACC - Driver Behavior - Traffic Flows

1 Introduction

Relation 5: ACC – Driver Behavior – Traffic Safety

It turned out in the paragraph about the relation ACC - Driver Behavior that preparation before using ACC is very important. Despite that, users do not prepare so well. This indicates a safety risk. Also the level of trust of drivers in the ACC-system is too high. And ACC-usage leads to more secondary activities according to several researchers. Two sources are found which underline this statement. The questionnaire executed in this research will elaborate this hypothesis.

When drivers do not prepare so well, this could lead to a too high level of trust in the system. Drivers are not able to correctly assess the risks of using it. A lot of sources, based on different types of research, state this. When drivers do not know the risks, they will perform more secondary activities. This is stated by four researches.

A drawback of the decrease in workload is that the reaction time of a driver is slightly longer. When an accident threatens to occur, a driver needs more time to push the brakes, since his right foot is not situated on the throttle. Several papers indicate this.

It turns out that several hypotheses indicate that safety is an important factor when assessing ACC.

No.	Hypothesis	Source(s)	Test Hypothesis with	
			Questionnaire	Field Test
5.1	Users tend to start using ACC before properly investigating the risks and limitations of ACC	*Bianchi Piccinini et al., 2014* (Driving Simulator); *Rudin-Brown & Parker, 2004* (Test Track)	X	
5.2	Drivers tend to have a too high level of trust in ACC	*Bianchi Piccinini et al., 2014* (Driving Simulator); *Dickie & Boyle, 2009* (Questionnaire); *Kazi et al., 2007* (Driving Simulator); *Rajaonah et al., 2006* (Driving Simulator); *Rudin-Brown & Parker, 2004* (Test Track); *Vollrath et al., 2011* (Driving Simulator)	X	
5.3	ACC leads to a reduction of the level of focus and an increase of secondary activities	*Bianchi Piccinini et al., 2014* (Driving Simulator); *de Winter et al., 2014* (Literature Review); *Rudin-Brown & Parker, 2004* (Test Track); *Vollrath et al., 2011* (Driving Simulator)	X	
5.4	ACC leads to a larger response time	*Bianchi Piccinini et al., 2014* (Driving Simulator); *Larsson et al., 2014* (Driving Simulator); *Rudin-Brown & Parker, 2004* (Test Track); *Vollrath et al., 2011* (Driving Simulator)	X	

Table 6 - Hypotheses, Sources and Ways of Data Collection for the relation ACC - Driver Behavior - Traffic Safety

1 Introduction

1.6 Reading Guide

In this report, the whole process of this research is described, including the results. In paragraph 1.4 the research methodology of this research is shown. This methodology of the research is linked to the set-up of this report in Figure 9.

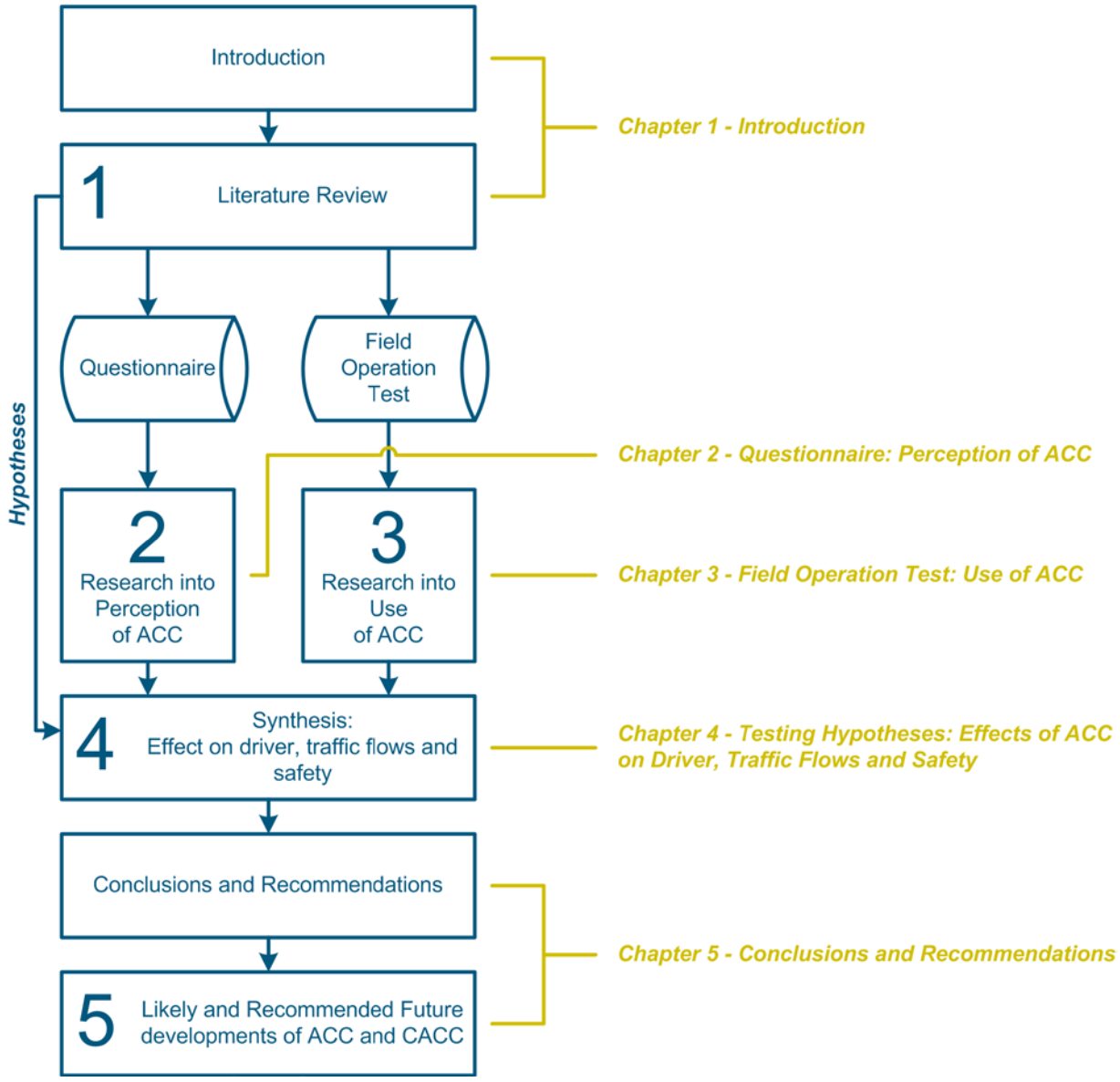


Figure 9 - Research framework and sub-questions with chapters

Visible is that the first two sections of the research, the introduction and the literature review, are shown in this chapter, chapter 1. The introduction is in the paragraphs 1.1 to 1.4, and the first sub-question of this research is described in paragraph 1.5, the Literature Review.

1 Introduction

Besides that, in paragraph 1.5 also several hypotheses are formulated based on the literature which is analyzed. These hypotheses, indicated with the arrow on the left side of Figure 5, are the input for the synthesis of the outcome of chapters 2 and 3, as it is described in sub-question 4. Al these hypotheses will be used to integrally determine the influence of Adaptive Cruise Control on driver, traffic flows and safety.

Chapter 2 describes the questionnaire which is designed to analyze the preferences of ACC users, and its outcome. Chapter 3 contains all necessary information about the Field Operation Test, which is designed to find out how ACC is used in practice. The results of both the field test and the questionnaire are combined in the synthesis in chapter 4. Here the hypotheses formulated in paragraph 1.5 are used to determine the influence of ACC on the driver, traffic flows and safety.

In chapter 5, overall conclusions and recommendations will be described. Based on these conclusions the future of ACC will be described in paragraph 5.3.

2 QUESTIONNAIRE: PERCEPTION OF ACC

2 Questionnaire: Perception of ACC

2.1 INTRODUCTION

The second research question in this research focuses on the way the users of Adaptive Cruise Control use it and experience the use of it. To elaborate that, a questionnaire is designed. This questionnaire was distributed amongst several Adaptive Cruise Control users. The questions in this questionnaire are formulated with help of the hypotheses in the literature review in chapter 1.

In paragraph 2.2, the research method will be described. The way the questionnaire is designed and distributed will be explained here. In paragraph 2.3 the outcome of the questionnaire will be elaborated. And finally in paragraph 2.4, conclusions and a discussion are represented.

The users of Adaptive Cruise Control are spread throughout the population of the Netherlands. This makes them hard to reach. This means that the questionnaire which is designed must be spread out amongst as many as possible car drivers. Therefore the Dutch Motorists Organization ANWB collaborates in this research. This organization plays an important role in the world of cars in the Netherlands, and is able to reach a wide variety of car users in the Netherlands.

2 Questionnaire: Perception of ACC

2.2 Research Method

In this paragraph the design and the distribution of the questionnaire is discussed.

2.2.1 Design of the Questionnaire

The questionnaire is designed as shown in Figure 10. In Appendix 1, the complete questionnaire is shown. First of all several general questions are asked, such as gender and age. When respondents indicate that their age is below 18 years or they do not have a driving license, they are directly referred to the end of the questionnaire.

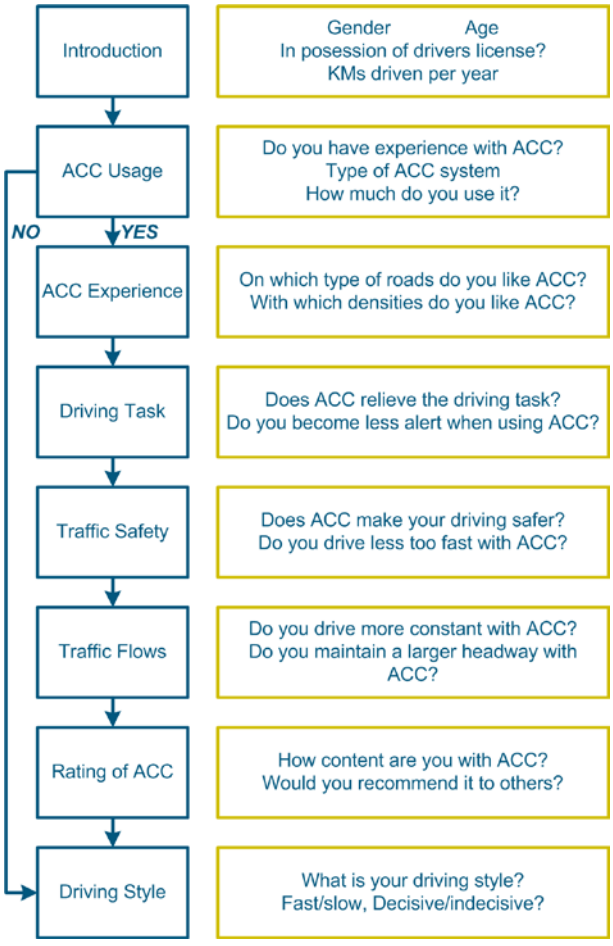


Figure 10 - Questionnaire: Framework with example questions per part

Then the second part is about the type of Adaptive Cruise Control the respondents are using. The first question here is: “Do you have experience with the usage of an Adaptive Cruise Control system?” When respondents answer this question with a “No”, they are directly referred to the questions at the very end of the questionnaire about driving style. When respondents indicate that they have experience with ACC, questions are asked which system they use, for how long, and so on.

2 Questionnaire: Perception of ACC

Then in the third part, the appreciation of users for different road types and different traffic conditions is researched. In the fourth part the relation between ACC and the driving task is investigated, and in the fifth part between ACC and safety. Then questions are asked about the influence of ACC on traffic flows. Then at last, respondents are asked to indicate what their overall appreciation is towards ACC.

Then finally several questions about the driving style of the respondents are asked. This is done to investigate whether a relation between the driving style of car drivers and their appreciation of ACC is present. These questions are based on the Driver Behavior Questionnaire (*Reason et al., 1990*) and the Learning to Drive Questionnaire (*Wells et al., 2008a*; *Wells et al., 2008b*).

Several checks are done to make the questionnaire and its outcome as reliable as possible. To gain only response from users which used the system recently, one of the questions was if users have used the ACC system in the past six months. When the latest usage of ACC was more than six months ago, the results are removed from the analysis. This is mainly because of two reasons. First of all it this research focuses on the most modern ACC systems, and the development of these systems has a high pace. This means that very old systems are outdated and replaced by more modern systems. So these old systems are not representative for the average ACC system. The second reason is that users which did use the system for more than half a year ago could remember things incorrectly. This makes their judgment less valid.

The parts of the questionnaire about ACC experience contain a few questions about the appreciation of ACC for different road types and density classes. These questions have a five point scale: Very Unpleasant – Unpleasant – Neutral – Pleasant – Very Pleasant.

The parts of the questionnaire which handle about the influence of ACC on driver comfort, traffic safety and flows, all contain several statements. Respondents have to indicate for every statement if they agree or not. A scale of seven options is given: Strongly Disagree – Disagree – Somewhat Disagree – Neutral – Somewhat Agree – Agree – Strongly Agree. Besides these statements, several situations that might happen are shown, and respondents have to indicate how often this happens. With these questions also a seven-point scale is determined: Never – Almost Never - Occasionally – Regularly – Often – Almost Always – Always. Throughout the questionnaire, lots of open questions are present which enable the respondents to give extra comments. These open questions are, in contrast to all other questions, not mandatory.

A questionnaire is part of the so called human research, and when executing this human research, it is important that the ethical impact of this research is determined. Therefore the Human Research Committee of the University of Technology in Delft is asked to assess this questionnaire research. This committee approved. The form used for this application is shown in Appendix 2.

2.2.2 Distribution of the Questionnaire

To help distribute this questionnaire, the ANWB collaborated. The website of the ANWB contains a “car”-tab (anwb.nl/auto), where all kinds of news articles about cars are shown. On this webpage, a news article is placed. This article, which is visible in Appendix 3, briefly describes the purpose of this research, and the need for participants in this questionnaire. At the bottom of the news article, a link to the online questionnaire is shown. To raise even more attention for this news article, a reference to it is made in the e-mail newsletter of the ANWB, which is sent every two weeks to approximately 100.000 people. By doing this, the questionnaire drew attention from a large amount of car users.

Besides the ANWB, also the social media accounts (LinkedIn, Facebook and Twitter) of the Department Transport and Planning of the faculty Civil Engineering of the TU Delft, and of Royal HaskoningDHV are used to spread this questionnaire amongst as much ACC-users as possible.

To push the amount of respondents even more, a reward was promised: amongst all respondents, four vouchers of the Dutch Tourists Organization, with a value of €25, were allotted.

2 Questionnaire: Perception of ACC

2.3 RESULTS

2.3.1 PARTICIPANTS

In total 267 people have completed the questionnaire. Of those people, 16 participants only started but stopped after the first few questions. Then there is a group of 22 participants who did not use ACC for the last six months. All these are excluded from the analysis. 29 participants indicate that they do not have any experience using ACC. These are used as reference group for the driving style questions. This means that 200 people with relevant Adaptive Cruise Control experience filled in the questionnaire. Of those 200, 14 did not totally finish questionnaire. Despite that, they are used in the analysis. This means that the N for all questions shown in this analysis is between 186 and 200.

Of all participants by far the largest part, 96%, is male. The average age and driving experience are high, as is shown in Figure 11. The amount of kilometers driven per year varies quite a lot, with an average of approximately 20.000 kilometers per year. This means that the largest part of the drivers who currently use Adaptive Cruise Control, are male drivers, aged older than 40, with a lot of driving experience.

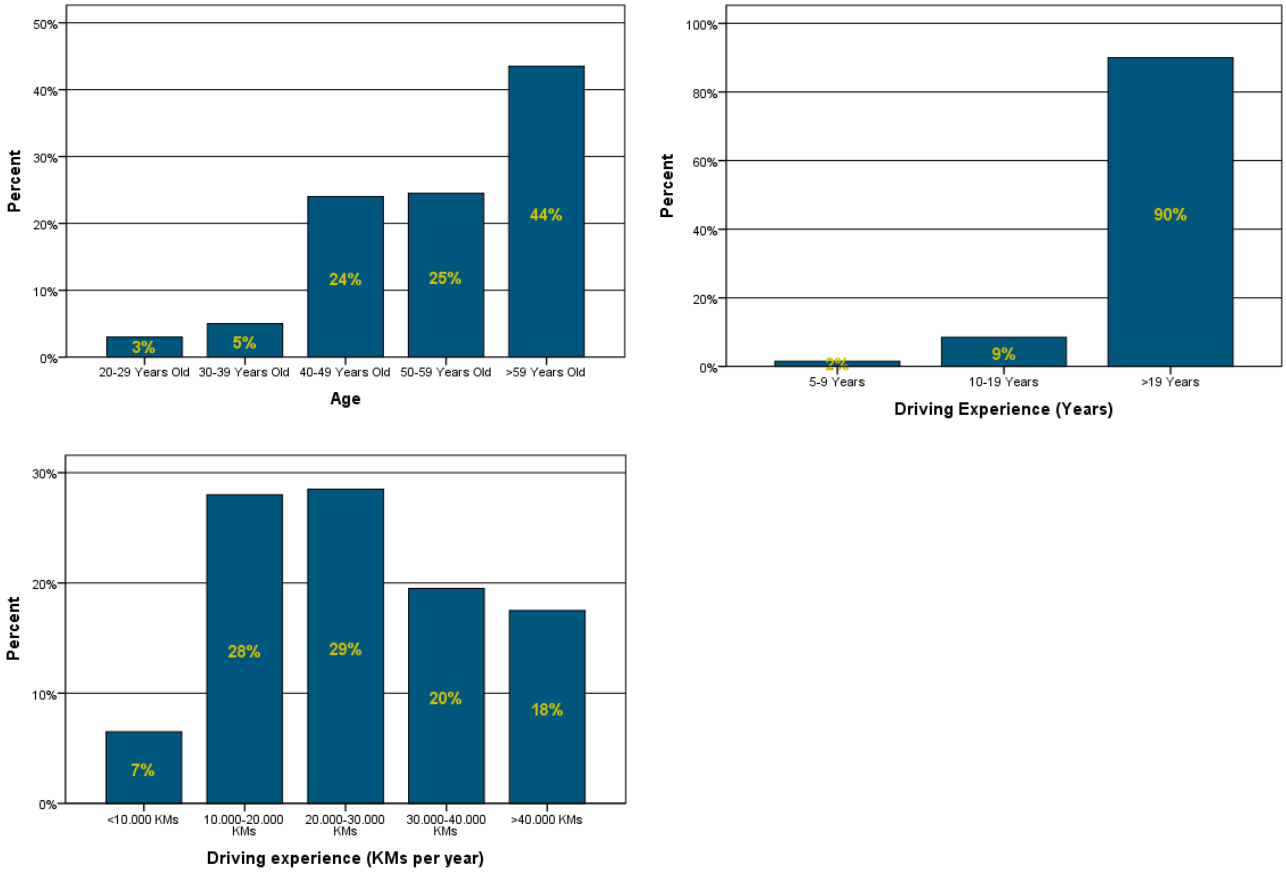


Figure 11 - Questionnaire: Participant Characteristics

2 Questionnaire: Perception of ACC

2.3.2 Driving Style

As described in paragraph 2.2.1, at the end of the questionnaire several questions about driving style are asked. Two types of questions are present. The first four questions each show two driving style characteristics which are each other's opposites and respondents have to class themselves somewhere between these two characteristics. The last five questions contain five situations that indicate a certain driving style, and users have to indicate how often that particular situation happens, on a scale from always to never. Both types of questions have a 7 point scale.

For every question an average result is computed. In Table 7 the average results are shown for the two different groups: the respondents with ACC-experience and without it. It stands out that overall ACC users consider themselves faster drivers compared to non ACC users, and indeed, they tend to speed a little bit more, and receive more penalties as well. They are more tolerant, and their average headway is larger. And they indicate that they undertake more secondary activities.

The cause-effect question is very important here. If a difference in driving style is present between users and non-users of ACC, is that because drivers with certain driving styles prefer ACC, or is it that ACC influences their driving behavior? In chapter 4 these questions will be further elaborated.

Driving experience with ACC		**No (N = 25)**		**Yes (N = 198)**	
		Mean	St.Dev	Mean	St.Dev
How would you describe your driving style?	Fast - Slow	3,1	1,05	2,8	0,86
	Careless - Careful	5,2	1,53	5,3	1,32
	Intolerant - Tolerant	4,7	1,31	5,0	1,15
	Decisive - Indecisive	2,0	0,79	2,0	0,94
How often is your headway so small you can't brake in time, in case of an emergency?		5.5	1,00	5,9	0,93
How often do you drive faster than permitted?		5,0	1,63	4,8	1,46
How often do you receive a penalty for a traffic violation?		6,4	0,57	5,9	0,70
How often do you feel annoyed by other road users?		4,5	1,39	4,6	0,97
How often do you undertake secondary activities while driving?		6,1	1,00	5,6	1,19

Table 7 - Average Scores for Driving Style Questions, on a 1-7 scale

2 Questionnaire: Perception of ACC

2.3.3 CARS

Several car brands are covered in this questionnaire, although several brands are much more represented than others. This can have several reasons. First of all a certain car brands are more popular than others in the Netherlands. Furthermore, certain car models can be very popular for example lease-drivers, because of the low additional tax on lease cars. Also a wide variety is present between ACC-models of the different car brands, and several models might be more popular than others. In Table 8 all car brands represented in the questionnaire, and their frequencies, are shown.

	Volvo	Toyota	Volkswagen	BMW	Peugeot	Audi	Mercedes	Mitsubishi	Ford	Citroën	Mazda	Skoda	Honda	Jaguar	Lexus	Opel	Subaru	Truck	Nissan	Total
Frequency	36	28	27	22	19	17	10	8	7	6	4	3	2	2	2	2	2	2	1	200
Percent	18%	14%	14%	11%	10%	9%	5%	4%	4%	3%	2%	2%	1%	1%	1%	1%	1%	1%	1%	100 %

Table 8 - Brands of ACC-users' Cars

In Table 9, the transmission of the cars with ACC and the range of the ACC system are shown. 22% of these cars has a manual gearbox, while the remaining 78% has an automatic gearbox. 40% of all cars has an ACC-system which is active at all speeds, the so called Stop-and-Go ACC. 48% of the ACC systems has a lower limit. This means that ACC deactivates at a certain speed. And 12% of the participants do not know whether their ACC system is active at all speeds or not. Almost all cars have an adjustable headway setting: 95%. 3% of the participants state that their headway is not adjustable, and another 3% does not know. Currently, no cars are available which do not have an adjustable headway. This means that either these respondents are mistaken, or they have a very old system.

As described in the literature review, the ACC of Peugeot and Toyota is, independent of the gearbox, inactive at lower speed. This is in accordance with what the drivers of these cars indicate in the questionnaire. Several brands, for example Volvo and Volkswagen, have ACC systems whose range is dependent on the gearbox: when an automatic gearbox is installed, ACC is active at all speeds. The relation between the transmission of the car and the range of ACC is shown in Table 9.

	Transmission of car with ACC		
Range of ACC	Manual	Automatic	**Total**
ACC Active at All Speeds	1%	39%	40%
ACC Inactive at Low Speeds	17%	32%	48%
Unknown	5%	8%	12%
Total	22%	78%	100%

Table 9 - Transmission of Car with ACC and ACC Range Cross-tabulation

2 Questionnaire: Perception of ACC

2.3.4 ACC USAGE

This paragraph goes into the motives of the respondents to use Adaptive Cruise Control and the way they use it. In Figure 12 the driving experience of the respondents is shown in months of total use, and in kilometers driven per week. Visible is that the time users use ACC varies a lot. Slightly less than a third of the respondents only uses ACC for less than six months, but another third of the respondents uses ACC for over two years.

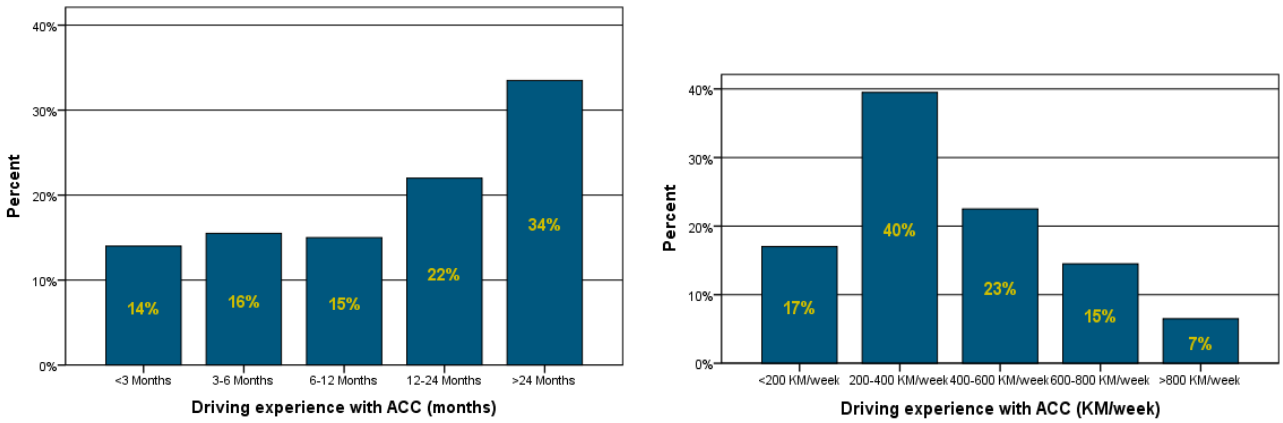


Figure 12 - Questionnaire: ACC usage Characteristics

In Table 10 the owner of the car with ACC is shown, combined with the reason users opt for ACC and the usage of the car with ACC. 63% of the drivers with ACC owns the car, and 31% leases the car. The remaining 6% either drives a car possessed by a relative or shares the car.

		Owner of car with ACC					
		Car Owned by Self	Car Owned by Relative or Acquaintance	Rental or Shared Car	Lease Car	Other	Total
Deliberate choice for ACC	No Deliberate Choice	18%	1%	0%	8%	0%	26%
	Someone Else Chose ACC	1%	2%	0%	2%	1%	6%
	Deliberate Choice of ACC	28%	1%	0%	15%	0%	43%
	Deliberate Choice of Package including ACC	17%	1%	1%	7%	0%	25%
Usage of car with ACC	Private Use	43%	2%	1%	0%	0%	45%
	Both Private and Business Use	1%	1%	0%	3%	1%	6%
	Business Use	20%	2%	1%	28%	0%	50%
Total		63%	4%	1%	31%	1%	100%

Table 10 - Owner of Car to Deliberate Choice and Usage of ACC Cross-tabulation

2 Questionnaire: Perception of ACC

A large group, 43% of respondents, has chosen ACC deliberately. 28% of this 43% owns the car, and 15% leases the car. Also a large part, 25% of users, chose an optional package with ACC included, when configurating their car. This can either be a driver assistance package like the 'Tour'-package from Audi or a safety package, like the 'Intellisafe'-package from Volvo. This means that amongst the respondents of this test, two third chose deliberately for ACC or a package including ACC. The remaining part of the respondents did not choose deliberately, either because it is not their car that has ACC and someone else chose it, or it was installed in the occasion-car they bought.

Half of the respondents indicate that the car with ACC they use is for business use only. 45% of the respondents only use it for private purposes, and the remaining 6% use the vehicle for private ánd business purposes.

Also a very important issue is whether users of ACC are aware of the risks of using ACC. A question about that was in the questionnaire as well. It is very hard to check whether respondents who think of themselves as aware of the risks, indeed are aware of the risks. But despite that, a noteworthy outcome is visible.

Table 11 shows a cross-tabulation of awareness of the risks and preparation before using ACC. Visible is that in total 45% of the users did receive instructions extensively, and 31% slightly. But another 22% is present which did not receive any instructions. Of this group, almost half indicates that they are, despite they did not receive any training, extensively aware of the risks. The other half states that they are more or less aware of the risks. Of the users which did not receive any instructions, a very small part indicates that they are indeed not aware of the risks. In contrary: of the users that did receive a little bit of instructions the part that admits not to know the risks is larger! Basically this means that a lot of users receive instructions to a certain extent, and this results in a proper assessment of the risks of using ACC. Another, smaller group, does not receive any instructions, but only gets to know the system by practicing. This results in an overestimation of their own skills, and an insufficient insight in the risks of ACC. This is also visible in the very right column in Table 11: 66% of all users indicate they know the risks extensively, while only 45% did receive instructions extensively. The difference consists apparently of either users which learned by practicing, or users which do not recognize the risks of using ACC.

Are you aware of the risks regarding usage of ACC?	**Did you receive any instructions before usage of ACC?**				
	No	Yes, Slightly	Yes, Extensively	Other	**Total**
No	2%	4%	1%	0%	7%
Yes, Slightly	10%	9%	9%	1%	28%
Yes, Extensively	10%	18%	36%	1%	66%
Total	22%	31%	45%	2%	100%

Table 11 - Instructions before using ACC and Risk Awareness towards ACC Cross-tabulation

2 Questionnaire: Perception of ACC

2.3.5 APPRECIATION OF ACC

In Table 12 the appreciation of ACC for different types of roads, and for the highway, for different traffic conditions are shown. This appreciation is measured by a scale of 1 to 5, where 1 is 'totally not pleasant', and 5 is 'totally pleasant'.

Range of ACC		ACC Active at All Speeds	ACC Inactive below approx. 50 kmh
How pleasant is ACC to use on …?	urban roads	3,0	2,8
	rural roads	4,1	4,1
	expressways	4,5	4,3
	highways	4,5	4,4
How pleasant is ACC to use under …?	quiet traffic conditions	4,4	4,6
	average traffic conditions	4,4	4,4
	heavy traffic conditions	3,6	3,4
	congested traffic conditions	3,9	2,9

Table 12 - Average score for Types of Roads and Traffic Conditions for ACC Active and Inactive below 50 kph. Scale 1-5

Overall users do think ACC is more pleasant to use for every road type when it is active at low speeds. But the difference is not that large. Visible is that appreciation of ACC on urban and rural roads is low, even for ACC systems which are active at all speeds. This means that even when users have an ACC system that is active at low speeds, e.g. suitable for urban roads, they still do not like ACC very much on these urban roads. This indicates that ACC is a system that is more preferred for roads with uniform traffic movements, like highways and expressways, but less for rural roads. The higher the speeds, the more ACC is appreciated.

The situation on the highways is separated per type of traffic condition in the lower four rows of Table 12. Visible is that ACC is appreciated most in quiet traffic conditions. The denser the traffic, the lower the appreciation of ACC. For quiet traffic conditions, only a small difference is found in appreciation between systems that are active at all speeds and systems which are not. This makes sense, since the two different systems act the same at higher speeds. It stands out that the difference between the two systems is large for congested conditions on the highway. An 'All Active' ACC is much more appreciated, while ACC with a lower limit is less appreciated for heavy traffic conditions and congestion.

Basically this indicates that indeed a system which is active at lower speeds is an enhancement compared to a system which is not active at lower speeds, but this is mainly for congested conditions on highways. For lower level roads like rural or urban roads, ACC is, regardless of its type, less fitted.

Also respondents had to indicate which rating they gave to their ACC system overall. This rating is a value between 1 and 10, where 1 is 'extremely negative', and 10 is 'extremely positive'. On average they scored ACC with an 8,03. This means that most of the respondents use ACC satisfactory.

In Table 13, the rating of ACC sorted out to different characteristics of the system is shown. ACC is better appreciated when an adjustable headway is present, and when it is active at lower speeds. Users grade ACC higher when the car is owned or leased by themselves, compared to when it is someone else's car. This will be because those who own or lease a car will have opted for ACC themselves.

2 Questionnaire: Perception of ACC

		Average Rating of ACC	Std. Deviation	N
Range of ACC	ACC Active at All Speeds	8,5	1,23	79
	ACC Inactive below approx. 50 kmh	7,9	1,42	86
	Unknown	6,7	2,31	21
Adjustable headway	No	5,5	2,61	6
	Yes	8,1	1,45	176
	Unknown	7,1	1,44	4
Owner of car with ACC	Car Owned by Self	8,0	1,66	117
	Car Owned by Relative or Acquaintance	7,9	1,43	6
	Rental or Shared Car	8,5		1
	Lease Car	8,1	1,43	60
	Other	8,3	0,35	2
Usage of car with ACC	Private Use	8,1	1,53	79
	Both Private and Business Use	8,5	0,76	11
	Business Use	8,0	1,66	96
Total		8,03	1,57	186

Table 13 - Rating of ACC sorted out to different Respondents Characteristics. Scale 1-10

Several other, scaled, parameters are present which can be prepared to the rating given to ACC. These are shown in Table 14.

Variable			Spearman Correlation	Sig. (2-tailed)
Driving Style Questions	How would you describe your driving style?	Fast - Slow	-0,04	0,562
		Careless - Careful	0,19	0,010
		Intolerant - Tolerant	0,14	0,052
		Decisive - Indecisive	-0,22	0,002
	How often is your headway so small you can't brake in time in case of an emergency?		0,23	0,002
	How often do you drive faster than permitted?		0,09	0,201
	How often do you receive a penalty for a traffic violation?		-0,03	0,735
	How often do you feel annoyed by other road users?		0,20	0,008
	How often do you undertake secondary activities while driving?		0,01	0,863
Driving experience with ACC (months)			0,25	0,001
Driving experience with ACC (KM/week)			0,06	0,423
Did you receive any instructions before usage of ACC?			0,34	0,000
Are you aware of the risks regarding usage of ACC?			0,18	0,013

Table 14 - Correlation of the Rating of ACC with Different Questionnaire Questions. Red: not significant. Yellow: significant at the 0,05 level. Green: significant at the 0,01 level

2 Questionnaire: Perception of ACC

In terms of driving style, several things stand out. ACC is appreciated by drivers which think of themselves as careful and decisive. They tend to have a larger headway, and they do not feel annoyed by other road users. For all other driving style questions, no correlation with the appreciation of ACC is found.

A correlation exists between the rating for ACC and the amount of time users have ACC in their car. This means that people have to get used to the system to appreciate it. This is in line with conclusions made earlier, where it turned out that users just start to use ACC, without taking any instructions. People teach themselves how to use ACC, and the more they get used to it, the more they appreciate it. No relation however is found between the appreciation of ACC and the amount of kilometers driven per week with the car with ACC. This indicates that appreciation of ACC comes with experience, but the time that passes is more important than the amount of kilometers driven.

Finally, it turns out that the way of preparation before using ACC has a positive influence on the appreciation. A strong, significantly positive correlation is visible between the amount of instructions users got before using ACC and their overall appreciation of the system. This means that the system works better and more convenient when drivers use it well-prepared. Awareness of the risks however does barely influence the appreciation of ACC: this statement is only loosely correlated with the appreciation of ACC.

2.3.6 Driving Task

After the part of the questionnaire which handles about user- car- and ACC-characteristics, several questions about three main topics are asked. These topics are driving task, safety and traffic flows. In this paragraph the driving task will be discussed, and in the following paragraphs safety and flows.

In Table 15 the results of the three statements about the driving task are shown. The average score, which is a number between 1 and 7, is shown, and also the correlation of the response of that statement with the overall rating respondents gave to ACC. This last parameter gives insight in the way the outcome of the statement influences the appreciation of ACC by users.

Variable	Average score (on 1-7 scale)	Correlation with ACC Rating	
		Spearman Correlation	Sig. (2-tailed)
"With ACC activated, car driving takes me less effort"	5,5	0,54	0,000
"With ACC activated, I don't need to watch traffic as much"	3,0	0,05	0,501
"With ACC activated, I undertake more secondary activities while driving"	2,3	0,04	0,626
"I prefer an ACC system that only warns instead of actively interfering"	2,2	-0,43	0,000

Table 15 - Questionnaire Questions regarding Driving Task: Average Score and Correlation with Rating of ACC. Red: not significant. Green: significant at the 0,01 level

Respondents massively agree with the statement that ACC relieves the driving task. The significant correlation with the appreciation of ACC shows that ACC is indeed appreciated because of that. This is one of the reasons users buy ACC. But does this lead to a decrease of the attention level or an increase of the amount of secondary activities? The average score of this question, which is much lower as the previous question, indicates that respondents do not agree with this statement. And respondents even more disagree with the statement that more secondary activities are motivated.

But, when taking a closer look to these last two statements, it turns out that not everyone agrees on this subject. When looking at the mutual correlations between the different statements about correlations as represented in Table 16, it stands out that users tend to be wise: car driving results in a relief of the driving task, but this decrease only leads to a

much smaller extent to a decrease of their attention level. The Spearman Correlation is significant, but it has only a value of 0,189. Besides, the correlation between the decrease of the driving task and the amount of secondary activities isn't even significant. But the respondents who indicate that they do not have to watch traffic so much when ACC is activated, do indicate that they undertake more secondary activities as well. The correlation between these two statements is very strong, 0,52, and significant as well.

		"With ACC activated, I don't need to watch traffic as much"	"With ACC activated, I undertake more secondary activities while driving"
"With ACC activated, car driving takes me less effort"	Spearman Correlation	0,189	0,064
	Sig. (2-tailed)	0,008	0,374
"With ACC activated, I don't need to watch traffic as much"	Spearman Correlation		0,524
	Sig. (2-tailed)		0,000
Did you receive any instructions before usage of ACC?	Spearman Correlation	-0,185	-0,222
	Sig. (2-tailed)	0,009	0,002
Are you aware of the risks regarding usage of ACC?	Spearman Correlation	-0,255	-0,264
	Sig. (2-tailed)	0,000	0,000

Table 16 - Mutual Correlations of Driving Task Statements. Red: not significant. Green: significant at the 0,01 level

In summary can be indicated that the largest part of the ACC users indicate that they do like ACC because it relieves their driving task. For a small group of people this leads to a decrease of attention level. This group of users uses ACC to perform more secondary activities. This is even more clearly visible in the distribution of the answers on the questions about the loss of attention due to ACC and the amount of secondary activities, which are shown in Figure 13. Visible is that both the answer graphs do not show a normal distribution, but have an increase on the right side of the spectrum. These are the respondents which indeed indicate that they use ACC to relax in the car and execute more secondary activities. The strong mutual correlation states that the respondents which agreed on the statement "With ACC activated, I don't need to watch traffic as much", also agreed on the statement "With ACC activated, I undertake more secondary activities while driving". Both the loss of attention level and the increase of secondary activities is definitely a potential risk.

Preparation before using ACC and awareness of the risks are key to prevent this behavior. In Table 16 the correlation with the two statements about losing attention and performing secondary tasks, are related with the questions about preparation and risk awareness. All four correlations are significant and negative. This means that the respondents who did prepare before using ACC and who are aware of the risks of ACC, indicate that they do not lose attention and do not perform secondary activities. This shows how preparation is important for safe use of ACC.

A question about the functionality of Adaptive Cruise Control was asked: "I prefer an ACC system that only warns instead of actively interfering". This was meant to investigate whether users like it to relinquish the task of braking or coasting behind another car. Then namely, is a system which only warns instead of actively interfering preferable. But respondents are very clear about this: they do like the active system as they use it. One respondent even indicated that he does not like the bleeps he hears every time he activates ACC. The system must be operating autonomously.

2 Questionnaire: Perception of ACC

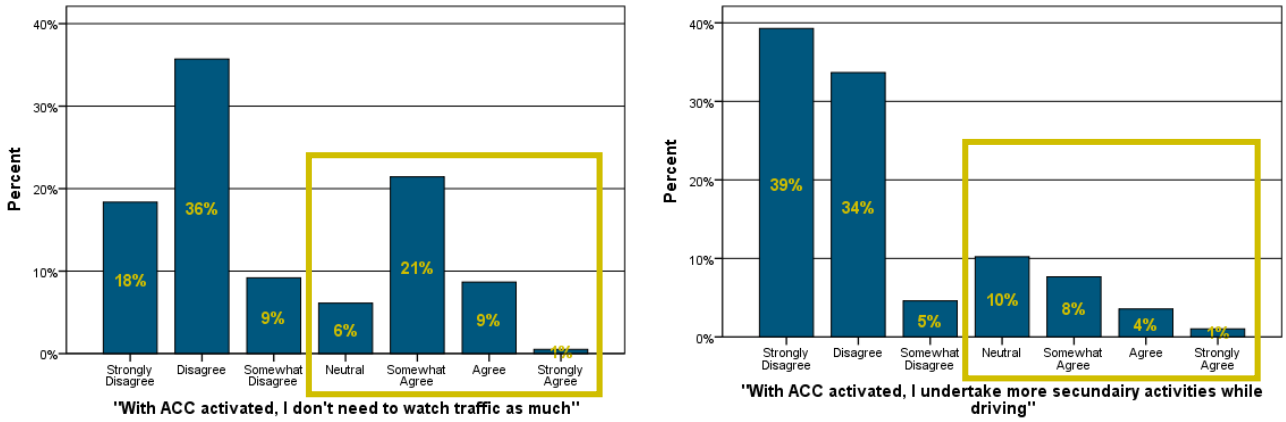


Figure 13 - Responses to Questionnaire questions regarding Driving Task

2.3.7 SAFETY

The part of the questionnaire that handles about safety is a large part. Five statements are shown and six questions after specific situations that happen when ACC is activated. In Table 17 the outcomes of the questions are stated. Also here the average score is shown, and the correlation between the outcome of the statement and the rating of ACC respondents gave.

Visible is that safety is definitely an important issue for the users of the system: all statements are significantly correlated with the rating users gave to ACC.

Variable	Average score (on 1-7 scale)	Correlation with ACC Rating	
		Spearman Correlation	Sig. (2-tailed)
"With ACC activated, my risk of a head-tail collision reduces"	5,6	0,45	,000
"With ACC activated, I less often end up in dangerous situations"	4,9	0,48	,000
"With ACC activated, I less often drive faster than permitted"	5,1	0,26	,000
"With ACC activated, I need more time to intervene (by braking or steering) when necessary"	2,9	-0,23	,001
How often does the car brake hard because another car inserts between you and your predecessor?	3,3	-0,22	,003
How often does ACC lose sight on your predecessor in a steep curve, which results in an unexpected acceleration?	2,6	-0,22	,002
How often does ACC suddenly deactivate itself when you are not expecting that?	1,6	-0,34	,000
How often does ACC suddenly brake or accelerate when you are not expecting that?	2,1	-0,35	,000

Table 17 - Questionnaire Questions regarding Safety: Average Score (Scale 1-7) and Correlation with Rating of ACC. Green: significant at the 0,01 level

2 Questionnaire: Perception of ACC

Users are very sure that ACC helps them prevent head-tail collisions. They strongly agree with that statement. Also the correlation with the appreciation of ACC is strongly positive. This means that respondents who agree with this statement, also appreciate ACC more. The same pattern is visible with the more general statement: “With ACC activated, I less often end up in dangerous situation”. The correlation of this statement with the ACC appreciation is strongly positive. Despite that, respondents do not agree that strongly with this statement. The opinion is slightly more skeptical about this one. This means that, despite ACC helping to prevent head-tail collisions, other safety risks are not eliminated according to the drivers.

The usage of Adaptive Cruise Control has a positive influence on the amount of speeding. This effect is also visible with the common Cruise Control. Users activate the system and very deliberately set the speed. This speed is often based on the speed limit. When driving manually, users do not so deliberately focus on the applicable speed limit, and they are more vulnerable for speeding.

Adaptive Cruise Control has a negative influence on the reaction time of the driver. When ACC is activated, the foot of the driver is often not on the accelerator anymore. Besides, his driving task decreases, so when something urgent happens, the driver needs more time to take back control over the vehicle. He has to put his foot on the accelerator or the brake pedal again and he has to assess the situation. This takes time. But it stands out that the respondents of the questionnaire do not agree with this. On average, the statement "With ACC activated, I need more time to intervene (by braking or steering) when necessary" is disagreed upon. This can mean two things basically. Users overestimate their driving skills and they think their reaction time is the same but in fact it is not, or they really stay alert in such a way despite the relief of the driving task the ACC gives, and when something happens, they really are ready to take action.

A complaint often heard about Adaptive Cruise Control is that the headway is too large. That will be further elaborated in the following paragraph. But this has another side effect, which has a negative influence on traffic safety. When the ACC-equipped car drives behind another car with a large headway, other drivers, which are on another driving lane, take advantage of the situation, and merge in front of the ACC-vehicle. This results in hard braking, because the ACC-radar suddenly detects a much smaller headway. This means that the ACC-vehicle brakes strongly. This could cause head-tail collisions and shockwaves. Also the occupants of the car with ACC get the impression that their car moves backwards in traffic. Everyone is overtaking them and merging in front of them. Whether this happens often is checked in the questionnaire. And indeed, when asked if this happens often, participants indicate that this happens quite often. The respondents who strongly agree with this statement, are more negative about ACC in general, which can be concluded based on the significantly negative correlation between these two.

Another safety hazard is a steep curve, where the ACC-radar looses sight on the predecessor. This results in an acceleration of the car, which is dangerous because of the steep curve and the predecessor. This is something that is known to be a risk. This means that drivers, if they are a little bit prepared, can avoid this. But the respondents still indicate that this is happening now and then. This is a safety risk, but also an even stronger indication that preparation is necessary to learn to use Adaptive Cruise Control correctly.

When the last three questions are answered with ‘often’, this indicates that respondents have troubles using and understanding the system. Can this be solved by preparation? That can be found out by investigating the correlations between these three statements and the amount of preparation respondents gained when using ACC. This is done in Table 18. Visible is that a negative relation exists between the amount of preparation and the awareness of the risks on the one hand and how often ACC suddenly deactivates, brakes or accelerates on the other side.

2 Questionnaire: Perception of ACC

		Did you receive any instructions before usage of ACC?	Are you aware of the risks regarding usage of ACC?
How often does ACC lose sight on your predecessor in a steep curve, which results in an unexpected acceleration?	Spearman Correlation	0,005	-0,079
	Sig. (2-tailed)	0,944	0,273
How often does ACC suddenly deactivate itself when you are not expecting that?	Spearman Correlation	-0,106	-0,063
	Sig. (2-tailed)	0,139	0,380
How often does ACC suddenly brake or accelerate when you are not expecting that?	Spearman Correlation	-0,165	-0,148
	Sig. (2-tailed)	0,021	0,039

Table 18 - Correlation of the Preparation and Risk Awareness with Questions regarding Safety. Red: not significant. Yellow: significant at the 0,05 level. Green: significant at the 0,01 level

2.3.8 Traffic Flow

The final part of this research handles the questions about traffic flows. Four key elements are important when assessing the influence of ACC on flows: headways, speeds, positions on the highway and amount of lane changes. All of them are discussed in the questionnaire.

The average results, again on a 1 to 7 scale, are shown in Table 19, as well as the correlation of the outcomes of these statements with the appreciation of ACC in general.

Variable	Average score (on 1-7 scale)	Correlation with ACC Rating	
		Spearman Correlation	Sig. (2-tailed)
"With ACC activated, I drive more steadily and smoothly"	5,3	0,50	,000
"With ACC activated, my average headway increases"	5,6	0,18	,016
"With ACC activated, I perform less lane changes"	4,6	0,31	,000
"With ACC activated, I more often drive on the right lane"	4,0	0,16	,031
How often do you manually decrease the headway maintained by ACC?	2,9	-0,27	,000
How often do you throttle up to overtake another car because your car would otherwise slow down behind that car?	3,6	-0,26	,000

Table 19 - Questionnaire Questions regarding Traffic Flows: Average Score (Scale 1-7) and Correlation with Rating of ACC. Yellow: significant at the 0,05 level. Green: significant at the 0,01 level

In the previous section unexpected braking was an issue, because of other drivers merging in front of the car with ACC. Despite that, drivers tend to think that ACC leads to more constant driving. On average they agree with the statement that they drive more steadily and smoothly with ACC activated. The reason for this will be that the speeds are more constant, and also the headway is more stable. The car always keeps a steady headway to the predecessor, in contrary to a manual driver. This obviously has a positive influence on the traffic flows on the highways. Users like this quality of ACC: a significantly positive correlation is present with the score they give to ACC. This means that the respondents who agree to this statement, also rate ACC higher.

2 Questionnaire: Perception of ACC

Besides this positive influence, a very clear influence is present as well, which is negative for traffic flows. This is the increase of the headway. Respondents are unanimous about this. Respondents are aware that ACC increases headways. But expectations are that respondents who agree to this statement, will also be more negative about ACC. This is not the case. Only a weak correlation exists between the two, and the correlation is positive. This means that respondents know that the headway increases, but this does not influence their opinion about ACC negatively. This indicates that they are willing to accept this characteristic of ACC, because its advantages outweigh this disadvantage. This is even further emphasized by another question about headway. This question is: How often do you manually decrease the headway maintained by ACC? Respondents on average do not do this often. This means that they know the headway is large, they also know that other drivers will merge in front of them, and despite that, they do not reduce the headway by pressing the accelerator. This indicates that they really rely on ACC to accelerate and brake for them, and they are not willing to do that by themselves. They prefer to accept ACCs large headways instead of compensating them by actively take over driving. The same pattern is visible at the following question: How often do you throttle up to overtake another car because your car would otherwise slow down behind that car? This is done quite frequently overall, and the respondents who do this the most, are also more negative about ACC in general.

A small group does often decrease the headway, and this influences their appreciation of ACC. This is visible in the correlation between this question and the score they give to ACC. This correlation is significantly negative. This means that a group of respondents is present who does not accept the large headways, and this makes them uncomfortable with ACC.

Then finally, there is the amount of lane changes and the position on the highways. According to the position on the highway: opinions differ about this statement. On the right side of Figure 14 the scatter of the answers is visible. A group is present which indicates that they drive more on the left side. This will most likely be because of the large headway. When they are driving on a left lane and they detect a gap on the right lane, they are more likely to decide not to merge into that gap. When they do, their car will directly respond by braking as a reaction on the predecessor. Therefore these ACC-drivers will decide to stay in the left lane. This will lead to a decrease of the amount of lane changes. The other group which indicates that they drive more on the right side, will have other reasons for that. They tend to show more car-following behavior: they decide to stay behind another vehicle instead of overtaking it. This will lead to a decrease of lane changes. And indeed, when looking at the perception of respondents towards the amount of lane changes, it stands out that overall the opinion is that ACC leads to less lane changes. This is either because drivers tend to drive more on the left lane because of the large gap, or drivers tend to show more car-following behavior.

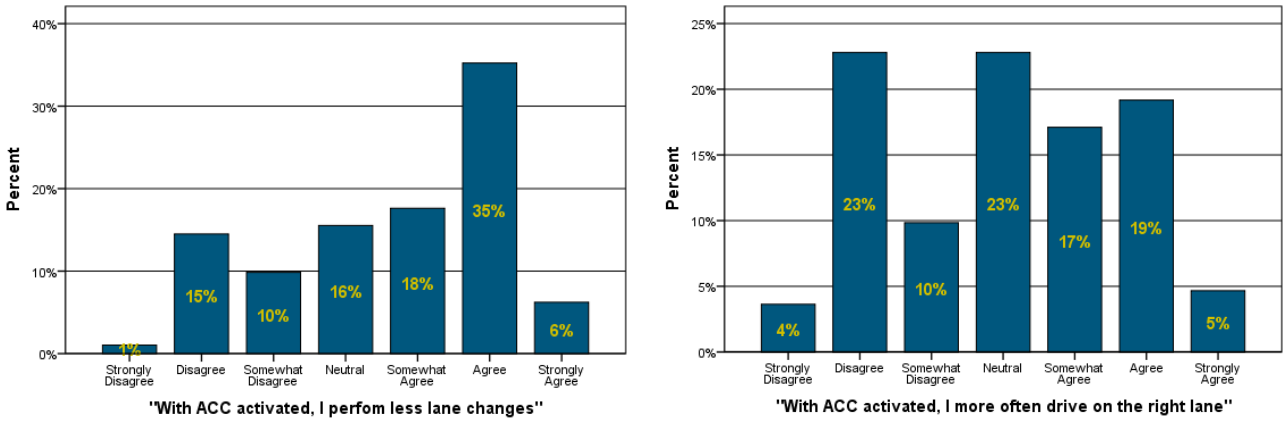


Figure 14 - Responses to Questionnaire questions regarding Position and Lane Changes

2 Questionnaire: Perception of ACC

2.4 Conclusions and Discussion

In this paragraph a wrap-up of this chapter will be done. First all conclusions that can be made will be shown, and then a paragraph containing discussion will be presented.

2.4.1 Conclusions

The research question answered in this chapter is: 'What are driver's experiences with ACC?' This research question is answered with help of a questionnaire, distributed amongst 200 car drivers with relevant ACC experience and a reference group of 25 respondents. The questionnaire provided the following conclusions about ACC driver's characteristics, experiences and preferences.

ACC users tend to be older, male, drivers, with a lot of driving experience. The cars they are driving are mainly Volvo's, Toyota's and Volkswagens. Also BMW, Peugeot and Audi-drivers are present.

They consider themselves 'fast' drivers compared to non-ACC users, which is underlined by their tendency to drive too fast, perform secondary tasks while driving, and receive more penalties for traffic violations. They are however tolerant drivers, which keep larger distances to their predecessors while driving.

Relatively many drivers have only a short period of using ACC. This is because it is installed more on modern cars. Roughly two third of the respondents of the test owns the car, and one third leases the car.

Approximately 50% of all drivers receives some sort of instruction before using ACC. This percentage is higher for the users who own or lease the car themselves: drivers who get in touch with ACC in someone else's car, are less likely to get some instruction before ACC-usage. Those drivers which indicate that they were prepared before using ACC, indeed say that they are more aware of the risks. A smaller group is present, approximately a fifth of all users, which tells that they did not get any instructions. Of that group, almost everyone indicates that they, despite the lack of preparation, do know what the risks of using ACC are. This can mean two different things: either they overestimate their own knowledge of the system, or they have learnt to use ACC and handle with the risks of it by practice. Either way, this means a safety risk. Users which overestimate themselves are undoubtedly a risk, but users who only learn by practice might also be a risk because the system can behave in an unforeseen way, because the users do not know what exactly can happen when using ACC. About the necessity of instruction before using ACC is wide consensus in literature: several sources (*Bianchi Piccinini et al., 2015*, *Beggiato & Krems, 2013*, *Dickie & Boyle, 2009; Larsson, 2012*, *Larsson et al., 2014*, *Weinberger et al., 2001*) indicate that instructions are necessary to ensure safe usage.

ACC is preferred on the highway. Even ACC systems which are active at lower speeds, so which could be applied on urban or rural roads, are not that much appreciated on these roads. This is because traffic on these lower level roads is much more chaotic, with other road users on bikes, walking or driving in all possible directions. On the highway, only other vehicles that all drive in the same direction with approximately the same speed are present. ACC-users overall are positive about ACC-usage on the highway, especially at higher speeds. In congested situations, an ACC-system which a full speed range is much more appreciated than a system which deactivates below a certain speed.

Overall, users are much more positive about these ACC-systems which are active at all speeds, compared with systems with a lower limit. Overall, users rate their ACC-system with an 8,03 out of 10 points.

A correlation exists between the rating users give with certain driving style characteristics. Drivers which consider themselves more decisive and careful appreciate ACC more. Also the drivers which themselves tend to have a larger headway are more positive about ACC. Driving styles influence the appreciation and usage of ACC according to several sources: *van Twuijver & Pol, 2004*, *Viti et al., 2008* and *Xiong et al., 2012* conclude this.

The longer drivers use ACC, the more they appreciate it. This is in line with the conclusions made about preparation: Not every user prepares so well before using ACC. This means that it takes time before they understand the system

2 Questionnaire: Perception of ACC

correctly, and know how to use it. Besides, users which are prepared to a certain extent, are also more positive. This means that the best way to use the system wisely is to be prepared. Otherwise, understanding takes time.

Adaptive Cruise Control is designed to make driving more comfortable and less tiresome. Indeed, users do think ACC relieves the driving task. The largest part of the users indicate that this does not lead to a reduction of attention levels and an increase of secondary activities. However, around 30% of the participants agrees on the statement that when ACC is activated, they do not have to watch traffic as much, and this group also performs more secondary activities when driving. This will have a negative impact on traffic safety. This group of “unwise” drivers, also indicates that they did not or barely receive instructions before using ACC.

Respondents are convinced ACC leads to less head-tail collisions. This leads to them stating that the overall safety increases. However, the influence of ACC on traffic safety in general is not unanimously agreed to be positive: unforeseen braking might in fact be negative for safety, some respondents indicate. This is in line with the questionnaire executed by *van Twuijver & Pol, 2004*, which has the same outcome.

Respondents are unanimously sure about speeding: ACC leads to less speeding. This is because drivers are much more aware of the maximum allowed speeds when using ACC; they tune their ACC settings to it. Also several other sources indicate this (*Alkim et al., 2007*, *van Twuijver & Pol, 2004*, *Vollrath et al., 2011*).

Overall, ACC works like drivers expect it. Some drivers indicate that sometimes ACC deactivates or brakes when they are not expecting it, but this is a minority. And again, a (weak) correlation is found between the drivers who indicate ACC behaves not as expected, and the way these users are prepared to use it.

ACC leads to more steady and smooth driving behavior, respondents indicate. This is observed by *Alkim et al., 2007*, *Marsden et al., 2001* and *van Twuijver & Pol, 2004* as well. This is because it overall brakes evenly and maintains a very constant speed. Despite that advantage for traffic flows, the headway is definitely higher. This means less vehicles fit on the road, which leads to lower capacities. Users agree on this, but this does not lead to lower ACC ratings. This means users are willing to accept this drawback. Also most drivers do not manually decrease the headway.

No consensus can be given about the position on the highway. Some drivers indicate they more drive on the right side of the road, because they show more car-following behavior, and decide to stay behind another vehicle instead of overtaking it, or they use ACC more preferably when densities are low. With lower densities, more driving on the right lane is possible. This is indicated by different literature sources as well (*Strand et al., 2011*, *van Twuijver & Pol, 2004*). Some drivers however indicate to drive more on the left side, because with ACC activated a very large gap on the right lane is necessary to merge to that lane. When drivers merge in a small gap, the ACC will lead to braking. This is in line with the conclusions of *Rudin-Brown & Parker, 2004* and *Alkim et al., 2007*.

Respondents say ACC leads to less lane changes. This will be because ACC leads to more car-following behavior.

2 Questionnaire: Perception of ACC

2.4.2 DISCUSSION

A questionnaire provides insight in how users of Adaptive Cruise Control experience it, and what they like about the system. Interpretation of a questionnaire needs to be done very carefully.

The respondents are approached via social media, but mainly via the news article and the newsletter of the ANWB. This means that the population of the respondents is not randomly picked. For example: it turns out that the average respondent of this questionnaire is a male, with a lot of driving experience, somewhere between 50 and 60 years old. Does this mean that the average ACC-user has these characteristics or is it the average reader of the ANWB-newsletter that can be described using these characteristics? Probably the answer is somewhere in the middle, but where exactly is unknown. Overall, the population of the questionnaire was quite wide spread, so the results will be reliable to some extent.

This research gives, to some extent, insight in what will happen when everyone or a large part of the drivers will have ACC installed in their cars. But the results of this questionnaire must be interpreted carefully: the users of Adaptive Cruise Control at the moment are not average car drivers. They own new, relatively expensive cars, and they have more driving experience than average. This means that the results of this questionnaire cannot be projected on the whole car-driving population.

Furthermore there is the sample size. 200 valid responses were used in the analysis. But with the comparison of the driving style of ACC-users and non-ACC-users, the group non-ACC-users was only 25 respondents. This means these results have to be interpreted carefully.

It is impossible to get a proper image of someone's driving style when asking only 9 questions. Both the Driver Style Questionnaire and the Learning to Drive Questionnaire consist of much more questions. Therefore the interpretation of the answers to these questions has to be prudent.

A questionnaire gives insight in the opinions and preferences of users. But it only shows what users think. This information is subjective. What users say might well be something different from what users actually do. For example the questions about the risks of ACC-driving: a part of the respondents might give socially accepted answers here. It is only barely accepted that people use the system without knowing the risks. Therefore reality might even be more pessimistic, compared to what respondents say.

3 FIELD OPERATION TEST: USE OF ACC

3 Field Operation Test: Use of ACC

3.1 INTRODUCTION

The third sub-question of this research is: How is ACC used in practice? Basically two options are available to answer this question. A driving simulator test can be carried out, or a Field Operation Test. For this research, it is important that the data collected is as close to the real situation on the Dutch roads as possible. Previous research (*Knapper et al., 2015*) indicates that data collected in a simulator study can significantly differ from practice. Furthermore a simulator will not provide that much data to really analyze statistically relevant differences between using and not using ACC. An advantage however of a simulator study is that the driving environment is fully controllable. This makes it very suitable for analyzing certain traffic situations, like for example merging or diverging traffic. But a lot of reports are already available of studies of this type using driving simulators[2]. The purpose of this study is not to look for specific situations occurring on the roads, but to analyze behavior of (the user of) ACC in general, and to investigate if any trends are visible which might influence traffic flows and/or safety. Therefore a Field Operation Test (FOT) is more suitable.

This field operation test consists of eight cars driven by Royal HaskoningDHV employees, equipped with ACC. These cars are leased by these employees, and they are using the system for a while already, when the test conducted. This means that the drivers have had the opportunity to get used to ACC. The Field Test is designed in such a way that equipment is installed in the cars, and then the car is returned to the driver. The test does not require action of the drivers; they only have to use their car like they always do. In this way, a clear view of the usage of ACC is gained. The behavior of the participants will be highly naturalistic.

This research solely focuses on highways. This is because ACC is mostly fitted to be used on the highways. This can be concluded based on the conclusions of the questionnaire in chapter 2.

This chapter first contains a paragraph ‘Research Method’, containing information about the data necessary to collect, information about the participants of this test, the materials needed to collect the data, and the way the data is preparated to use in the analysis.

Then a ‘Results’-paragraph is shown, containing all results from the analysis. This chapter ends with a paragraph containing the conclusion and a discussion about the results and the way of data collection.

[2] *Beggiato & Krems, 2013*, *Bianchi Piccinini et al., 2014*, *Hoedemaeker & Brookhuis, 1998*, and many more…

3 Field Operation Test: Use of ACC

3.2 Research Method

3.2.1 Necessary data

The database of this field test consists of several driver-, car- and traffic characteristics for every second that is analyzed. This means that the analyzed trips provide all these different characteristics for every moment during that trip.

The following data is collected for every moment that is analyzed:

- Adaptive Cruise Control Settings (On or Stand-by/off)
- Car characteristics
    - Speed
    - Spacing
    - Location on highway
    - Lane changes
- External factors
    - Time of day
    - Weather conditions

Together these parameters will provide enough data to perform this analysis.

3.2.2 Participants

When designing this field test, first is determined how large the group of participants must be to gain a significant database. A few factors are important when choosing the correct amount:

- Several different participants must be used to incorporate variety in driver characteristics, such as type of trips that are made, driving style and so on;
    - Estimated is that approximately six participants in this field test are at least necessary
- Per participant enough data must be collected to gain a significantly large database;
    - Three or four weeks of data collection is at least necessary
- The amount of time necessary for data collection and data preparation must be fitted in the schedule for this graduation project;
    - Four weeks data collection per driver is acceptable to analyze in the given time frame
- Enough ACC-users must be willing to participate in this test. It is very important that all participants are enthusiastic about the project, since a bit of flexibility and willingness is asked from them;
    - As much potential participants are approached, and the most willing and enthusiastic ones of them are selected to be part of the test
- Some kind of buffer must be present for unforeseen problems. The amount of participants must be larger than the absolute minimum according to the other factors, to create room for drawbacks in data collection or data preparation.
    - One or two drivers more than the minimum amount are necessary to anticipate on unforeseen problems

Based on these criteria, chosen is to perform the test with eight participants. These participants are divided in two phases. The first four participants have taken part in the test for approximately four or five weeks, and then the equipment is removed from their cars and installed in the cars of the participants of phase two of the test.

The participants are Royal HaskoningDHV employees. This is done because this group is easy to reach, because they are likely to be enthusiastic about the project, and they have confidence in the quality of the project.

3 Field Operation Test: Use of ACC

Data with ACC on and off must be collected. Therefore when reading the camera images, investigation is necessary whether a good equilibrium between footage with ACC on and with ACC off is present. When it turns out that a participant (almost) always has ACC activated, he will be asked after three weeks if he can stop using ACC. Then reference data will be collected, which makes a comparison possible between the situation on the road with and without ACC.

At the beginning of the test, the whole procedure, including an explanation of the materials used, is made clear to the drivers, so that it becomes very clear what is expected from them. Also a user manual is handed out. This manual contains all information the drivers need to know before participating in the test. This user manual is included in Appendix 4 of this report.

3.2.3 EQUIPMENT

To execute the Field Operation Test, some equipment is necessary. This will be described in this paragraph.

The eight cars which are used are equipped with two cameras and a data logger. The two cameras have to be distinct so that they are invisible for the driver, and they have to be strong and steady so that they stick to their place and work correctly. The data logger has to be small and should under no circumstances make changes to the performance of the car.

The devices that are selected to be used are shown in Figure 15. The data logger is the CarChip Pro, which is an OBD2 logger. This logger is installed in the OBD2 plug in the cars. This plug is situated somewhere around the driver seat and is directly connected to the CAN network of the car, where all engine parameters are managed and recorded. This CarChip Pro device is able to record the speed of the car during the trip. Based on the change of speed also the acceleration can be computed.

Figure 15 - FOT Equipment: CarChip Pro OBD2 Data Logger and Ambarella Mini 0801 Dashcam

Besides information about the speed and acceleration, it is crucial to know whether ACC is activated or not. It is hardly possible to record this parameter, the status of ACC, via the motor management of the car. Even more complicating is that cars of different brands and types are used for the FOT. Therefore is decided to determine the ACC status in another way: by installing a dashboard-camera (see Figure 15) in the car facing the dashboard of the car. Here an LCD-screen is situated which shows the status of ACC. With help of this camera can be determined what the status of ACC is. This enables the viewer in an easy way to determine whether ACC is active or not. This camera is installed in such a way that the driver does not get hindered by it in any way, and still has clear sight on his dashboard.

3 Field Operation Test: Use of ACC

Also information on spacing, location on highway and lane changes is necessary. Therefore another dash cam is installed in the car. It is installed behind the windscreen and the rear view mirror. The location of the camera facing the dashboard and the one behind the windscreen are shown in Figure 16.

Figure 16 - Locations dash cams on dashboard (left) and behind windscreen (right)

The camera used for filming both the dashboard and the road, is an Ambarella Mini 0801, shown in Figure 15. This is a very small camera: 7x4x4cm, on a small base of 3x3x2cm, which blends in in a very distinct way in the car. Of course the camera is installed in such a way that the actions and attention of the driver are not hindered. Both dash cams are connected to a power supply in the car. The cameras are programmed in such a way that these activate when the car is started, and automatically deactivate when the car shuts down at the end of a trip. So activating and deactivating the cameras does not require action of the participant, all equipment works automatically.

The view of the two installed cameras is shown in Figure 17. Visible is that the dashboard is clearly visible, and on this dashboard the green icon indicates ACC is activated. By the camera behind the windscreen, a wide-angle view on the highway is provided.

Figure 17 - Camera stills dash cams on dashboard (left) and behind windscreen (right)

The Field Operation Test is preceded by a test period, where all equipment is tested in one vehicle. After testing is done, the FOT itself is executed.

3 Field Operation Test: Use of ACC

3.2.4 Data Preparation

To distract the necessary information from the dash cam images and the OBD2-logger, a methodology has to be designed.

The OBD2-logger requires special software. This software reads the data saved on the logger. The data designed as a table with times and corresponding speeds, can be exported to Microsoft Excel.

The dash cam camera images are synchronized to this database, and the ACC-settings which can be read from these images, are linked to the Excel-file from the logger. Also the windscreen camera is synched, and from the images of this camera, the spacing, the position on the highway and the lane changes are read. These data are also combined with the times in the Excel file. This results in one excel file per made trip, with all necessary data for every second of that trip.

The recorded parameters, with the units and the values these parameters can get in the database, are shown in Table 20.

Parameter	Unit	Possible Values
ACC Settings	-	On Stand-by/Off
Speed	kmh	-
Acceleration	Kmh per sec	-
Spacing	m	1 = >50m 2 = 40-50m 3 = 30-40m 4 = 20-30m 5 = 15-20m 6 = 10-15m 7 = 5-10m 8 = 0-5m
Headway	s	-
Location on highway	-	1 = Right Lane … 6 = Left Lane
Lane changes	-	Lane Change to Left Lane Change to Right
Traffic Conditions		Free Flow Conditions Capacity Conditions Congested Conditions

Table 20 - Recorded Parameters with Units and Possible Values

The Adaptive Cruise Control settings are recorded with three different options: on, stand-by and off. For the analysis only active and inactive are relevant. Therefore in the analysis, off and stand-by are combined, resulting in ACC having two options: on and stand-by/off.

The speed of the car is measured in kilometers per hour (kph). The acceleration is defined as the change of speed, with an interval of one second. This means that the unit of acceleration is kph per second, or kph/s.

To determine the spacing, an overlay is projected over the dash cam images. After installing the dash cam in the car, the car is parked in an area with at least 50m of space in front of the car. Then, using measuring equipment and pylons, the distances 5m, 10m, 15m, 20m, 30m, 40m and 50m from the front end of the car are determined. These distances are

3 Field Operation Test: Use of ACC

recorded on camera. With help of the camera images of these pylons placed on different lengths, an overlay is made which is digitally added to the camera images of the car driving on the road. With this overlay it is possible to measure the spacing to the predecessor with an accuracy of between 5 and 10 meters, depending on the distance and the clearness of the camera footage. The line scheme with the pylons is shown in Figure 18, and a still of the camera images with added overlay is shown in Figure 19.

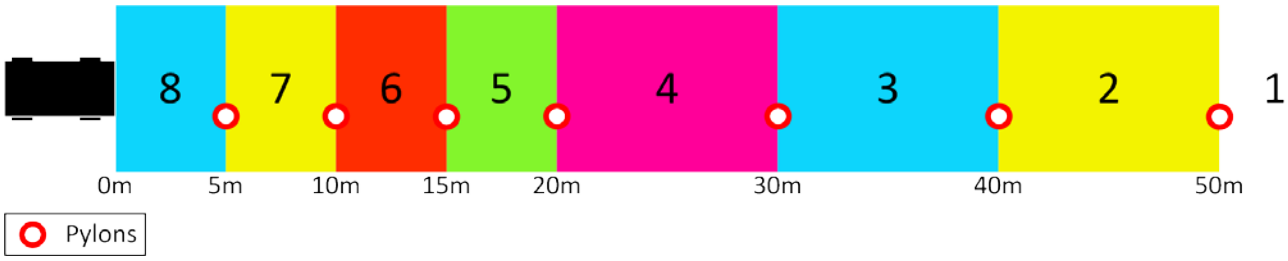


Figure 18 - Line scheme used to determine spacing

Figure 19 - Dashcam image with added overlay

To assess the influence of ACC on the capacity on the roads, headway is an even more important variable than spacing. Therefore this spacing needs to be converted to headway as well. This can be done using the following formula:

$$h = \frac{s}{\frac{v}{3,6}} = \frac{3,6 \times s}{v},$$

h = headway (s), s = spacing (m), v = speed (kmh).

3 Field Operation Test: Use of ACC

The spacing however, is only known with an accuracy of 5 or 10 meters, because it is measured in intervals. Therefore for each interval, the average spacing is determined, and this average spacing is used in the formula. This means for example that when on a certain moment the predecessor of the car is in area 6, which means that he is between 10 and 15 meters away, the average value with which the headway is measured, is 12,5m. When looking on a very small scale this conversion method is not precise enough, but when calculating the average over a very large database, this method is expected to lead to accurate headways. Spacing area 1 means that a car is more than 50 meters away. In practice this either means that no car is driving in front of the ACC-equipped car, or the distance in time and space between the two cars is so large, that no interaction between the two cars exists. This means that this area, of which it is impossible to calculate the average spacing since no upper boundary exists, can be removed from the analysis when calculating the headway. This means that the headways presented in the results of this research, are headways when a vehicle is driving less than 50 meters in front of the car. The really tranquil moments, when no other vehicle drives in front of the car, are not incorporated in this research. This can be done, since these tranquil moments are not in any way critical when assessing the traffic flows.

This headway can be used to assess the influence of ACC on the road capacity. The difference in headway between ACC activated and ACC not activated indicates how ACC influences headways. But since the lengths of the vehicles are not included in the calculation, it is impossible to directly convert the calculated headways to capacities in vehicles per hour. Therefore, based on the calculations regarding headways, the influence of ACC on the road capacity can only be calculated in an indicative way.

The dataset containing the headways contains outliers. These are shown in the box-plot on the left side of Figure 20. These outliers occur at very low speeds. Because the speed is so low, the headway in seconds can become extremely large, and when the speed is 0 kph, the headway is even infinite. Therefore the outliers are removed by deleting their entries from the database, resulting in a new box-plot, shown on the right side of Figure 20.

In the box-plot, the upper quartile, the lower quartile and the median are shown. These are the upper and lower boundary of the blue box, and the horizontal line in the blue box. Outliers are defined as values that are higher than the upper quartile plus 1,5 times the inter-quartile range, where the inter-quartile range is the size of the blue box, so the difference between the upper quartile and the lower quartile.

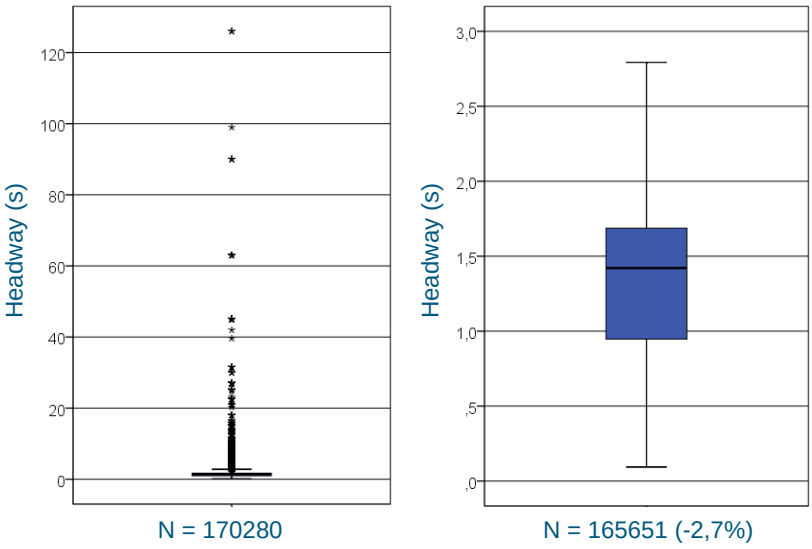


Figure 20 - Box-plots of the Headway, with and without outliers

3 Field Operation Test: Use of ACC

The location on the highway is measured by numbering all lanes: the most right lane is numbered 1, one lane to the left is numbered 2, and so on. The 'Lane Changes'-parameter has two options: Lane change to the right and Lane change to the left.

Also a methodology to determine Traffic Conditions in a quantitative way is designed. To do this, several parameters are available, for example speed, headway, and so on. But to avoid circular reasoning, the headway cannot be used. In the Results paragraph, the relation between ACC usage and the headway is researched. Therefore a framework based on the speed of the car is determined. In Figure 21 is visible that three different classes of density are formulated, purely based on average speed.

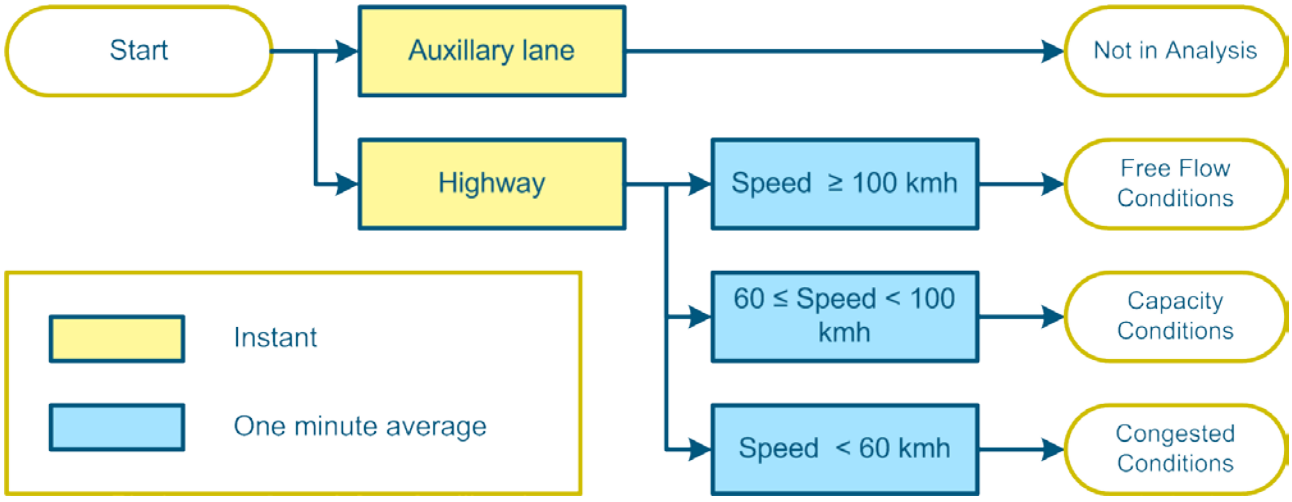


Figure 21 - Framework for determination density classes

3 Field Operation Test: Use of ACC

3.3 RESULTS

3.3.1 PARTICIPANTS

It is important that the participants of the field test are representative for the ACC-driver in general. The eight different participants all have their own driving characteristics. These are described in Table 21 and Table 22.

Gender	**7x Male**		**1x Female**	
Age	1x 40-49 Years	6x 50-59 Years	1x 60+ Years	
Driving Experience	1x 10-19 Years		7x 20+ Years	
KMs driven per year	3x 20.000-30.000 KM/year	1x 30.000-40.000 KM/year	4x 40.000+ KM/year	
Car Usage	1x Business		7x Private + Business	
Driving experience with ACC	6x 3-6 months	1x 6-12 months	1x 24+ months	
Driving experience with ACC	4x 400-600 KM/week		4x 600-800 KM/week	
Car Brand	4x Volvo	2x Peugeot	1x Skoda	1x BMW
Transmission	3x Manual		5x Automatic	
Lower Limit	4x Yes		4x No	

Table 21 - Driver and Car Characteristics (1)

Visible is that seven male and one female test subjects are present. In this research, individual drivers will be indicated with 'he', but this does not mean the driver must be male, since also a female driver is present. This is done to guarantee privacy for the participants. Also visible is that all drivers can be called experienced drivers. They have at least 10 years of driving experience, often more. And they drive a large amount of kilometers per year.

A difference with the population found for the questionnaire is that the participants in the field test all use their car for business. This is reasonable, since they are all lease drivers. Expectations are that this has no influence on ACC-usage. It does however have influence on the times and the days of week of usage of the car. It makes sense that business-used cars drive more on weekdays and during peak hours. This proves to be useful, since the peak hours on weekdays are critical in terms of traffic flows. If ACC can have an influence on traffic flows, it will especially be these moments that that influence will make a difference.

All drivers have gained a few months experience with Adaptive Cruise Control. They use their car with ACC at least for three months, and the amount of driven kilometers per week is large. This is very important: from this can be concluded that all drivers are more or less experienced ACC-drivers. This is a large difference with a lot of (driving simulator) tests executed in the past, where no experienced drivers were tested. In this field test, the results show the behavior of people who have gained experience in ACC use. Therefore the results will be more representative for average ACC-usage in reality.

Four different car brands are represented in the test. For both the Peugeot and the Volvo both cars with manual and automatic gearboxes are present. Only on the Volvo that influences the range of the ACC: the car with automatic gearbox has an ACC-system which is active until lower speeds. Of the BMW and the Skoda only one car is available.

What can be said about the preferences of the drivers towards Adaptive Cruise Control? That is shown in Table 22. Visible is that all drivers except one deliberately chose Adaptive Cruise Control or at least some kind of package ACC is

3 Field Operation Test: Use of ACC

part of. Almost without exception they think they are extensively aware of the risks regarding using ACC. They partly have taught themselves, since not all received instructions before using ACC. This shows the same pattern that was visible in the results of the questionnaire. It stands out that one driver did not choose ACC, but did receive instructions. But despite his received instructions, he indicates that he is not fully aware of the risks. It is possible that he still has to get used to ACC, since he does not use it often, but often chooses to leave the system inactivated. The fact that all drivers are to some extent aware of the risks, is related to the amount of experience they have with Adaptive Cruise Control. From the questionnaire, it stood out that the largest part of the drivers teaches themselves how to use ACC. They are barely instructed beforehand, but they learn by experience. The same is the case with the participants in the field test.

Did you choose ACC deliberately as an option?	**5x Deliberate Choice of ACC**				**2x Deliberate Choice of Package including ACC**			**1x No Deliberate Choice**
Did you receive any instructions before usage of ACC?	2x No		3x Yes, Slightly		2x Yes, Extensively			1x Unknown
Are you aware of the risks regarding usage of ACC?	2x Yes, Slightly				6x Yes, Extensively			
Rating of ACC (value between 1 and 10)	6,5	7	7	7,5	8	8,5	9	9,5
Would you recommend ACC to others?	2x Neutral				3x Agree			3x Strongly Agree

Table 22 - Driver and Car Characteristics (2)

The rating of ACC is quite positive for all drivers. A few really high marks are present. These drivers use ACC where possible. Also some lower marks are given, by drivers who are slightly more skeptical about ACC. They use it and they like it, but they are aware of the shortcomings of the system.

Overall, the eight different drivers who participated in the field test, represent a variety of different drivers, all with their own characteristics, preferences, car brands and ACC-systems.

In Table 23, the amount of trips recorded is shown. Visible is that the total recorded length is almost 48 hours, two natural days. These hours are correctly synchronized, usable hours of highway driving. These days are distributed over the eight drivers, some drivers having almost eight hours, and some less than three hours. This is dependent on different factors. Some drivers drive a large amount of kilometers per week, others less. Also the performance of the equipment was critical here: the cameras did not work flawlessly all the time.

Strived is to analyze more than six hours per participant. Two of the drivers did not collect that much data, but for all the others, even more data was collected than analyzed in the end. For these drivers, the analyzed data is chosen from the total database of collected data. Three factors were critical when selecting the data to be analyzed:

- The collected data must be complete (thus OBD2- Dash camera- and Windscreen camera-data present)
- Driving times with ACC activated and not activated must be approximately equally distributed
- Every trip takes a certain amount of time to manually synchronize the three different data sources. Therefore longer trips are preferred over shorter trips. This makes data preparation easier, and thus more data can be analyzed.

Overall, several remarks can be made for the drivers. Driver 4 and 8 did not provide that much data, so all available data is analyzed for these drivers. Drivers 2 and 6 did not use ACC all the time, but only used it now and then. Therefore it was impossible to reach the amount of 50% ACC-activated driving data. Therefore the ACC-usage here is only 19%.

3 Field Operation Test: Use of ACC

Drivers 1, 2, 5 and 7 did provide a lot of data, and all used ACC a lot. Therefore these drivers are asked after a few weeks of data collection to not use their ACC-system for two weeks. This provided reference data. Then the trips to be analyzed were selected in such a way that in the end the ACC-usage turned out to be between 50 and 75%.

Driver	Amount of Trips	Total Recorded Length	Length of Trip			ACC Usage (%)
			Mean	Minimum	Maximum	
1	36	7:47:24	0:12:59	0:03:11	0:54:25	59%*
2	10	6:35:00	0:39:30	0:06:23	0:57:32	59%*
3	15	6:57:45	0:27:51	0:07:03	1:09:21	19%**
4	5	2:43:25	0:32:41	0:09:29	1:40:16	92%
5	9	7:11:33	0:47:57	0:29:22	1:25:23	71%*
6	13	6:55:21	0:31:57	0:04:31	1:00:37	19%**
7	9	7:01:03	0:46:47	0:03:47	1:19:37	65%*
8	11	2:30:31	0:13:41	0:02:54	0:32:39	50%
Total	108	47:42:02	0:26:30	0:02:54	1:40:16	54%

*** ACC Usage not representative since users are asked to deactivate the system for a couple of trips**

**** ACC Usage barely representative since analyzed trips are not randomly selected from collected database**

Table 23 - Amount and length of trips collected per participant

The data is collected between 24 January and 24 April 2015. In Table 24 the days of the week on which the trips are collected are shown. Visible is that almost all trips are collected on weekdays. In Figure 22 the time of day is shown, and it turns out that most trips are recorded in the peak hours. This is in line with the information the participants gave themselves: they mainly use their ACC-equipped car for business purposes.

Day	Amount of Trips	Percentage
Monday	16	15%
Tuesday	16	15%
Wednesday	23	21%
Thursday	27	25%
Friday	15	14%
Saturday	4	4%
Sunday	7	6%
Total	**108**	**100%**

Table 24 - Collected Trips per day of Week

3 Field Operation Test: Use of ACC

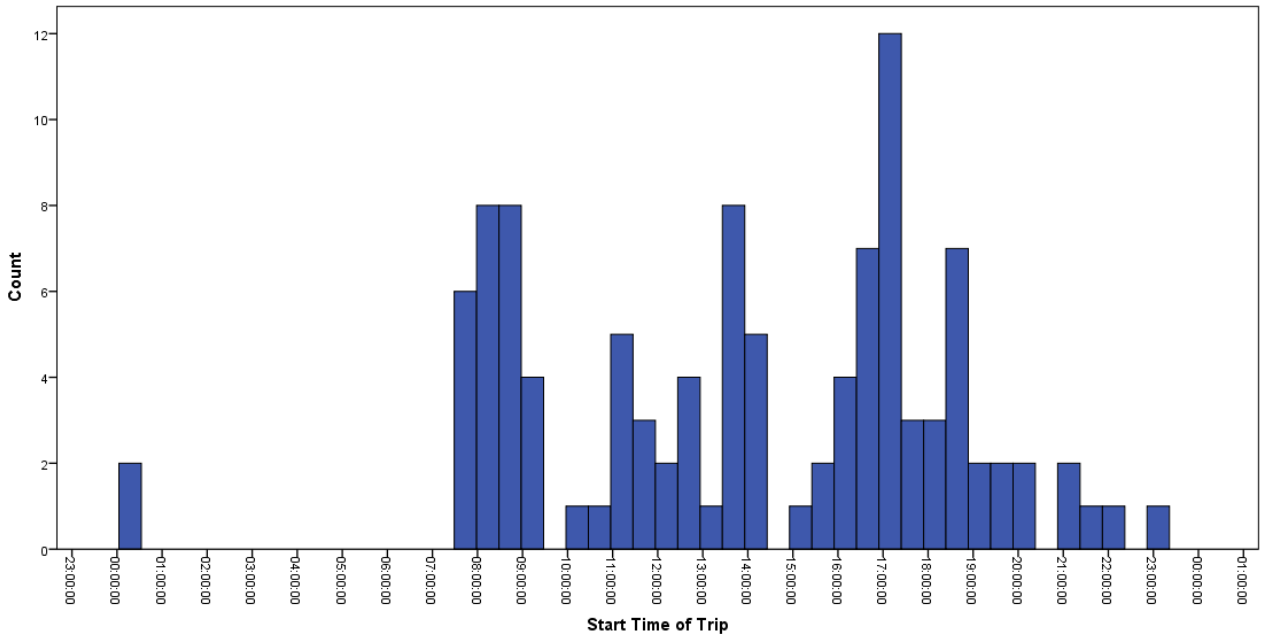


Figure 22 - Collected Trips per Start Time

In Table 25 the total amount of analyzed data is shown per driver, traffic conditions and ACC setting. In the table is visible how much data is collected for every situation. A few entries in this table show that for certain circumstances less than 5 minutes of data is collected. These entries are marked red. These 5 minutes are considered to be too less to do a valid analysis. Therefore these entries are not taken into account in the research done in the following paragraphs.

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Total
Free Flow Conditions	Off / Stand-By	2:38:55	1:38:37	3:37:00	0:02:16	1:11:19	3:23:42	1:18:55	0:43:06	14:33:50
	On	3:57:38	3:37:37	1:06:23	1:56:24	3:19:10	0:53:03	3:24:14	0:45:37	19:00:06
	Total	6:36:33	5:16:14	4:43:23	1:58:40	4:30:29	4:16:45	4:43:09	1:28:43	9:33:56
Capacity Conditions	Off / Stand-By	0:21:15	0:30:51	1:06:42	0:02:15	0:32:20	1:11:36	0:34:59	0:18:18	4:38:16
	On	0:38:00	0:16:52	0:11:59	0:33:49	1:07:22	0:27:51	0:59:53	0:24:12	4:39:58
	Total	0:59:15	0:47:43	1:18:41	0:36:04	1:39:42	1:39:27	1:34:52	0:42:30	9:18:14
Congested Conditions	Off / Stand-By	0:11:36	0:31:07	0:55:47	0:08:12	0:19:42	0:59:10	0:33:05	0:14:04	3:52:43
	On	0:00:04	0:00:00	0:00:00	0:00:30	0:41:40	0:00:00	0:10:06	0:05:14	0:57:34
	Total	0:11:40	0:31:07	0:55:47	0:08:42	1:01:22	0:59:10	0:43:11	0:19:18	4:50:17
Total	Off / Stand-By	3:11:46	2:40:35	5:39:29	0:12:43	2:03:21	5:34:28	2:26:59	1:15:28	23:04:49
	On	4:35:42	3:54:29	1:18:22	2:30:43	5:08:12	1:20:54	4:34:13	1:15:03	0:37:38
	Total	7:47:28	6:35:04	6:57:51	2:43:26	7:11:33	6:55:22	7:01:12	2:30:31	23:42:27

Table 25 - Amount of Collected Data per Driver and Traffic Conditions

3 Field Operation Test: Use of ACC

The set-up of this table will be used in the analysis into headway, speed, position and lane changes as well. This is because only the total column and row are not very reliable sources for an analysis. The outcome of the analysis is strongly dependent on the size of all datasets corresponding with the entries in this table. Therefore the results of the analysis in the following paragraphs will be showed in detail: for every driver and every traffic condition the comparison will be made between the situations with ACC activated and deactivated.

3.3.2 Headway and Spacing

Based on literature as well as on the outcome of the questionnaire, can be stated that the average headway increases when users activate Adaptive Cruise Control. This is very important, because the average headway directly influences the capacity on the roads. The headway is one of the most important parameters when investigating traffic flows. Especially when ACC is implemented widely, the influence of an increase or decrease in headway might influence traffic flows heavily.

The headway is calculated based on the spacing and the speed of the car. This is described in the preceding paragraph. In this analysis only the moments where the spacing is smaller than 50m are taken into account. Also the outliers are removed, which can occur at very low speeds.

In Table 26, the average headway with and without Adaptive Cruise Control activated are shown. The headways are divided per driver and per traffic condition. Visible is that large differences exist between drivers and driving styles. For example, driver 1 and 5 on average have a much smaller headway than drivers 2 and 3, for all traffic conditions.

Also in Table 26 the change of average headway is shown for every combination of driver and traffic conditions. Visible is that for every driver and almost every traffic condition the headway increases. When the total database is combined, the increase of average headway for free flow conditions is 16,7%, for capacity conditions it is 25,8%, and for congested conditions, it is even 40,1%. For all drivers individually the same pattern occurs. Only for driver 2 driving under capacity conditions the headway decreases, but for all other drivers the headway increases with at least 5%.

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off / Stand-By	0,79	1,16	1,15	-	0,81	1,04	0,97	0,98	0,99
	On	0,94	1,27	1,26	1,00	0,87	1,29	1,27	1,14	1,13
	Change	19%	10%	9%	-	7%	24%	31%	16%	16,7%
Capacity Conditions	Off / Stand-By	0,68	1,14	1,41	-	0,70	0,97	1,11	0,84	0,98
	On	0,95	1,07	1,48	1,13	0,89	1,38	1,46	1,19	1,19
	Change	39%	-6%	5%	-	27%	42%	31%	42%	25,8%
Congested Conditions	Off / Stand-By	1,41	2,68	3,82	3,37	2,69	1,88	3,11	1,89	2,61
	On	-	-	-	-	2,88	-	5,68	2,47	3,68
	Change	-	-	-	-	7%	-	83%	31%	40,1%

Table 26 - Average Headway in sec. per Driver and Traffic Condition

To provide more insight in the difference in headway for different traffic conditions, the frequencies of the different headways of driver 5 for all three traffic conditions are shown in Figure 23. Visible is that headways are equally spread, but that overall the headway without ACC activated shorter is than when ACC is activated.

3 Field Operation Test: Use of ACC

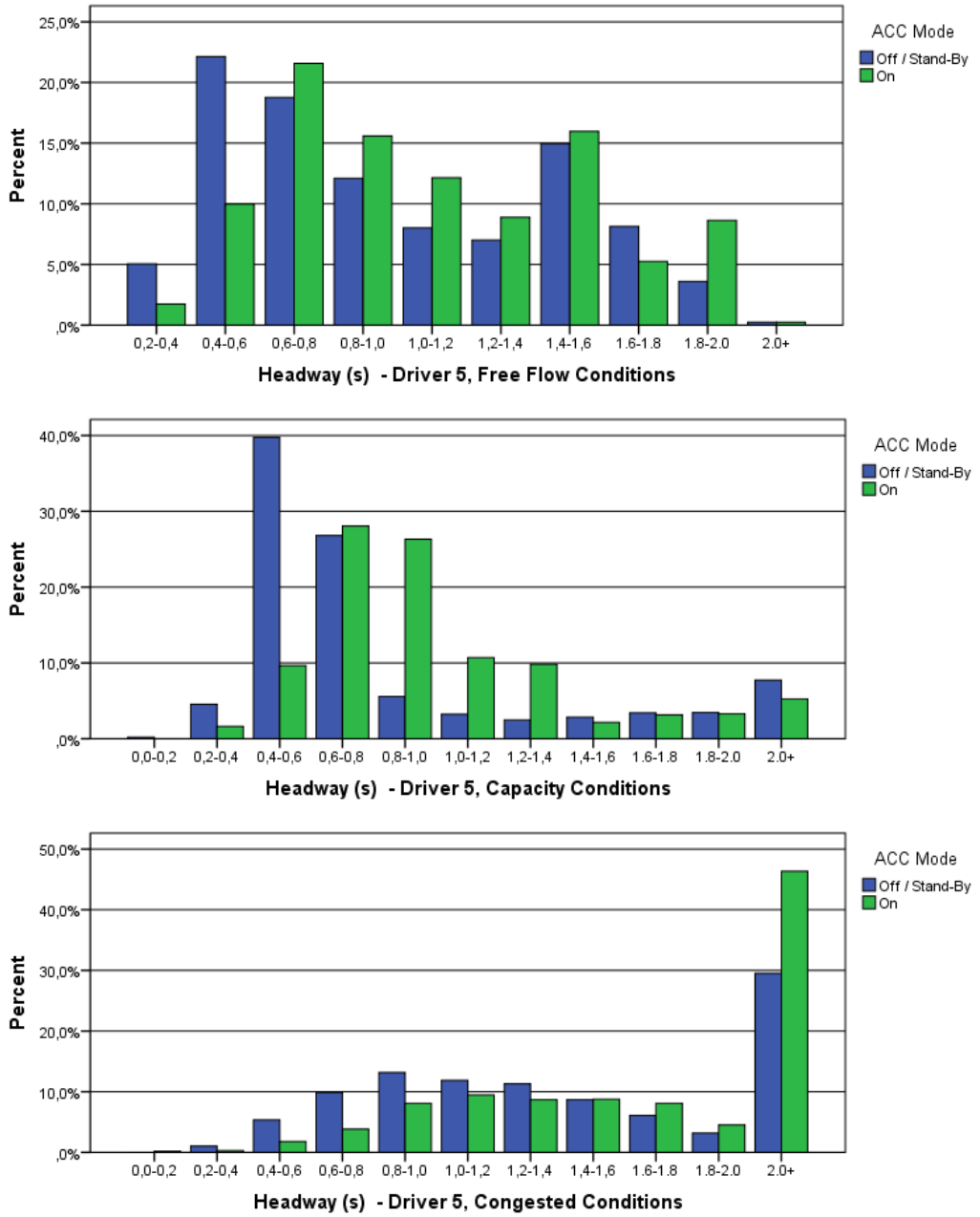


Figure 23 - Frequencies of Headway of Driver 5 for Different Traffic Conditions

In Table 26 is visible that in congested conditions the average headways for different drivers vary a lot. This is because the headway is dependent on the speed, because headway is spacing divided by speed. But this formula will lead to very high headways at lower speeds. The spacing is divided by a small speed, leading to a large headway. Therefore at lower speeds the spacing itself is a variable which is worth to be taken into account. In Table 27, exactly the same data as in Table 26 is shown, but here the spacing variable is shown instead of the headway.

3 Field Operation Test: Use of ACC

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off / Stand-By	26,3	34,6	35,2	-	25,5	31,7	30,6	29,5	30,5
	On	30,0	37,1	38,3	32,4	26,8	39,5	39,6	34,5	34,8
	Change	14%	7%	9%	-	5%	25%	29%	17%	15,1%
Capacity Conditions	Off / Stand-By	16,7	28,2	32,6	-	16,9	22,5	25,6	19,2	23,1
	On	23,6	29,0	36,8	27,9	21,6	35,3	36,4	27,3	29,7
	Change	41%	3%	13%	-	28%	57%	42%	42%	32,2%
Congested Conditions	Off / Stand-By	11,1	11,6	21,6	10,7	8,4	12,1	15,8	13,3	13,1
	On	-	-	-	-	10,7	-	17,0	15,5	14,4
	Change	-	-	-	-	27%	-	7%	16%	16,8%

Table 27 - Average Spacing in sec. per Driver and Traffic Condition

Visible is that the average spacing decreases with higher speeds. This is in line with the fundamental diagram, which states that as long as traffic gets busier and busier, the speeds drop and the densities increase.

The spacing shows exactly the same pattern as the headway. Especially at higher speeds, the percentages of the differences in spacing between ACC-on and ACC-off are almost the same. At lower speeds, the spacing shows a more stable pattern: the extreme outlier of driver 7 is now reduced a bit. But the conclusion stays the same: Adaptive Cruise Control leads to an increase of highways.

To gain a capacity of the road, it is necessary that traffic is as stable as possible. When intensities on the road get higher and higher, the chance that congestion occurs becomes larger. When intensities are high, only a very small disturbance in traffic can cause a tipping point, and immediate congestion. Therefore traffic stability is an important goal to strive for.

These small disturbances can be caused by a single braking action. One car breaks lightly, the driver behind this car brakes slightly harder, the car behind that one brakes even harder, and a few cars later traffic comes to a full stop. Therefore braking behavior is very important: cars have to break smoothly and approximately as hard as the predecessor. Braking behavior is analyzed in the next paragraph, but the headway can be used as well to indicate the robustness of traffic in terms of braking. When a car brakes or accelerates in dense traffic, best is that the car follows his predecessor as constant as possible. An indicator that gives insight in the following behavior is the standard deviation of the headway. The smaller the standard deviation, the more constant the headway. And a very constant headway indicates following behavior which improves traffic stability. When the standard deviation is high, indicating that the headway varies a lot, this shows that a car often comes very close to his predecessor, or rather leaves a wide gap.

In Table 28 the standard deviation of the headways is shown, and in Table 29 the standard deviation of the spacing. Both are separated per driver and traffic condition.

3 Field Operation Test: Use of ACC

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off / Stand-By	0,36	0,29	0,30	-	0,35	0,34	0,28	0,35	0,32
	On	0,27	0,28	0,28	0,27	0,28	0,22	0,25	0,27	0,27
	Change	-23%	-6%	-8%	-	-20%	-36%	-12%	-21%	-17,9%
Capacity Conditions	Off / Stand-By	0,37	0,38	0,48	-	0,36	0,43	0,36	0,43	0,40
	On	0,34	0,24	0,35	0,22	0,31	0,19	0,33	0,37	0,29
	Change	-7%	-36%	-27%	-	-14%	-55%	-8%	-15%	-23,3%
Congested Conditions	Off / Stand-By	2,25	3,40	4,56	5,17	4,42	2,74	5,48	3,88	3,99
	On	-	-	-	-	3,73	-	13,14	4,54	7,14
	Change	-	-	-	-	-16%	-	140%	17%	47,1%

Table 28 - Standard Deviation of the Headway in sec. per Driver and Traffic Condition

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off / Stand-By	12,2	9,1	9,4	-	11,1	10,2	9,1	10,4	10,2
	On	9,4	8,2	7,6	8,4	9,1	6,8	7,4	8,5	8,2
	Change	-23%	-11%	-20%	-	-18%	-33%	-18%	-18%	-20,2%
Capacity Conditions	Off / Stand-By	9,2	10,2	10,0	-	8,2	10,1	7,9	10,3	9,4
	On	8,5	6,7	8,5	5,9	7,7	5,1	7,7	8,5	7,3
	Change	-8%	-35%	-15%	-	-6%	-50%	-2%	-18%	-18,9%
Congested Conditions	Off / Stand-By	6,5	7,4	11,3	6,0	7,1	6,6	9,7	8,6	7,9
	On	-	-	-	-	4,9	-	10,3	7,7	7,6
	Change	-	-	-	-	-31%	-	6%	-11%	-12,2%

Table 29 - Standard Deviation of the Spacing in sec. per Driver and Traffic Condition

In the “average”-columns of these tables is visible that overall, independent of the ACC setting, the scatter of the headway increases when speeds get lower. The scatter in congested conditions is larger than in capacity conditions, which is larger than in free flow conditions. The spacing does not show that pattern. There the scatter is more or less constant for all traffic conditions. This is because at lower speeds, a small change in speed will have a large influence on headways. The spacing is less dependent on speed, so this fluctuates less.

The standard deviation, and thus the scatter, of both the headway and the spacing decrease undoubtly in free flow- and capacity conditions when ACC is activated, compared to when it is not activated. The largest decrease in scatter is visible for the capacity conditions. This makes sense. In free flow conditions ACC often functions as a normal cruise control, and now and then the ACC coasts or brakes to anticipate on another driver. In capacity conditions however, much more car-following behavior will be detected, because always another car is present in front whose speed is adapted.

The effect of Adaptive Cruise Control on spacing variations is clearly visible in Figure 24. In one trip, this driver both drove with and without ACC activated. The upper graph shows the speed and spacing without ACC are shown, and in the lower graph with ACC. Keep in mind that the higher the spacing number, the smaller the spacing. Spacing phase 7 means a spacing of 5-10 meter, and phase 1 means a spacing of more than 50 meter. Visible is that the speed in both

3 Field Operation Test: Use of ACC

situations is quite constant, which indicates densities which are not very high. But in the upper graph, the spacing varies a lot. When approaching another car without ACC, the driver chooses to decrease the speed only slightly when driving manually. This means that the spacing decreases. When the predecessor accelerates or changes lanes, the spacing increases again and the car accelerates. When ACC is activated, the car breaks earlier. This means that the spacing does not become so small, and the speed decreases more and stronger. Then when the predecessor accelerates or leaves, the speed of the car also increases.

Figure 24 - Speed, Position on the Highway and Spacing Class for one driver and trip, without ACC activated (Upper) and with ACC Activated (Lower)

Overall ACC leads to earlier and more constant braking. This leads to larger, but also to more constant headways. Especially in congested situations, this can have a very positive effect on the amount and strength of disturbances, and thus on traffic stability.

In congested situations, the spacing again gives a more reliable image than the headway. Also here the variation of headways and spacings decreases. This means that cars drive more constantly through congestion.

3 Field Operation Test: Use of ACC

3.3.3 SPEEDS

The speed and acceleration of a car is one of the most important parameters when analyzing a vehicles performance and effect on traffic flows and safety. Therefore it is necessary to investigate this parameter thoroughly.

The acceleration pattern of a vehicle can be represented graphically. This is done by determining the acceleration of a car on every second, and then make a histogram where all accelerations and decelerations are shown, and how often they will occur. This histogram will have a coned shape, with a peak in the middle, where the acceleration is 0. This is because most of the time a car will drive at a more or less constant speed, and then the acceleration is (almost) 0. On both sides of the cone, the lines of the histogram will near the horizontal axis, since very strong decelerations and very strong accelerations will not often take place.

This histogram contains a lot of information. A determination can be made what the ideal shape of this cone-shaped figure is. This ideal pattern is shown in Figure 25. Three areas in this histogram are important. They are numbered 1 to 3 in the figure. These three areas will be discussed.

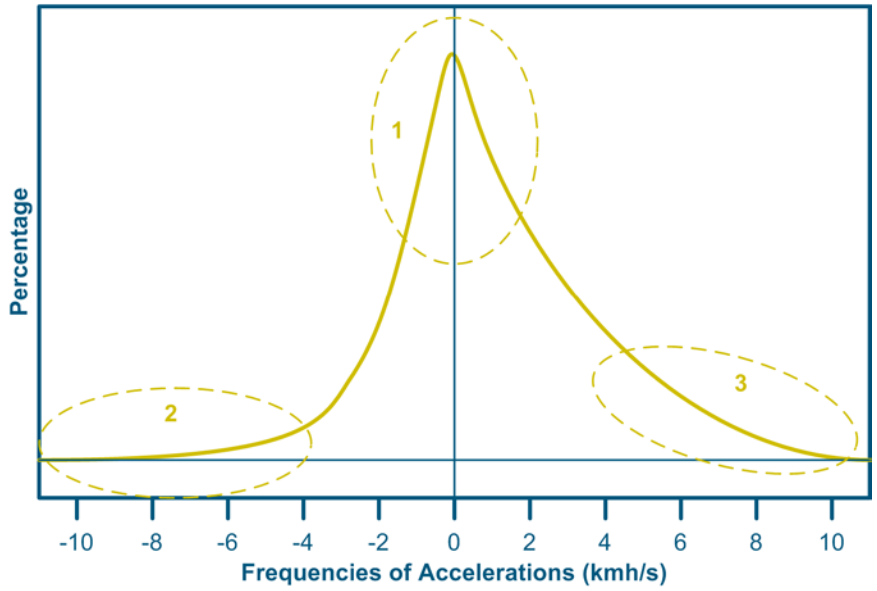


Figure 25 - Ideal Pattern of 'Frequencies of Accelerations' figure

First of all the peak of the accelerations shown with the number 1, must be as steep as possible. That means that an acceleration of 0 kph/s (e.g. maintaining the same speed) occurs the most. This indicates a constant speed. The steeper and higher the peak the better, since speeds will be as homogeneous as possible. Speed variations (especially decelerations) must be prevented as much as possible to prevent snowball-effects which decrease the traffic flows. Therefore the influence of ACC on speed variations influences the flow. Besides the influence on the flows, a huge influence on safety exists as well. Front end collisions with the car behind the ACC-car must be prevented as much as possible.

Secondly the amount of strong decelerations must be as small as possible. This is indicated with area 2. Strong decelerations are unsafe, since the risks on a head-tail collision increase. Also in terms of traffic flows strong braking actions are negative, because they cause and increase shockwaves.

3 Field Operation Test: Use of ACC

And at last, area 3 must be as large as possible, since that area represents the strong accelerations. These are important, especially when moving out of congested situations. Then it is necessary to accelerate as fast as possible, since then the congestion dissolves as soon as possible.

Visible is that the ideal histogram shape is a shape with a small left size, a sharp peak and a larger right size. Several variables are present which can quantitatively indicate whether this ideal shape is reached. First there is the standard deviation of the accelerations. The smaller the standard deviation, the smaller the scatter of accelerations, and the steeper the peak of the histogram. Also there is the skewness. The ideal histogram shape is asymmetrical, with more space on the right than on the left. This is indicated with a positive skewness value.

In Table 30 the standard deviations of the speed are shown. Visible is that in almost all cases the speed varies less. In free flow conditions this makes sense, since ACC, just like Cruise Control, maintains a constant speed. But in capacity- and congested situations this is remarkable, since in these conditions the speed of the car is not dependent of the preferences of the driver, but of the speed of the predecessor. This table shows that the gain in stability is even higher in capacity conditions than it is in free flow conditions! Vehicles with ACC drive more smooth and steady, even in car-following behavior. This means that Adaptive Cruise Control not only prevents shockwaves, but is also able to resolve them. A car without ACC drives with a lot of speed variations, and the car with ACC which is driving behind that car, shows fewer variations and thus he resolves potential instabilities caused by predecessors.

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off/Stand-By	1,06	0,71	1,04	-	1,19	0,67	1,08	0,72	0,90
	On	0,88	0,57	0,86	1,15	1,05	0,6	0,94	0,71	0,85
	Change	-17%	-20%	-17%	-	-12%	-10%	-13%	-1%	-12,9%
Capacity Conditions	Off/Stand-By	2,32	1,33	1,44	-	2,11	1,56	1,68	1,91	1,76
	On	1,33	0,93	0,89	1,09	2,06	0,77	1,22	1,25	1,19
	Change	-43%	-30%	-38%	-	-2%	-50%	-27%	-34%	-32,0%
Congested Conditions	Off/Stand-By	2,56	2,10	2,34	2,06	1,83	2,46	2,18	3,38	2,36
	On	-	-	-	-	1,92	-	2,77	2,37	2,35
	Change	-	-	-	-	5%	-	27%	-30%	-0,7%

Table 30 - Standard Deviation of the Accelerations per Driver and Traffic Condition

In congested conditions the outcome is slightly more spread. The average change in standard deviation of accelerations stays approximately the same when ACC is active, compared to when it is not.

In Table 31 the skewness is shown of the histogram of acc- and decelerations with and without Adaptive Cruise Control. For free flow conditions, the skewness increases for six drivers, and for one driver it decreases. For one driver not enough data is collected to show reliable results. In capacity conditions, three drivers show an increase in skewness, and two drivers show a very small decrease. For two drivers a larger decrease in skewness is measured. This shows a very mixed outcome. Also in congested situations, results are mixed: one driver gives a large increase, two drivers a large decrease. This shows that overall a lot of spreading in the results exists. Therefore it is necessary to address these histograms in more detail.

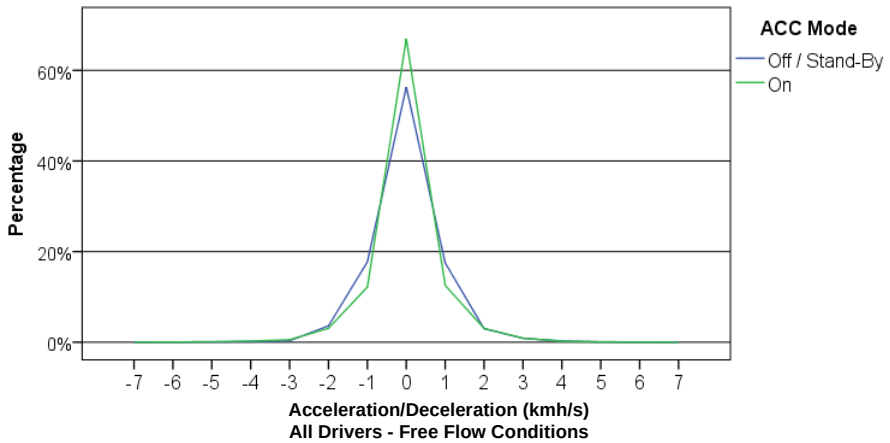
3 Field Operation Test: Use of ACC

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off/Stand-By	-0,14	-0,39	0,34	-	-0,31	-0,02	-0,50	-0,21	-0,18
	On	0,00	1,03	1,01	-0,84	-1,16	0,37	-0,45	0,05	0,00
	Change	0,14	1,42	0,67	-	-0,85	0,38	0,05	0,25	0,29
Capacity Conditions	Off/Stand-By	-0,32	-0,54	-0,01	-	-0,86	-1,35	-0,63	-0,55	-0,61
	On	0,91	-0,5	0,63	1,09	-2,34	0,07	-1,08	-0,63	-0,23
	Change	1,23	0,04	0,64	-	-1,48	1,42	-0,46	-0,08	0,19
Congested Conditions	Off/Stand-By	-0,15	-1,06	-1,04	0,62	-0,43	-0,11	-0,35	2,61	0,01
	On	-	-	-	-	-0,85	-	4,02	-0,33	0,95
	Change	-	-	-	-	-0,42	-	4,38	-2,94	0,34

Table 31 - Skewness of the Speed per Driver and Traffic Condition

This detailed analysis is separated in three parts, corresponding with the three areas in Figure 25. First of all the peak of the histogram will be discussed, then the braking part, and then the strong acceleration part.

In Figure 26 the whole histogram is shown of all accelerations for all drivers added up. The three graphs show the accelerations in the three different traffic conditions. Visible is that for all traffic situations the peak of the histogram is steeper and higher when ACC is activated. This confirms the conclusions from Table 30 and its explanation: ACC indeed leads to more constant speeds. Especially in capacity conditions the difference is evident. This is very positive from a traffic flows perspective. In capacity conditions, the speed differences that cause and strengthen shockwaves are very critical. When these shockwaves can be prevented from happening, the effect on traffic flows will be large. Also visible is that the difference in acceleration and deceleration behavior is only small in congested conditions. This might lead to the conclusion that the behavior of an ACC-driven car is very comparable to the behavior of a human-driven car.



3 Field Operation Test: Use of ACC

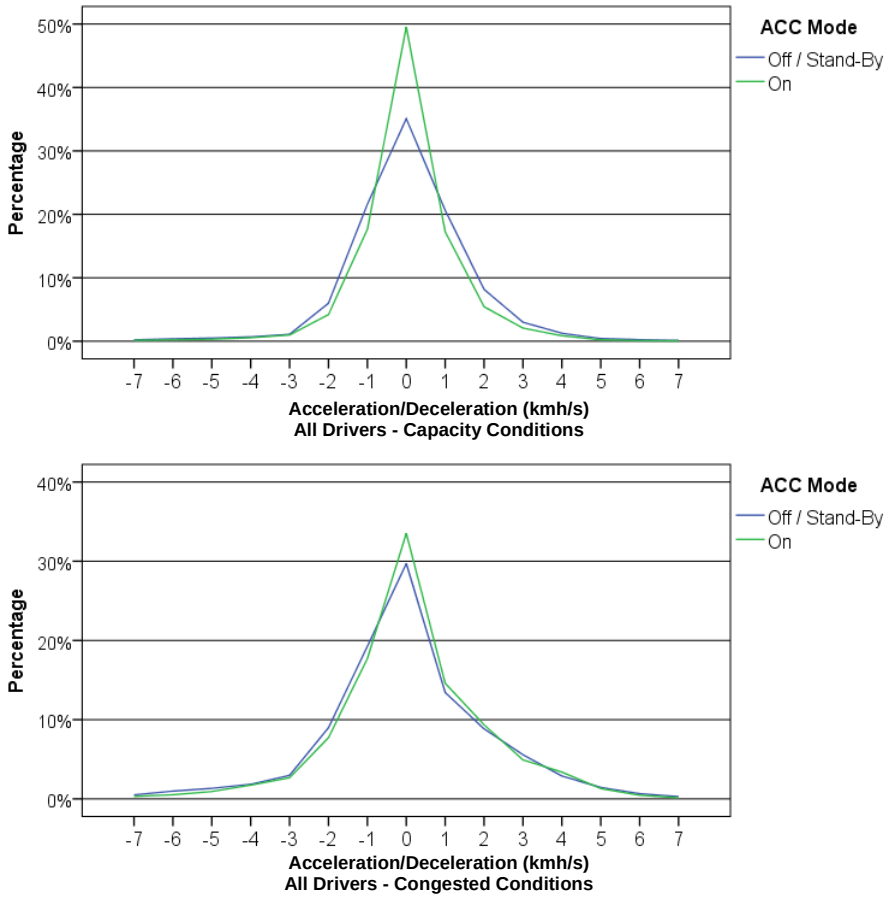
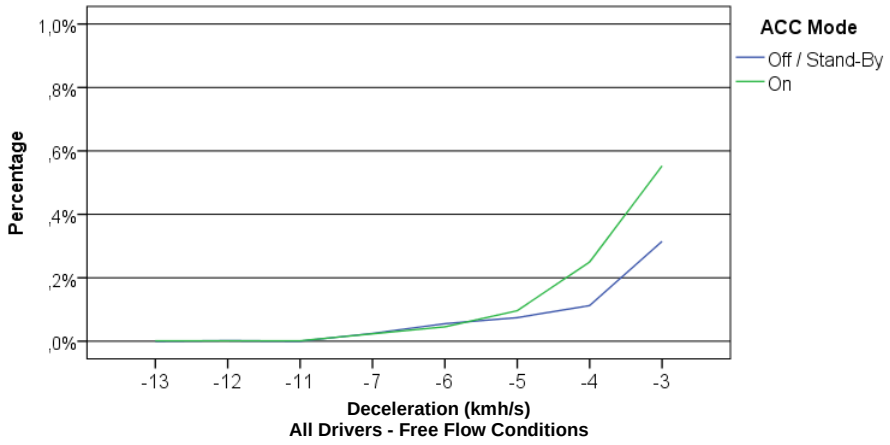


Figure 26 - Frequencies of Accelerations and Decelerations for All Drivers, for Different Traffic Conditions

From a safety perspective, it is very important that strong braking actions are prevented. These can cause head-tail collisions. Also for traffic flows these actions are disastrous: They cause shockwaves. In Figure 27 the frequencies of decelerations of more than 3 kmh per second are shown.



3 Field Operation Test: Use of ACC

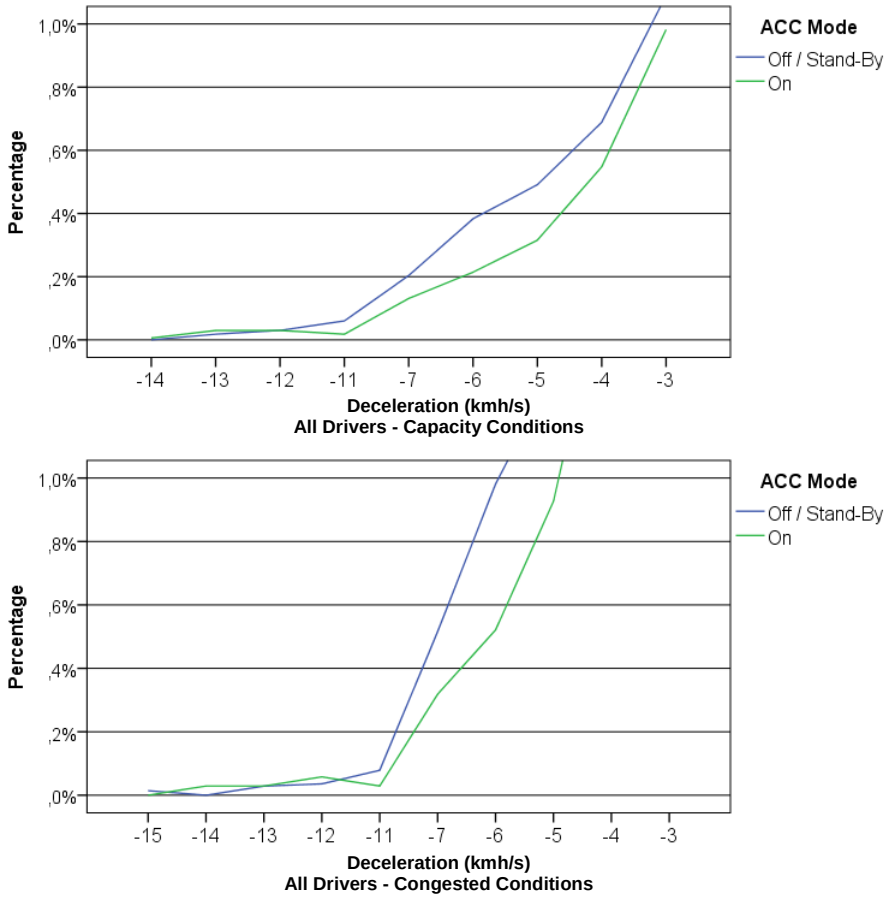


Figure 27 - Frequencies of Strong Decelerations for All Drivers, for Different Traffic Conditions

Visible is that in all traffic conditions very large decelerations (stronger than 10 kmh/sec speed reductions) are approximately as likely to happen when ACC is activated as when ACC is not activated. Very few of these strong decelerations are detected in the field test. But the decelerations from 3 to 10 kmh/sec show another pattern. In capacity conditions and in congestion, these decelerations happen less often. The blue line, representing the amount of decelerations when ACC is not active, is higher than the green line, representing the brakings when ACC is active. This means that ACC brakes more gently than the manual driver. This is positive from both a safety and flows perspective. But in free flow conditions, the pattern is the other way around. Accelerations of 3 and 4 kmh/sec happen roughly twice as often when ACC is on, compared to when it is off or stand-by. This outcome is remarkable. Adaptive Cruise Control apparently tends to overreact in free flow conditions. The percentages on the left show how often these accelerations occur. Visible is that decelerations of 4 kmh/sec happen in 2,5% of all driving moments. This is on average one and a half time per minute, in contrary to the situation without ACC. Then these decelerations happen only 1,25 times per minute on average. This implies negative effects on safety and flows in free flow conditions.

Finally, the influence of ACC on the strong accelerations will be assessed. The histogram parts showing the strong accelerations are shown in Figure 28. Visible is that in free flow conditions the acceleration behavior of a car with ACC is approximately equal to the behavior of a manual driver. The slower the traffic, the more difference occurs. Overall, accelerations are less strong when ACC is activated compared to when ACC is deactivated. This means that ACC-cars are slower than manually driven cars when decelerating. Earlier in this research it turned out that car-following behavior

is motivated by ACC. This car-following behavior only goes as long as speeds are the same. When another car accelerates fast, the ACC-driven car follows slightly slower, leaving a gap in front of it. Or the ACC car anticipates better to its predecessor, which means he does not have to accelerate strongly to follow its predecessor. The large and constant headway enables the car to follow another vehicle without needing strong accelerations.

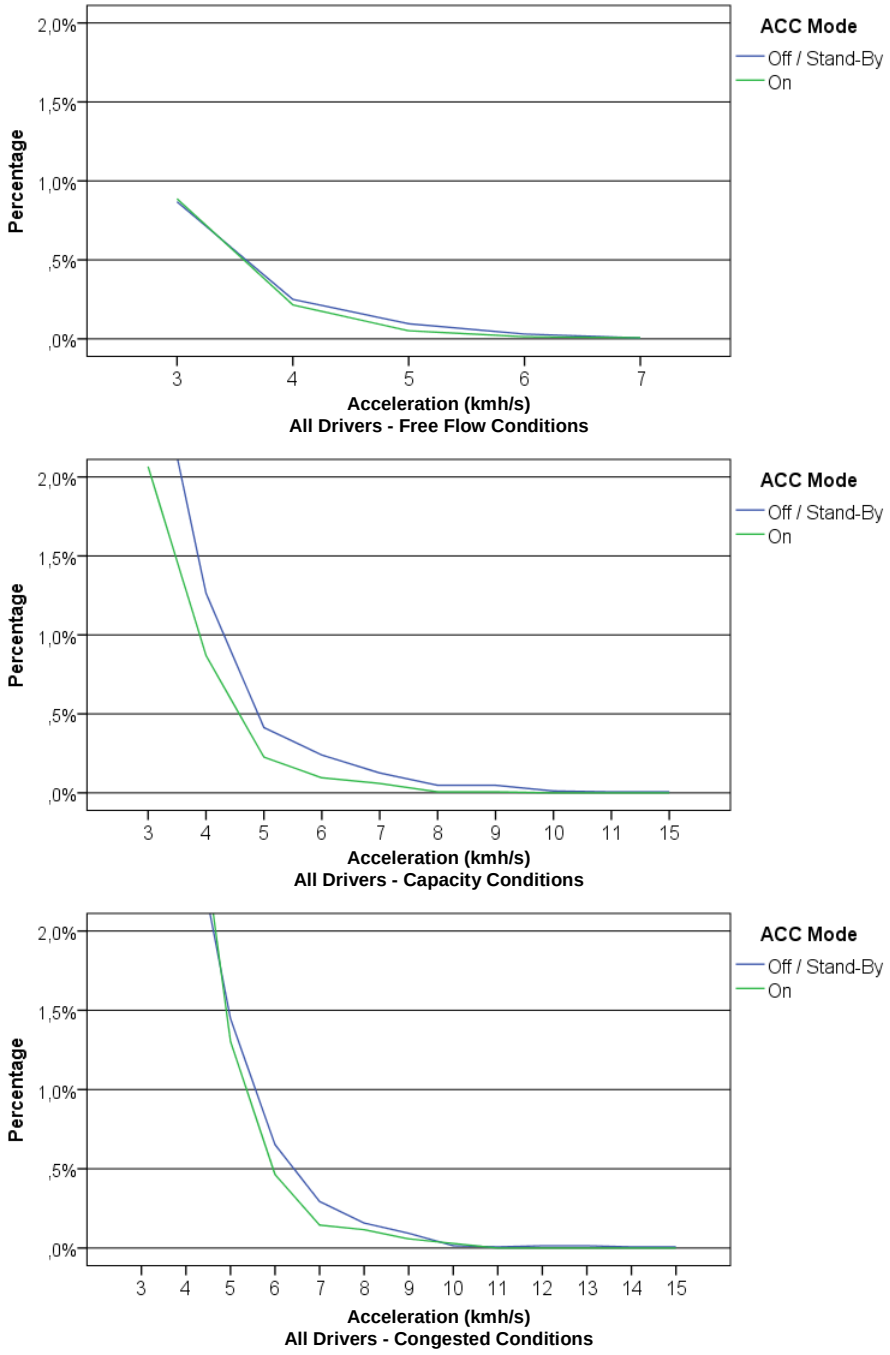


Figure 28 - Frequencies of Strong Accelerations for All Drivers, for Different Traffic Conditions

3 Field Operation Test: Use of ACC

3.3.4 Speed Limit Violations

In the questionnaire, respondents were asked if Adaptive Cruise Control leads to less speeding. They massively agreed on that. Here will be tested if this can also be detected in the field test. In Figure 29 the frequencies of all speeds are shown in a graph. This graph only shows the speeds in free flow conditions, since in congested and capacity conditions the maximum speed of the road is much less likely to be reached.

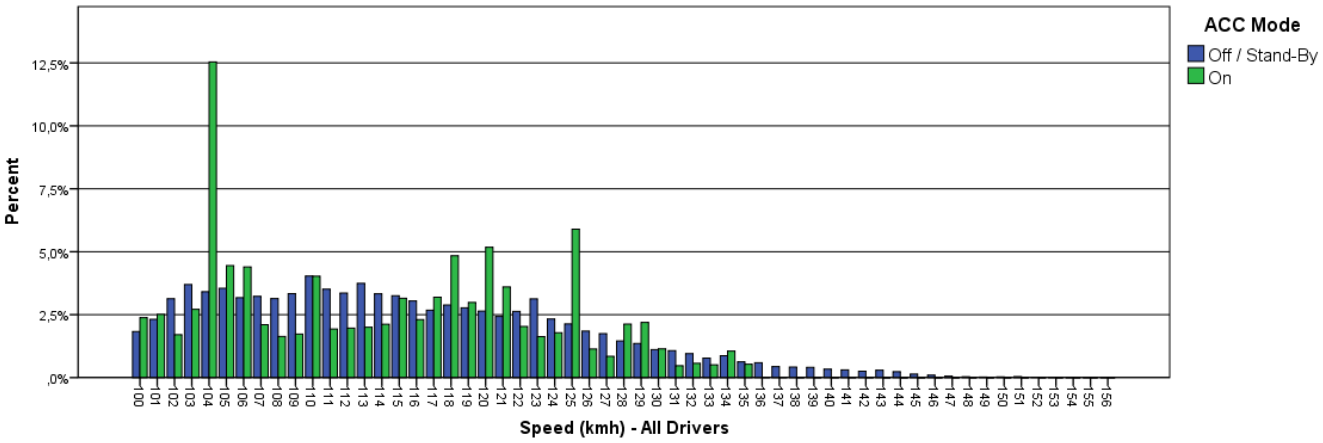


Figure 29 - Frequencies of Speeds in Free Flow Conditions with and without ACC for All Drivers

Visible is that the speed with Adaptive Cruise Control is shows some peaks. The four peaks which stand out are at 104, 118, 120 and 125 kmh. These are easily to reduce to maximum speeds: 104 kmh is the setting when the maximum speed is 100kmh, and 118, 120 and 125 kmh are driven when the maximum speed is 120 kmh. Participants in the test indicated that they are very alert on the maximum speed, and adjust their speed to it. Often they know what the margin is their speedometer differs from the real speed, and they know what the bandwidth is for the police to not give a fine, and this calculation leads to a certain speed which is just inside the margin of not getting a fee.

Visible is that the higher speeds are only present when ACC is deactivated. The highest speed reached with ACC is 135 kmh, which is most likely on a road stretch where 130 kmh is allowed. This means that this speed is too fast, but it is still within the margin of getting a speeding ticket. The fastest speed detected when ACC was not activated is 156 kmh. This is too fast under all circumstances. This means that the statement “ACC leads to less speeding” is approved by the field test.

3.3.5 Position on the Highway

The position on the highway is related to how efficient the highway is used. In ideal situations the road is filled from right to left when traffic intensities get higher. This means that the more traffic uses the right lane, the more efficient the road is used.

Table 32 shows the results of the field test. The number represented in the table is the average road position. The lanes of the road are numbered from right to left, so the right lane is lane 1, one lane to the left is lane 2, and so on. Per driver and traffic conditions the average lane is calculated, and this average lane with ACC is compared to the average lane without ACC activated.

3 Field Operation Test: Use of ACC

Traffic Conditions	ACC Mode	Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off/ Stand-By	1,94	1,51	2,33	-	2,02	2,23	1,56	2,83	2,06
	On	2,72	1,50	2,18	1,77	2,00	1,54	1,62	2,53	1,98
	Change	0,78	-0,01	-0,15	-	-0,02	-0,69	0,06	-0,30	-0,05
Capacity Conditions	Off/ Stand-By	1,99	1,49	1,91	-	1,89	1,95	1,56	2,20	1,86
	On	1,75	1,48	1,91	1,40	2,00	1,46	1,37	2,40	1,72
	Change	-0,24	-0,01	0,00	-	0,11	-0,49	-0,19	0,20	-0,09
Congested Conditions	Off/ Stand-By	3,34	1,56	2,49	2,81	1,40	2,41	2,08	2,46	2,32
	On	-	-	-	-	1,66	-	1,48	3,24	2,12
	Change	-	-	-	-	0,26	-	-0,60	0,78	0,15

Table 32 - Average Position on the Highway per Driver and Traffic Condition (1 = Right Lane, 2 = Second Lane, ...)

In literature and in the results of the questionnaire, it turned out that users activate ACC preferably in tranquil traffic conditions. In tranquil traffic conditions, more opportunities are for drivers to drive in the right lane. Therefore in the interpretation of this table, it is important to notice that in free flow conditions, it makes sense that drivers drive more on the right side with ACC activated.

Visible is that, just in line with the questionnaire, the results are mixed here. In free flow conditions, three out of seven drivers show a change of less than 0,1, which is very small. Three drivers tend to drive more on the right side, and one driver drives much more on the left. This shows that the influence of ACC on driver behavior differs per driver. The decrease of average position can be due to the fact that ACC is used more in tranquil situations.

In capacity conditions, the preference of drivers to use ACC more in tranquil situations does not have influence, since capacity conditions imply that intensities are higher. Here two drivers out of seven show a very small change, three drivers tend to drive more at the right side with ACC on, and two drivers tend to drive more on the left lane. The same two drivers drive more on the left side in congested conditions with ACC activated as well. One driver drives more on the right side when ACC is on when traffic is congested.

An overall conclusion is that ACC has influence on the position on the highway for most drivers, but two options are available: either users drive more left or they drive more right.

The drivers who drive more on the right lane will do so because ACC activation motivates them to follow the car in front of them instead of overtaking. When this is the case, the amount of lane changes will decrease as well. This will be investigated in the next paragraph. Figure 30 indicates that this can very well be the case. Visible is that for both the free flow and the capacity conditions driver 5 drives more on the second lane, and less on the first ánd the third lane. This shows that the driver likes to drive continuously on the middle lane, and chooses not to go to the right when a possibility is there (probably because of the large headway), and neither to go to the most left lane to overtake his predecessor. This indicates that ACC leads to a driver which chooses to follow his predecessor instead of performing lane changes to the right or to the left.

3 Field Operation Test: Use of ACC

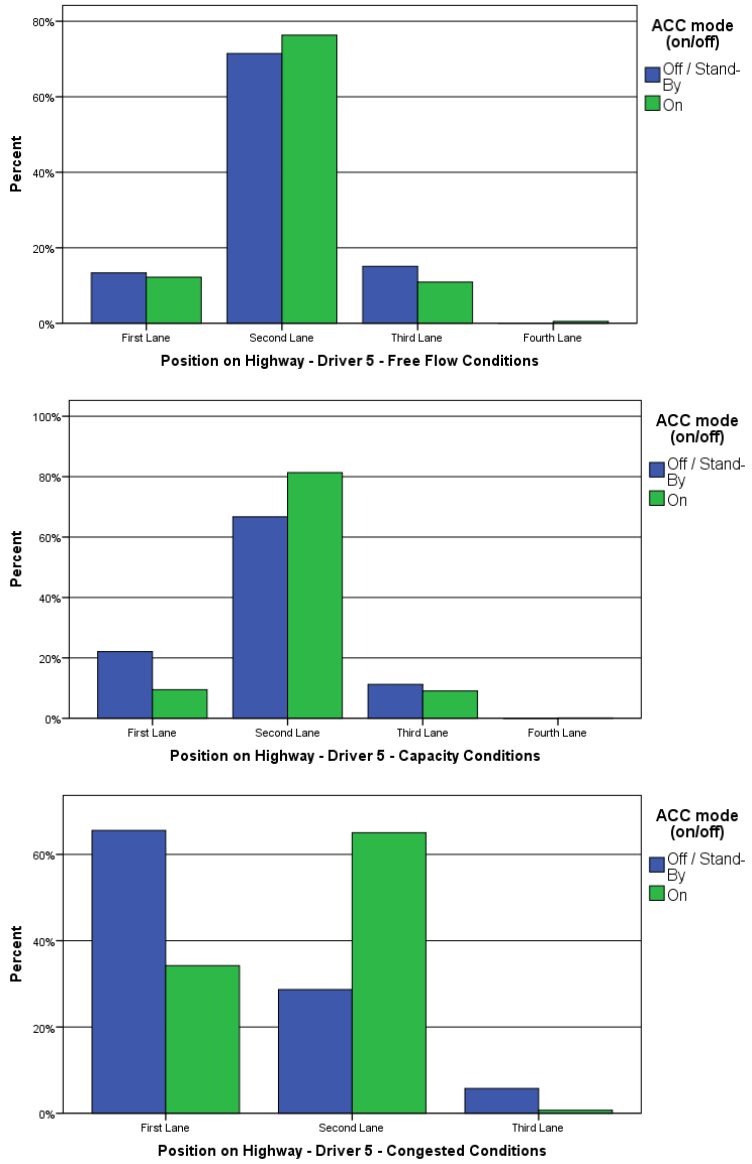


Figure 30 - Position on the Highway per Traffic Condition for Driver 5

An example of this behavior is visible in Figure 31, where the speeds, position and distance to the predecessor is shown of a participant in the field test, driving with ACC activated. Visible is that he only now and then reaches the speed he has set his ACC on, but most of the time the car adapts his speed to the speed of the predecessor. The driver decides to not overtake, but stay in the right lane, and just follow his predecessor.

3 Field Operation Test: Use of ACC

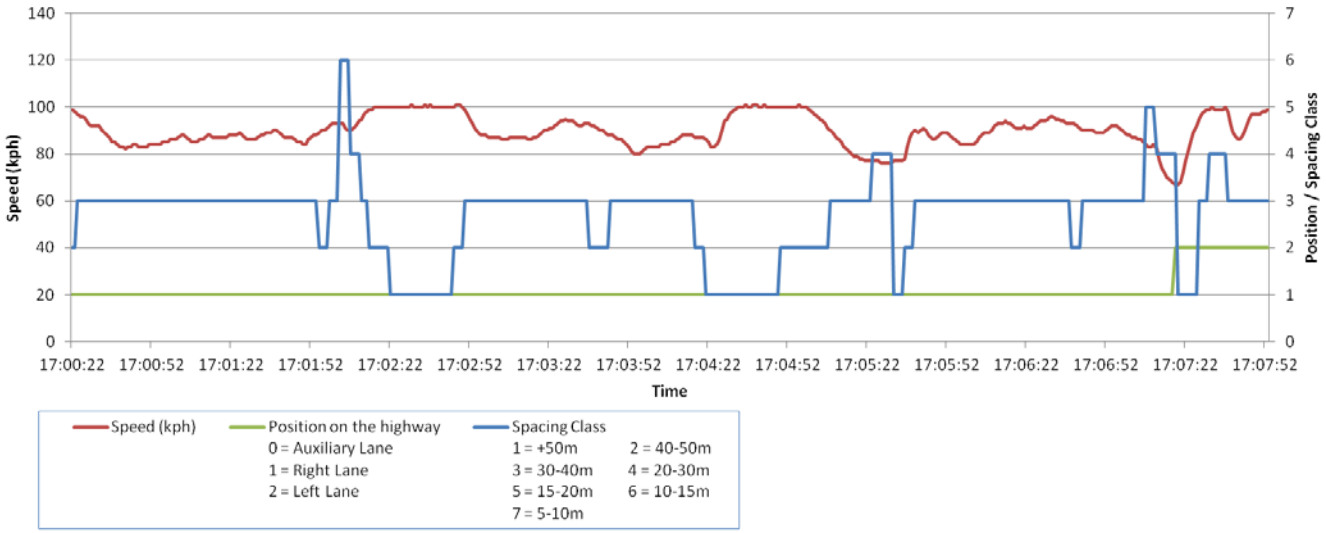


Figure 31 - Speed, Position and Distance profile of a driver following another vehicle

The drivers who drive more on the left lane with ACC activated, will do that because of the large headway. They more often decide not to merge to the right when that is possible, since otherwise their car will brake before its predecessor in the right lane. An example of that is shown in Figure 32, where a part of a trip of one of the participants is shown. Visible is that this participant enters the highway, and immediately decides to drive at the third lane. This is definitely the fast lane, since his speed on that lane is 120 kph, and some moments later it is even 125 kph, and no one drives in front of the vehicle. Being on that lane, he is not hindered by any other road user, and his ACC maintains the set speed. At one moment, the driver decides to move one lane to the right, but immediately the distance to the predecessor decreases and his car starts to coast. The driver goes back to the left lane and the car maintains the set speed of 125 kph again.

Figure 32 - Speed, Position and Distance profile of a driver continuously driving on the left lane

3 Field Operation Test: Use of ACC

Visible is that the driver chooses to drive on the left lane, because this lane is the most tranquil. When he decides to go to the right, his car immediately starts to break for other vehicles.

Another driving style with ACC is the 'overtaking'-style. This means that a driver does drive on the right lane, but as soon as his car approaches another vehicle, he moves to the left and overtakes it. A clear example is shown in Figure 33. A car with ACC activated is driving on the second lane, and the ACC maintains a certain speed. Then the car approaches another car, resulting in a decrease of the distance, and the car starts to coast. The driver switches lanes to the left, overtakes the car, and moves to the right again. To prevent his car from braking too hard, the driver switches lanes very early when overtaking his predecessor. Some moments later the same occurs. This overtaking behavior leads to an overall increase in usage of the left lane.

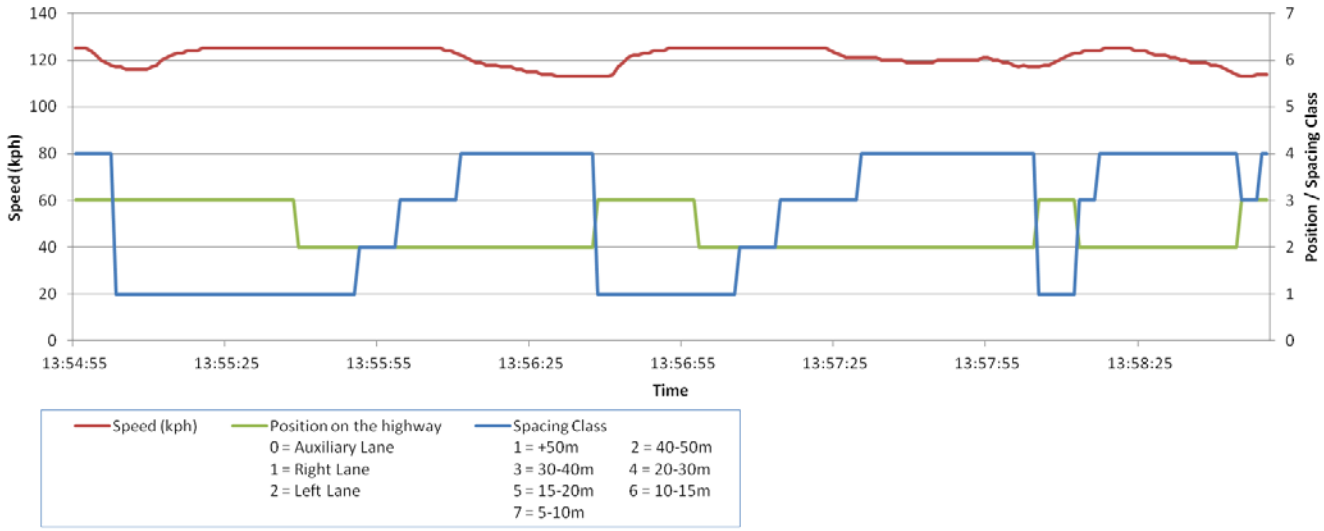


Figure 33 - Speed, Position and Distance profile of a driver overtaking other vehicle

3.3.6 Lane Changes

In the previous paragraphs, data analysis showed that drivers tend to show more car-following behavior when ACC is activated. The amount of lane changes is a very good parameter to check if this is indeed the case.

In Table 33 the amount of lane changes per hour (L.C./Hour) are shown. Obviously, cars on the roads are not always changing lanes. Therefore the amount of lane changes detected in the field test is much lower than the amount of totally analyzed moments. This means that the amount of lane changes detected in the field test is very important when assessing the results. Therefore the detected lane changes are shown in the table, denoted by N. For example: Driver 1 shows in free flow conditions that he performs 41% less lane changes per hour. This percentage is based on 302 detected lane changes when ACC was deactivated, and 268 lane changes when ACC was activated.

All cases where less than 10 lane changes were detected in total were removed from the analysis.

3 Field Operation Test: Use of ACC

Traffic Conditions	ACC Mode		Driver 1	Driver 2	Driver 3	Driver 4	Driver 5	Driver 6	Driver 7	Driver 8	Average
Free Flow Conditions	Off/ Stand-By	L.C./Hour	114,0	62,7	55,0	-	63,1	66,9	83,6	96,1	77,34
		N	302	103	199	2	75	227	110	69	1087
	On	L.C./Hour	67,7	56,0	58,7	46,9	42,5	63,3	78,7	69,7	60,44
		N	268	203	65	91	141	56	268	53	1145
	Change		-41%	-11%	7%	-	-33%	-5%	-6%	-27%	-16,6%
Capacity Conditions	Off/ Stand-By	L.C./Hour	112,9	62,2	34,2	-	50,1	40,2	42,9	91,8	62,04
		N	40	32	38	2	27	48	25	28	240
	On	L.C./Hour	47,4	71,1	-	21,3	28,5	21,5	44,1	42,1	39,43
		N	30	20	4	12	32	10	44	17	169
	Change		-58%	14%	-	-	-43%	-46%	3%	-54%	-30,7%
Congested Conditions	Off/ Stand-By	L.C./Hour	-	-	-	-	-	13,2	-	42,7	27,95
		N	3	4	4	1	9	13	5	10	49
	On	L.C./Hour	-	-	-	-	-	-	-	-	-
		N	0	0	0	1	9	0	2	1	13
	Change		-	-	-	-	-	-	-	-	-

Table 33 – Amount of Lane Changes per hour (L.C./Hour), per Driver and Traffic Condition. N = Amount of detected Lane Changes

In Table 33 is visible that drivers, regardless of the settings of their Adaptive Cruise Control, perform much less lane changes in congested conditions than in free flow or capacity conditions. This is in line with the note in paragraph 3.3.5, that the amount of lane changes in congestion is low, and does not influence flows.

Furthermore is clearly visible that ACC has influence on the amount of lane changes: in free flow or capacity conditions the amount of lane changes reduces. In free flow conditions, six out of seven drivers perform less lane changes when ACC is activated, and three of those six perform more than a fourth less lane changes. This is undoubtfully significant. Also in capacity conditions this result is visible: four out of six drivers show a very large decrease (approximately 50% less lane changes), while two drivers show a (much smaller) increase of lane changes.

This, together with the other conclusions made in this “Results”-paragraph, indicates that more car-following behavior is shown by drivers when they activate ACC.

3 Field Operation Test: Use of ACC

3.4 Conclusions and Discussion

3.4.1 Conclusions

A field test is executed with eight drivers. The driving of these participants is recorded during their normal use of the car. The eight drivers are business drivers, but in terms of age, gender, driving experience and the type of ACC they use, their characteristics differ, so that a wide variety of driver characteristics is included in the test. They have gained some experience using ACC already, so they can be called experienced ACC users.

In total these eight drivers provided almost 48 hours of driving data. The largest part of this data was collected on weekdays, during peak hours.

Overall, the headway and spacing of a car using ACC increase, compared with driving without ACC. In free flow conditions, all drivers showed an increase of the headway, on average with 16,7%. For capacity conditions, the increase was even larger, 25,8%. And in congestion, the average spacing increases with 16,8%. This means that in capacity conditions, the capacity of the road decreases significantly. About this finding wide consensus is found in literature: amongst others *Bianchi Piccinini et al., 2014*, *Pauwelussen & Feenstra, 2010*, *Pauwelussen & Minderhoud, 2008* and *van Twuijver & Pol, 2004* state this.

Despite the negative influence of the increasing headway on flows, the headways do become much more constant. The standard deviation of the headway decreases with 23,3% in capacity conditions, and with 17,9% in free flow conditions. The standard deviation of the spacing in congested conditions decreases with 12,2% when ACC is activated. More constant spacings and headways, create a more stable traffic situation, which is much better able to cope with shockwaves: to prevent them or even help eliminate them. More constant headways are also detected by *Alkim et al., 2007* and *Rakha et al., 2001*.

Also speeds become much more constant when ACC is activated. The standard deviation of the speeds decreases with 12,9% on average in free flow conditions, and even with 32,0% in capacity conditions. The standard deviation of the speed does not change significantly when ACC is activated in congested conditions. This is in line with the findings of *Alkim et al., 2007*, *Marsden et al., 2001* and *van Twuijver & Pol, 2004*.

From a safety perspective, it is preferable that strong braking actions are prevented. Visible in the results is that the amount of strong accelerations (between 3 and 10 kmh decrease in speed per second) decreases when ACC is activated in capacity and congested conditions. ACC leads to less strong braking actions in these traffic conditions. This is a positive outcome from safety as well from flow perspective. A decrease in strong brakings reduces the amount of head-tail collisions and shockwaves. But in free flow conditions the amount of decelerations between 3 and 6 kmh/s double. This is a negative outcome, since it can cause shockwaves and unsafe situations. Also *Hoedemaeker & Brookhuis, 1998* detected this in a driving simulator test.

When traffic starts driving again after moments of congestion, it is important that accelerations are as high as possible. By doing this, the congestion can be resolved as good as possible. When acceleration behavior with ACC activated is compared with behavior when ACC is not activated, it stands out that ACC leads to less strong accelerations in capacity- and congested traffic conditions. This is something which is not preferable from a traffic flows perspective.

Adaptive Cruise Control does lead to less speed limit violations. This is because drivers tend to adjust their ACC settings to the maximum allowed speed. They are thus much more aware of the speed limits when driving with ACC activated. This influence is assessed by other sources as well (*Alkim et al., 2007*, *van Twuijver & Pol, 2004*, *Vollrath et al., 2011*)

ACC has influence on the position on the highway. Two different trends are visible in the outcome of the field test. Either drivers tend to drive more on the left side of the road, because they need a larger gap on the right lane to merge into, because of the large headway ACC maintains, or drivers tend to show more car-following behavior. This motivates them to stay behind another car instead of overtaking it. This results in a better use of the right lane. More use of the left lane is found in *Rudin-Brown & Parker, 2004*, and more use of the right lane in *Strand et al., 2011* and *van Twuijver & Pol, 2004*.

This car-following behavior leads also to less lane changes. When ACC is activated in free flow conditions, the amount of lane changes on average decreases with 16,6%. In capacity conditions, this decrease is even more: 30,7%.

3.4.2 DISCUSSION

The field test described in this chapter has led to several conclusions, which give insight in the way it is used in practice and its influence on the traffic system. But it is necessary to interpret the results as good as possible. Therefore some remarks have to be made on the reliability of the analysis and the value of the results.

First of all the field test is executed with eight drivers. This amount of participants is not that much. When some result, for example an increase of the average headway, is observed for all drivers, with a certain reliability can be said that this apparently holds for almost all drivers with Adaptive Cruise Control. But when outcomes vary per driver, interpretation needs to happen carefully.

Another complicating notion is that the data is installed in a car, which can be driven by different drivers. The data is car-bound, not driver-bound. For the trips analyzed, it is not known who drove the car. It is to be assumed that by far the largest part of moments in this analysis, the lease car driver him/herself was driving. But moments can occur where this is not the case. And this means that differences in driving style or attitude towards Adaptive Cruise Control can change for a vehicle which is part of this analysis.

Furthermore the drivers of the cars know that they are part of a field test. Conversations with the drivers during the test showed that the drivers indicate that they just forget about the cameras installed, and that they, while driving, most of the time do not realize their driving behavior is analyzed. But despite this, it can be possible that the drivers in this test show not purely natural behavior.

Another behavioral notice that needs to be made is that the drivers are used to driving with ACC activated. Therefore, this field test shows insight in the difference between driving with ACC activated and driving without ACC activated. This does not necessarily mean that this is the same as driving with ACC activated and driving without ACC even installed in the car. It could very well be that ACC usage in the past has influenced the behavior of these drivers. For example, it turned out that ACC leads to larger headways. It is possible that these drivers get used to driving with large headways, and thus, when they do not have ACC activated, their headway is still larger then it was when the drivers did not have any ACC experience. This was noticed in the questionnaire, which showed that ACC drivers, regardless of their ACC settings, tend to have a larger headway than non-ACC drivers.

Also the amount of data collected and analyzed differs per participant. Combinations of drivers and traffic conditions exist which have hours of data analyzed, but also combinations of drivers and traffic conditions are present which have not so much data coverage. In the interpretation of the results a minimum amount of collected data was determined. This minimum was 5 minutes of analyzed data for the headways, speeds and position on the highway, and 10 lane changes for the paragraph about the lane changes. These minimum values are chosen arbitrarily, and assumed is that for all combinations of driver and traffic conditions which contains at least 5 minutes or 10 lane changes, the outcome is reliable. This is not correct by definition. Therefore it is important when interpreting the outcome of this research, to analyze all drivers, and not to pick one driver and deeply analyze his behavior, without taking other drivers into account.

The headway is measured using camera images and an overlay. The accuracy of this method is variable. Close to the car, the accuracy is 5m, and farther away, the accuracy is 10m. Assumed is that this is accurate enough. The large database will account for small inaccuracies. But this does say something about the reliability of the data. This goes also for all other recorded parameters based on the camera images. These images are analyzed by hand. Therefore it is possible that the person analyzing the images is mistaken now and then.

Overall this field test gives valuable insight in the difference between driving with ACC activated and without it activated. But analysis of the results needs to be done carefully.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

4.1 Introduction

So far three different types of research have been executed: literature research in chapter 1, a questionnaire amongst Adaptive Cruise Control users in chapter 2, and a field test in chapter 3.

In the literature research several hypotheses are formulated, divided in five different relations. These five different relations and the hypotheses described there will be used to interpret the results of the three different data types. The paragraphs of this chapter are formulated according to the five relations from the literature research.

At the end of this chapter, a discussion is added. This discussion gives insight in the reliability and valuability of the results stated in this chapter.

4.2 Relation 1: ACC - Traffic Flows

Hypothesis 1.1: ACC leads to more constant speeds

The field test gives insight in the speeds of cars with and without ACC activated. Part of the research was to determine the acceleration, expressed in change in speed in kmh per second (kmh/s), for every moment. Histograms of all acceleration values, from strong decelerations to strong accelerations, are made, and the difference in acceleration behavior with and without ACC activated was evident. When ACC is activated, small decelerations and accelerations were much less present. This makes sense, since the car, just like when normal CC is activated, maintains a constant speed. But also strong accelerations and strong decelerations were less present. The only exception on this was the amount of strong decelerations in free flow conditions: these increased.

The standard deviation of these histograms is computed. This parameter indicates whether the accelerations are scattered or if they are concentrated more. The lower the standard deviation, the more constant the speeds. In the analysis is computed that the average standard deviation of the speeds decreases with 12,9 in free flow conditions, and even with 32,0% in capacity conditions. In congested conditions, the standard deviation did not change. It stands out that especially in capacity conditions the speeds become much more constant. This is definitely positive from both a safety and a traffic flows perspective. The more constant traffic, the fewer disturbances occur, which results in less congestion and less safety hazards.

This result of the field test is in line with the results of a field test executed in the Netherlands in 2006 (*Alkim et al., 2007*).

Also in 2004 a questionnaire study is executed in the Netherlands (*van Twuijver & Pol, 2004*), and the respondents of this study also indicated that they drive more constantly. In the questionnaire which is carried out in this research, also a question about speeds was asked. When asked whether drivers think they drive more steadily and smoothly, they agree with a 5,3 out of 7 (where 1 is totally disagree and 7 is totally agree). So they tend to agree with the thesis.

Based on this can be stated that ACC leads to more constant speeds. When no traffic is around, the speed of the car stays exactly the same, but when ACC is interfering by braking or accelerating or following another car, the acceleration and deceleration behavior is also calmer. This means this hypothesis can be accepted.

Hypothesis 1.2: ACC leads to an increase of headways

The questionnaire shows that users of ACC definitely think ACC increases average headways: They agree with this thesis with an 5,6 out of 7 (where 1 is totally disagree and 7 is totally agree). The users of ACC are right about the headway. The field test indeed shows that overall the headway increases. In free flow conditions, all seven participants show an increase in average headway, with an average of 16,7%. In capacity conditions, six out of seven drivers show an increase. The average increase is 25,8%. In congestion the spacing is a better parameter to describe the distance between two vehicles than the headway, since headways tend to get very large at lower speeds. For congested conditions the spacing increases for all three drivers, on average with 16,8%.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

This increase of headways is one of the characteristics that indicates that ACC behaves differently than a normal driver. This is clearly visible in Figure 34, containing a camera still of a participant using ACC: the participant drives in traffic with an average speed of approximately 80 kph. The cars on the left and the right side all have a very small distance between them and their predecessors. The car with ACC in the middle has a much larger headway.

Figure 34 - Large Headway with ACC compared to cars without ACC (left and right)

But overall, this does not influence the opinion of the users of ACC. Despite the increase of the headway, users tend not to manually decrease the headway, according to the questionnaire. Their average answer on the question how often they manually decrease the headway, they answer on average with a 2.9, on a scale where 1 means 'never', and 7 means 'always'.

Users do however indicate they do not like this characteristic. ACC behaves different compared to them driving themselves. But they accept this drawback, and learn to cope with it. Another question was about overtaking: how often does a driver throttle up to overtake another car because his car would otherwise slow down behind that car? Respondents indicated this does happen more often: on average they scored this question a 3,6 on a 1-7 scale. This means that drivers do incorporate the behavior of ACC in their driving style, and they easily anticipate on the large headway when overtaking. However, the more users are accounting for the inconveniences of ACC, the lower they rate ACC overall.

Of course the increase of headway has a positive influence on traffic safety. But the disadvantage for traffic flows is evident as well. An average increase of the time headway in capacity conditions of 25,8%, means that the capacity of a highway stretch decreases significantly.

Overall it is clear that this hypothesis can be accepted. This is undoubtly in line with analyzed literature. A Dutch field test (*Pauwelussen & Feenstra, 2010*, *Pauwelussen & Minderhoud, 2008*) shows the same result, and also a driving simulator study (*Bianchi Piccinini et al., 2014*) and a questionnaire executed in the Netherlands (*van Twuijver & Pol, 2004*) show this.

HYPOTHESIS 1.3: ACC LEADS TO MORE CONSTANT HEADWAYS

The increase of the headways implies a negative influence of ACC on traffic flows. But positive influences are present as well. One of them is the change in headway. It turns out that the headway becomes much more stable when ACC is activated. Visible in the data is that the standard deviations of the headway decrease overall.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

The spreading of the headway decreases with 17,9% on average in free flow conditions, and with 23,3% in capacity conditions. Also the standard deviation of the spacing in congestion decreases: on average with 12,2%. This means that cars with ACC show much more car following behavior, and the drivers anticipate better on speed variations of the predecessor. The distance between the car with ACC and its predecessor is very constant. This prevents head-tail collisions and shockwaves from happening. This hypothesis can be accepted.

Disadvantage is that the car only anticipates on the predecessor, where drivers themselves react much better on surrounding traffic. The ACC is solely focused on the speed and headway of the predecessor. This makes the driving behavior very constant in homogeneous traffic, but the attention of the driver is still required to anticipate on traffic movements of the cars driving on the adjacent lanes.

The 'Assisted Driver'-research in 2006 (*Alkim et al., 2007*) showed as well that headways become more constant, as well as a field test executed in 2004 in Michigan, USA (*Rakha et al., 2001*).

4.3 Relation 2: ACC – Traffic Safety

Hypothesis 2.1: ACC leads to a reduction of the amount of front end collisions, with the preceding vehicle as well as the vehicle behind.

To test this hypothesis, the only source to be relied on is the questionnaire, since fortunately no head-tail collisions are detected in the field test. The respondents of the questionnaire overall agree with this thesis. They score an 5,6 out of 7 (where 1 is totally disagree and 7 is totally agree).

Despite real head-tail collisions not being recorded, the headway characteristics can be used to indicate whether the chance of a head-tail collision with the predecessor increases or decreases when ACC is activated. Visible in the previous paragraph is that the average headway increases for all traffic conditions, and that it becomes much more stable. The variation in headway decreases, and small headways do not occur so often. This indicates that indeed head-tail collisions on the front side are prevented more when ACC is activated. This hypothesis can considered to be true, as far as the collisions with the predecessor concern. The only indicator that can properly indicate whether the risk of head-tail collisions at the back side of the car is decreased, are the amount of strong decelerations. These will be described with the following hypothesis.

Literature which underlines this statement is also based on a questionnaire in the Netherlands (*van Twuijver & Pol, 2004*). It is not surprising that the results of these two questionnaire researches align.

Hypothesis 2.2: ACC leads to stronger braking

ACC leads to much more constant speeds for all traffic conditions. This means that a deceleration of 0 kmh/s, representing a constant speed, occurs far more often when ACC is activated, compared to when ACC is deactivated. A result of this is that weak decelerations (1-3 kmh/s speed decrease) occur far less often when ACC is activated. Stronger decelerations (3-10 kmh/s speed decrease) occur less often in congested and capacity conditions. This means that in these traffic conditions ACC outperforms the normal driver concerning shockwave- and collision prevention.

In free flow collisions however, the outcome is different. The amount of decelerations between 3 and 6 kmh/s is almost double as high when ACC is activated, compared to when it is off. This might have to do with the large headway: because of the large headway other road users decide to merge in front of the car with ACC, which reacts directly by strongly braking. This is not only uncomfortable, but also unsafe.

This means that this hypothesis is true for free flow conditions, but not for capacity and congested conditions. This can be prevented by decreasing the headway in free flow conditions, so that other road users are not motivated to merge in front of the ACC-driven vehicle.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

The literature basis of this statement is not strong. It is based on only one paper (*Hoedemaeker & Brookhuis, 1998*), based on a Driving Simulator test executed in 1998.

HYPOTHESIS 2.3: ACC LEADS TO LESS SPEED LIMIT EXCEEDING

In the field test is detected that indeed less high speeds are detected. The maximum speed is not recorded using the field test, so not for every moment can be elaborated whether the driver speeds or not. But when looking at all frequencies of speeds under free flow conditions, it stands out that really high speeds, above 130 kph, solely are detected when ACC was not activated. When ACC was activated, these really high speeds did not occur.

Also respondents of the questionnaire overall agreed with this thesis: a 5,1 out of 7 was scored (where 1 is totally disagree and 7 is totally agree).

Visible in the field test is that drivers deliberately adjust their speed to the maximum allowed speed on a certain road stretch. This makes them much more aware of the maximum speed. Some respondents of the questionnaire stated that one of the reasons they bought ACC in the first place was prevention of speeding tickets. This hypothesis can thus be confirmed.

Other researchers agree on this statement: different studies (*Alkim et al., 2007*, *van Twuijver & Pol, 2004*, *Vollrath et al., 2011*) show the same outcome. The paper of *Hoedemaeker & Brookhuis, 1998* rejects this thesis, but the insight gained in this research ánd the other studies which show another outcome provide enough basis to conclude that ACC indeed leads to less speeding.

4.4 RELATION 3: ACC – DRIVER BEHAVIOR

HYPOTHESIS 3.1: ACC LEADS TO AN INCREASE IN DRIVING COMFORT

This is the feature of ACC the car manufacturers advertise, and it is the reason people actually buy it. This is confirmed by the questionnaire: on a scale of 1 to 7, respondents agree on average with this statement with a score of 5,5. A strong and significant correlation is visible with the outcome of this statement and the appreciation respondents have for ACC. This means that the respondents who state that ACC relieves the driving task, also value ACC higher in general. This means that this increase in driving comfort is appreciated by ACC-users.

Three different research papers (*Bianchi Piccinini et al., 2015*, *Strand et al., 2011*, *van Twuijver & Pol, 2004*), based on three different sources (respectively driving simulator, focus groups and a questionnaire) show the same outcome: users like ACC because it relieves their driving task.

HYPOTHESIS 3.2: ACC LEADS TO A CALMER DRIVING STYLE

In the field test it turned out that the activation of ACC results in more constant driving. For example the speeds become more homogeneous, less speeding occurs, the headways get more constant, and the amount of lane changes reduces. This can indicate that the behavior of the vehicle and thus the driver, gets calmer.

The questionnaire found that a relation is present between the driving style of the user and the appreciation of ACC. Overall, the calmer driver appreciates ACC more.

Based on the above, can be stated that indeed ACC leads to a calmer driving style. This hypothesis is accepted, in line with the outcome of the questionnaire executed by *van Twuijver & Pol, 2004*. But a relation the other way around is also present: the driver with a calmer driving style appreciates ACC more.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

Hypothesis 3.3: Drivers have to learn using ACC

Based on the results of the questionnaire, this hypothesis can be approved. Learning to use ACC can happen in two different ways: by getting instructions beforehand, or to learn by doing. The first method is the best option: users start to use ACC well prepared, and they more or less know what they can expect when using the system. It stands out that the drivers who did get instructions beforehand either by someone explaining ACC to them or by reading the instruction manual, reviewed ACC more positive. A cause-effect relation will be there to a certain extent: instructions make a driver more prepared, which leads to a higher appreciation of ACC. But another cause will be there as well: users who receive instructions are apparently willing to learn to use ACC and use it correctly. These will also be the people who beforehand are already more positive about ACC.

In the questionnaire three examples are given of situations that might occur when users have ACC activated. The first one is ACC losing sight on a predecessor in a steep curve, the second one is ACC suddenly deactivating itself, and the third one is ACC suddenly braking or accelerating while users do not expect it. The last two situations indeed occur more when users did not receive instructions before using ACC. The correlation between the level of instructions users got and how often ACC accelerates or decelerates was significant on the 0,05 level. This indicates that a learning process is present.

Finally, the questionnaire showed that the longer users use ACC, the more they appreciate it. Respondents who use ACC for a longer time, rate ACC higher compared to users who use ACC for a short time period. This indicates that the longer drivers use ACC, the more they can cope with it and anticipate on its unexpected behavior, and thus the more they like it. This is also found by *Alkim et al., 2007*, *Beggiato & Krems, 2013*, *Larsson, 2012*, *Larsson et al., 2014* and *Weinberger et al., 2001*. This indicates that this statement is reliably accepted.

Hypothesis 3.4: Preparation beforehand is necessary for users to use ACC correctly and satisfactory

The analysis of the results of the questionnaire to validate the previous hypothesis showed that a learning process is present when using ACC. The question is: which way of learning to use it is better: preparation beforehand or learning by doing?

Sudden actions by ACC like braking or accelerating can be prevented or anticipated on by experienced ACC users. The questionnaire shows that this unexpected behavior occurs more with inexperienced ACC users.

Learning by doing will provide a solution here: when ACC brakes unexpectedly once, the next time the driver understands what happens, and he will take better care the next time. But this unexpected braking will cause a safety hazard. This means that when drivers learn by doing, they go through a quite unsafe period in the first months of usage. This can be prevented by instructions beforehand. Not totally of course, because experience is one of the best teachers, but when users are prepared, they could prevent these risks in the first place.

This goes not only for unexpected braking, something that just happens now and then, but also for specific situations that only happen very occasionally. The instruction manual warns for all types of safety hazards: ACC malfunctioning in rain, ACC not reacting when a solid object is in the way, ACC not detecting motorcycles and so on. These situations happen not often, and thus the driver, despite having some ACC experience, might be not prepared to these safety risks when they occur, when he only learned driving with ACC by practice. These safety hazards can be explained when the driver gets instructions or reads the manual. This will prevent them from leading to an accident.

In general, preparation before using ACC is very important. Only learning by doing is not enough, and therefore some sort of instruction before using ACC is very strongly advised. This hypothesis is accepted, in line with the results of the research of *Beggiato & Krems, 2013* and *Dickie & Boyle, 2009*.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

HYPOTHESIS 3.5: ACC MUST BE CUSTOMIZABLE BECAUSE OF THE DIFFERENCES BETWEEN DRIVING STYLES

The largest part of the users of ACC which filled in the questionnaire had chosen ACC themselves. This means that they have a preference towards using ACC, and that they, to a certain extent, know what ACC is and how it works.

Different car brands all have their own ACC system, and the one system is more customizable than the other. It turns out that the systems which are very customizable, are more appreciated than systems which are not. Volkswagen and BMW for example, have developed ACC systems where not only the headway is variable, but also the way ACC interferes. Users can choose whether they like ACC interfering very early, or if ACC has to brake very late when approaching another car. These customizable systems are appreciated more by users.

The questionnaire showed that the more ACC behaves like a human driver, the more it is appreciated. But the differences in driving style and behavior between human drivers are large. Therefore an ACC system which is highly customizable, will be more appreciated by the drivers. And appreciation is very important for this system, because if car drivers do not like ACC, they will not opt for it and they will not use it.

Customizability is positive, and therefore this hypothesis is approved, not only by this research but also by *van Twuijver & Pol, 2004*, *Viti et al., 2008* and *Xiong et al., 2012*. The customization has to be mainly in the headway settings, and in the way ACC interferes. Some drivers like ACC when it breaks very early, other drivers need an ACC that only interferes when approaching another car very closely.

4.5 RELATION 4: ACC – DRIVER BEHAVIOR – TRAFFIC FLOWS

HYPOTHESIS 4.1: ACC LEADS TO LESS LANE CHANGES AND MORE USE OF THE RIGHT LANE

The field test shows indeed that the amount of lane changes decreases when ACC is activated. In free flow conditions the average decrease of lane changes is 16,6%, for capacity conditions it is 30,7%, which means almost a third less lane changes. This definitely makes traffic more homogeneous. A likely effect on traffic flows is that fewer disturbances take place, and thus shockwaves are prevented. Especially in capacity conditions, this effect is positive. A decrease of lane changes is also detected by *Strand et al., 2011* and *van Twuijver & Pol, 2004*.

In terms of lane changes, three different trends are visible. Two out of seven drivers do not show a change in position on the road when ACC is activated. Two drivers tend to drive more on the left side of the road. This is reasonable. When the ACC-user wants to overtake another car, he decides to go to the left lane earlier than when ACC is off. Otherwise, the car starts braking for that car. Also when driving on the left lane, ACC-users will wait for a really large gap between two cars on the right lane to merge to that lane. When the gap is smaller, these drivers will not merge, because their car will start braking because of the cars driving on the right lane. This has a negative effect on the capacity of the road, because the capacity of the road is less efficiently used. This pattern is recognized by *Rudin-Brown & Parker, 2004*.

Another group of users is however present, in the field test three out of seven drivers, who drive more on the right side of the road. This can be explained with help of the questionnaire. Respondents of the questionnaire indicate that they like ACC the most when conditions are tranquil on the highway. This means that on average the situation on the road is more tranquil when ACC is activated. When these tranquil conditions occur, cars drive more on the right side of the road. This means that in the data, it would make sense that the average position in free flow conditions is more to the right when ACC is activated.

Another explanation for the tendency of drivers to drive more in the right lane is the car following behavior. The amount of lane changes decreases, which indicates that users of ACC tend to choose to stay behind another car instead of overtaking it. This implies that they keep driving on the right side of the road. This is approved by *Strand et al., 2011* and *van Twuijver & Pol, 2004*.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

The first part of this hypothesis is tested to be true, the second part is partly true. More car following behavior is shown, resulting in more use of the right lane. But users tend to drive more in the left lane because of the effects of the large headway as well.

Hypothesis 4.2: ACC leads to more car-following behavior

Until now, several hypotheses are tested, and the results indicate that more car-following behavior is observed. The amount of lane changes decreases strongly, which indicates that drivers less often overtake another car. The fact that almost half of the analyzed participants in the field test drives more in the right lane in free flow and capacity conditions, emphasizes this. Not only more car-following behavior is detected, but the way the car follows its predecessor is improved as well. Headways and speeds become more constant, which means that the car drives in such a way that shockwaves are prevented, and even occurring shockwaves can be eliminated. Also from a safety perspective this constant driving style is an improvement.

A focus group research carried out by *Strand et al., 2011* in Sweden shows that more car-following behavior is found as well.

The only negative consequence of this car-following behavior is the large headway that is maintained by the ACC system. This implies a decrease of road capacity.

Hypothesis 4.3: Drivers tend to manually decrease the headway proposed by the ACC system

Despite the fact that drivers think the headways proposed by ACC are too large, they do not manually decrease it, is shown by the outcome of the questionnaire. This statement is scored with a 3,6, on a scale where 1 means ‘never’, and 7 means ‘always’.

This indicates that drivers might not always be happy with the working of ADAS systems, or in this case, ACC, but they do not feel the need to manually interfere. This indicates that drivers get used to it and accept its shortcomings. This hypothesis is therefore rejected. This is not in line with the research of *Viti et al., 2008*. This paper is based on the data collected during the ‘Assisted Driver-‘project. This field test is executed with inexperienced drivers. An explanation could be that experienced drivers are more willing to accept the headways proposed by ACC, compared to inexperienced drivers.

Hypothesis 4.4: Users tend to go to the left earlier when overtaking a car, to prevent the ACC system from braking before that car

Some users of Adaptive Cruise Control drive on average more on the left lanes when ACC is activated. This indicates that they decide to change lanes to the left earlier when overtaking another vehicle. Also respondents of the questionnaire state that they indeed go to the left earlier, or they overrule their ACC by accelerating manually. This hypothesis is likely to be true, which has a positive influence on safety, since cars do not approach each other closely when overtaking, but for flows this is more negative. The overtaking car needs more space on the highway, which decreases the road capacity. The ‘Assisted Driver’-research (*Alkim et al., 2007*) has analyzed this behavior as well.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

4.6 Relation 5: ACC – Driver Behavior – Traffic Safety

Hypothesis 5.1: Users tend to start using ACC before properly investigating the risks and limitations of ACC

One of the questions in the questionnaire was: did you receive any instructions before usage of ACC? 45% of the participants indicated that they received instructions extensively, 31% slightly received instructions, and 22% of all participants did not receive any instructions. Half of those 22% indicate that they are extensively aware of the risks, and half of them say that they are slightly aware of the risks. From the respondents that indicate to have received a little bit of instructions, a larger part admits not to know what the risks are compared to the group that did not receive any instructions. This means that a fifth of all users of ACC does not receive any instructions, and this group overestimates their knowledge of the risks. The only way this group could have learned to use ACC is by using it. This only partly gives proper insight in the risks of ACC.

The questionnaire also shows that the group of users which did not receive any instructions beforehand, also is more vulnerable to lose attention on the road and undertake more secondary activities. This shows that this group indeed does not have a clear sight on the risks of using ACC.

In summary: a large part of the users of ACC receive some kind of instructions before using ACC. Someone explains the operation of ACC to them, or they read the instruction manual. However a significant part of the users does not or barely receive any instructions before using ACC. This group learns using ACC by doing it, but their assessment of the risks is incomplete, which could lead to unsafe usage of ACC. This hypothesis is partially true. The potential unsafe situation created by a lack of preparation is also recognized by *Bianchi Piccinini et al., 2014* and *Rudin-Brown & Parker, 2004*.

Hypothesis 5.2: Drivers tend to have a too high level of trust in ACC

The main part of ACC users uses it wisely. This group is aware of the risks to a certain extent, and they know how ACC works. This is roughly the same group which starts using ACC while they got some kind of instructions. A group of users does not receive any instructions, and this group overestimates their knowledge of ACC. They admit they lose attention, and perform more secondary activities. This group also indicates that ACC behaves unexpected now and then. The system accelerates or brakes unexpectedly, or ACC deactivates itself.

If these users have a too high level of trust in ACC is hard to check, but at least it is clear that this group is not aware of the risks while using it. This indicates that their level of trust is indeed too high. This indicates that this hypothesis is true. The theoretical background of this statement is very strong: the research papers who state that drivers have a too high level of trust in ACC are amongst others *Bianchi Piccinini et al., 2014*, *Dickie & Boyle, 2009*, *Kazi et al., 2007*, *Rajaonah et al., 2006*, *Rudin-Brown & Parker, 2004* and *Vollrath et al., 2011*.

Hypothesis 5.3: ACC leads to a reduction of the level of focus and an increase of secondary activities

With a small group of users the increase of driving comfort leads to a decrease of attention levels and an increase of the amount of secondary activities. This is dangerous.

For a part of the drivers the relief of the driving task leads to a drop of the attention level and more secondary activities. This group will definitely have a larger response time. The largest part of the respondents of the questionnaire indicated that their attention level does stay the same. Of course this answer is the only socially acceptable answer, and therefore it is hard to correctly interpret these answers. Thus, it makes sense that ACC will lead to a decrease in attention and a longer response time. How large this decrease is, depends on the driver. This hypothesis is accepted for a certain group of ACC users. The same researches which agreed on the previous statement, also state that this statement is true (*Bianchi Piccinini et al., 2014*, *de Winter et al., 2014*, *Rudin-Brown & Parker, 2004*, *Vollrath et al., 2011*).

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

HYPOTHESIS 5.4: ACC LEADS TO A LARGER RESPONSE TIME

When car drivers have ACC activated, this leads to a relief of their driving task. Previous hypotheses state that this leads to a drop in attention level and an increase of secondary activities for some drivers. This will lead to a larger response time. This research is unable to reliably state that the response time increases, but based on the outcome of the questionnaire according the attention level and secondary activities, this hypothesis can be considered to be likely to be true for a part of the ACC users. A lot of other researches (*Bianchi Piccinini et al., 2014*, *Larsson et al., 2014*, *Rudin-Brown & Parker, 2004*, *Vollrath et al., 2011*) analyze the same outcome.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

4.7 DISCUSSION

This research is done with the highest carefulness possible. Despite that, several notions have to be taken into account when assessing and interpreting the results of this analysis.

First of all the literature research is executed. It stands out that different data sources for this research base their conclusions on simulations. These are as reliable as the input parameters used for the research. This research itself focuses on the performance of ACC in practice, which is really different compared to simulation. Visible in the assessment of the hypotheses is that hypotheses based on simulation research are more often rejected than hypotheses based on driving simulators or Field Operation Tests.

Also a questionnaire is executed. This questionnaire gives to a large extent insight in the opinion and preferences of ACC users. This means that valuable information is gained. But everyone who reads the results of the questionnaire, has to keep in mind that this all is subjective information. The information is not objectively collected, but purely based on the opinion of the respondents. And this opinion is very different from one user to another. Also certain incentives can be present which make respondents give certain answers, which are biased. For example questions about secondary activities. In the Netherlands, drivers are motivated to behave responsibly. Therefore it is less socially accepted to admit that drivers do not behave responsibly in some occasions. Therefore it could be that drivers, despite sometimes using their smartphone while driving, indicate in the questionnaire that they never do that. This is a phenomenon which is recognized by social researchers (*Lee, 1993*). This has to be kept in mind when interpreting the results of the questionnaire.

Furthermore, in interpretation of the results fallacies have to be avoided. For example the *cum hoc ergo propter hoc* (with this, therefore because of this) fallacy (*Van Eemeren & Grootendorst, 1992*) can occur in interpreting the results. This fallacy states that when two observations are correlated, a cause-effect-relation between the two exists. This is a wrong assumption, if not correctly underpinned. An example is that users of ACC which prepared before using ACC are more positive about it in general. Some sort of cause-effect relation is present here, but also an underlying mechanism is there. People who buy a new car and deliberately choose ACC as an option, will already be positive about ACC in advance. This group is also very likely to receive instructions before ACC usage. Both the positive attitude towards ACC and the amount of instructions are both the results of the choice of the user. This can not only occur in the questionnaire, but also in the field test.

Not only fallacies can create bias, also some other patterns are visible, which have a psychological reason. For example, several statements were part of the questionnaire, and participants had to indicate whether they agree with it or not. These questions can be answered using a seven point scale: strongly disagree – disagree – somewhat disagree – neutral - somewhat agree - agree - strongly agree. An example of a question of this type is shown in Figure 35. Visible is that the largest part of the respondents agrees with the statement, and a part of users does not agree. It stands out that the percentage of respondents who ‘disagrees’ with the statement (11%), is larger than the percentage who ‘strongly disagrees’ (5%), or ‘somewhat disagrees’ (4%). This pattern is visible for a large part of the questions of this type. This indicates that respondents have a preference to just ‘agree’ or ‘disagree’ with a statement, and that the ‘strongly ...’ and ‘somewhat ...’ are chosen less often. This might influence the outcome of the questionnaire questions.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

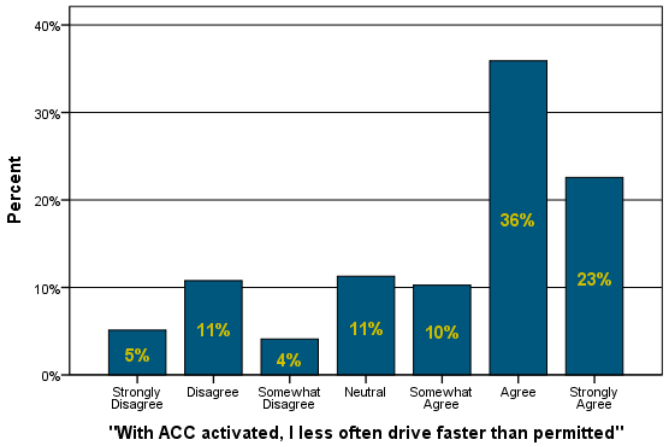


Figure 35 - Results of Questionnaire Statement 'With ACC activated, I less often drive faster than permitted'

In general, it is very important to differ between the pure results of this research, and the interpretation of these results. In chapter 2 and 3, a 'Results'-paragraph is visible. This paragraph describes purely the results of the questionnaire and the field test. Strived is to show these results as 'clean' as possible, with as less interpretation as possible. In the 'conclusions'-paragraphs of chapter 2 and 3, and in this chapter, the results are explained and interpreted. This interpretation is done by combining the two different data sources, and relating them to the hypotheses, which are based on literature. This way, conclusions are made which are as reliable as possible. But still, the researcher has to be as critical as possible, so that the results he states indeed are reliable and true.

Furthermore the value of the questionnaire is not only determined by the questions and the interpretation of the answers, but also by the respondents themselves. The recruitment strategy is very important, since it indicates whether the respondents are indeed representative for all other ACC users. The main way the respondents were linked to the questionnaire, was by means of a news article on the website of the ANWB. Are the characteristics of the respondents of the questionnaire representative for the average ACC driver, or the average reader of the ANWB-newsletter, or a combination of both? Overall, the population of the questionnaire was quite wide spread, so the results will be reliable to some extent.

The total amount of respondents was at least 186, and for the largest part of the questions it was 200. This is quite a large dataset when taking into account that the penetration of ACC in the Netherlands is not that high, but in terms of an average questionnaire, it is not that much. This means that the results are not unconditionally reliable. They are to some extent, but the interpretation needs to happen carefully.

The field test described in this chapter has led to several conclusions, which give insight in the way it is used in practice and its influence on the traffic system. But it is necessary to interpret the results as good as possible. Therefore some remarks have to be made on the reliability of the analysis and the value of the results.

First of all the field test is executed with eight drivers. This amount of participants is not that much. When some result, for example an increase of the average headway, is observed for all drivers, can be said with a certain reliability that this apparently holds for almost all drivers with Adaptive Cruise Control. But when outcomes vary per driver, interpretation needs to happen carefully.

The field test contains uncertainties too. The results for example are based on the analysis of eight drivers, from which two drivers did provide only slightly more than 2:30 hours of data. The other drivers did provide more data, at least 6:30 hours. But the distribution over different traffic characteristics was not equal, and also the percentage of these trips where ACC was used. Four out of eight cars did have an ACC system on board with a lower limit. This meant that in

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

congested situations, only of four cars behavior with ACC activated was recorded. For the other four cars it was impossible to collect data in congestion with ACC activated, since ACC did not work then. This means that for certain circumstances the database was only small. This has influence on the applicability of the results. Therefore it is important when interpreting the outcome of this research, to analyze all drivers, and not to pick one driver and deeply analyze his behavior, without taking other drivers into account.

Also the collected data is car-bound, which means that the behavior of a certain car is followed. It makes sense that the main driver of the car mainly drove in the vehicle, but it is very well positive that certain trips are made by another driver, for example the partner of the main driver. This influences the outcome of the field test, since another driver behaves differently.

The data collection is done by hand for the largest part. This means that it is very well possible that errors are made when analyzing the data. Because the database is quite large, this will account for small errors, but because of the manual data preparation, the reliability of the database must be kept in mind when analyzing the results.

This research is done using two main ways of data collection: the questionnaire and the field test. This makes comparison of the results of the two possible. This is very positive. When some statement is endorsed by the objective data of the field test as well as by the subjective data of the questionnaire, this will strongly indicate that this statement is actually true.

Overall this field test gives valuable insight in the difference between driving with ACC activated and without it activated. But analysis of the results needs to be done carefully, and extrapolation of the results to all ACC-drivers in general needs to happen only with valid arguments.

4 Testing Hypotheses: Effects of ACC on Driver, Traffic Flows and Safety

5 CONCLUSIONS AND RECOMMENDATIONS

5 Conclusions and Recommendations

5.1 INTRODUCTION

This is the final chapter of this research. It contains different paragraphs. Paragraph 5.2 contains overall conclusions. In the end of this research, recommendations are formulated. Not only recommendations about further research, but also some research into future developments of ACC is done. This is included in paragraph 5.3. The last paragraph, paragraph 5.4, contains a reflection.

5 Conclusions and Recommendations

5.2 Conclusions

5.2.1 Research Outline

This research consists of a questionnaire distributed amongst 200 respondents with Adaptive Cruise Control experience, and a field test which contains eight drivers which have gained some experience using ACC already. The driving of these participants is recorded during their normal use of the car. In total these eight drivers provided almost 48 hours of driving data. The largest part of this data was collected on weekdays, during peak hours.

The results of the field test and the questionnaire are combined, and with these two databases and the literature review executed in chapter 1, an analysis is given of the influence of ACC on the driver, on traffic flows and on safety.

5.2.2 Main Conclusions

ACC leads to larger headways, but also to more constant speeds and headways, less lane changes and more car-following driving behavior. This results in more homogeneous traffic. These characteristics enable ACC to prevent shockwaves and head-tail collisions.

ACC leads to more relaxed driving and a relief of the driving task. Two third of the drivers indicates that this does not lead to a decrease of attention level, but another third does indicate they lose attention when driving with ACC. Half of this group uses this opportunity to perform more secondary activities.

Preparation before using ACC is very important, since prepared users do encounter unexpected situations when using ACC less often. Also they use ACC more prudent: they do perform less secondary activities and stay alert.

22% of the respondents of the questionnaire did not receive any instructions at all. They learn to operate ACC by using it in practice. They show less insight in the risks of using ACC. This means this group might use ACC in an unsafe way.

ACC systems which are active at all speeds are rated more positive compared to systems with a lower limit. Despite that, all systems, regardless of their range, are barely used on rural and urban roads. ACC is a system most fitted to be used on highways.

Users tend to get used to ACC quite quickly and are willing to accept the working of ACC, despite it not always performing well. They seem to easily adapt to using ACC. This is hopeful for the further development of improved ACC systems and other ADAS-systems.

ACC is less intelligent: it only looks to one predecessor. Therefore its driving style is sometimes too defensive (it brakes much too early) and sometimes too offensive (it breaks too late). Other safety risks are in the lack of preparation of some users, resulting in an invalid assessment of the risks of using ACC.

5.2.3 Detailed Overview of all Conclusions

This paragraph contains a further explanation and expansion of the previous paragraph, which contains only the most important conclusions. This paragraph is separated into four sections: ACC driver and car characteristics, the influence of ACC on driver behavior, on traffic flows and on safety.

ACC Driver and Car Characteristics

96% of all respondents of the questionnaire is male, and 93% of all respondents is at least 40 years old. 90% of all respondents owns a drivers license for 20 years or more, and 67% of all respondents drives more than 20.000 kilometers per year. This means that the respondents of the questionnaire are mainly male drivers which are older than 40 years, and have a lot of driving experience. Different car brands are present, but mainly Volvos (18% of all respondents),

5 Conclusions and Recommendations

Toyotas (14% of all respondents) and Volkswagens (14% of all respondents) have ACC on board. The average time users use ACC at the moment they answered the questionnaire was quite short: a third of all respondents only used ACC for less than 6 months, and another third for between 6 and 24 months. This probably is because ACC is installed on newer cars. The respondents of the questionnaire mainly bought or leased the ACC-equipped car themselves (94% of all respondents), a smaller part used someone else's car (5% of all respondents), or bought a used car with ACC pre-installed (1% of all respondents).

There is a difference between the average ACC driver and the reference group in terms of driving style: ACC drivers more often think of themselves as 'fast' drivers. They indicate to more often drive faster than permitted compared to the reference group and receive more traffic fines. Also they indicate they perform more secondary tasks. They are however tolerant drivers, which keep larger distances to their predecessors while driving.

The last two characteristics, more secondary tasks and a larger headway, are both known to be related to ACC. ACC could indeed lead to more secondary activities, and also it turns out that ACC usage leads to a larger headway on average. This could lead to the conclusion that ACC usage influences the driving style of its users. Regarding the amount of secondary activities, this can cause safety hazards.

The driving style of the user also influences his appreciation of ACC. Drivers who say that they are more decisive and careful and who tend to have a larger headway rate ACC higher, compared to users who are more indecisive, careless and who tend to have a smaller headway. Here a two way relation is present as well: ACC leads to larger headways, and drivers who themselves tend to have a larger headway compared to other drivers appreciate ACC more.

Influence of ACC on Driver Behavior

According to the manufacturers, a primary purpose of ACC is to make driving more comfortable and relieve the driving task. Also safety is a reason of opting for ACC; drivers are convinced it reduces the risk on head-tail collisions.

According to the results of the questionnaire, the driving task is indeed relieved when ACC is activated. The largest part of the drivers indicates that this decrease of driving task does not have any influence on their level of alertness (64% disagreed with the statement "With ACC activated, I don't need to watch traffic as much"). They stay alert so that they can interfere as soon as the situation requires that. This is something which is specifically stated by the car manufacturers in the manuals. The driver stays responsible, and must always be able to immediately take over control.

29% of all respondents admits that his attention level decreases after he activates ACC. Approximately half of this group, 13% of all respondents, uses the decrease in driving task to perform more secondary activities. The answers on the questions about losing attention and performing secondary activities can be socially biased. Therefore the part of drivers who loses attention can in reality be expected to be even bigger than this 30%. This will have a negative impact on traffic safety.

The questionnaire shows there is a strong relation between this group of 'irresponsible' drivers, and the amount of instructions they got when they started using ACC, either by reading the owner's manual or by receiving instructions from an experienced user. The less instructions a driver received, the more likely he is to perform more secondary activities or loose attention. 45% of the drivers using ACC receives instructions extensively, and 31% does slightly receive instructions before ACC usage. Obviously this percentage is highest for users who opt for ACC themselves. The users who received instructions, indicate that they are more aware of the risks. This can also be proven by the fact that ACC does less often behave unexpectedly for this group, for example by deactivating itself or by suddenly braking or accelerating.

22% of all respondents states that they did not get any instructions. Of that group, almost everyone indicates that they, despite the lack of preparation, do know what the risks of using ACC are. This can mean two different things: either they overestimate their own knowledge of the system, or they have learnt to use ACC and handle with the risks of it by practice. Either way, this might imply a safety hazard. Users who overestimate themselves are undoubtedly a risk, but

users who only learn by practice might also be a risk because the system can behave in an unforeseen way, because the users do not know exactly what could happen when using ACC.

A large part of the drivers learns ACC by using it in practice. This is visible for example in the appreciation of ACC: the longer users use ACC, the more they appreciate it. Also the group of users which is prepared before using ACC is more positive. This means that preparation makes the driver better understand and appreciate ACC. Another relation exists here as well: the users who opt for ACC themselves are more likely to get instructions before using it, and this group is per definition more positive about ACC.

Although ACC systems are present that do not have a lower limit, so which theoretically could be deployed on urban or rural roads, the appreciation of ACC on these roads is not very high. It is very high on highways and expressways. Especially in quiet traffic conditions, ACC is highly appreciated. The systems without a lower limit are also rated very positive in congested conditions on the highway. This means that ACC is a system which fits best on the highways, and users use it on these roads in particular. Users are much more positive about the ACC-systems which are active at all speeds, compared to systems with a lower limit. In general, users rate their ACC-system with an 8,03 out of 10 points.

Influence of ACC on Traffic Flows

The headway increases when users activate ACC. This is a significant increase, for all traffic conditions, and visible with all participants of the field test. The headway (from the front of the car with ACC to the back of the predecessor) increases with 16,7% in free flow conditions, and with 25,8% in capacity conditions. The spacing in congested conditions (also from the front of the car with ACC to the back of the predecessor) increases with 16,8%. This means that the capacity of the road decreases significantly, which has a negative influence on flows, especially in capacity conditions. Users also notice this, but this does not lead to lower ACC ratings. This means users are willing to accept this characteristic. Also most drivers do not manually decrease the headway.

The headways do however become more constant. Very small headways become rare. The standard deviation of the headways and the spacing decreases significantly. In free flow conditions the standard deviation of the headway decreases with 17,9%, and in capacity conditions with 23,3%. The standard deviation of the spacing in congested conditions decreases with 12,2%. This means that traffic with ACC activated will be better able to prevent and eliminate shockwaves and risks on head-tail collisions.

ACC is a speed maintaining system, so activating ACC leads to more constant speeds. In free flow conditions but also in capacity conditions, when intensities on the road are higher, the standard deviation of the speeds decreases significantly. In free flow conditions the standard deviation of the speeds decreases with 12,9%, in capacity conditions with 32,0% and in congested conditions with 0,7%.

Respondents of the questionnaire analyze these effects of ACC as well. They state that ACC leads to more steady and smooth driving behavior.

This smooth driving behavior is also visible in the amount of strong braking actions: they occur less in capacity and congested situations. In free flow conditions they increase, probably due to merging traffic in front of the car. Also accelerations are less strong compared to when ACC is not activated.

ACC has two effects on the position on the highway. A group of users exists who more often decides to follow another car, instead of overtaking. This car-following behavior leads to an increase of use of the right lane. Another group exists who often does choose to overtake other cars, and this group needs a very large headway to return to the right lane, because otherwise their ACC will immediately start braking again. Therefore they more often decide to stay in the left lane. This results in more use of the left lane. It differs per driver which effect is visible. Not only the field test shows this behavior, but also the questionnaire indicates that two different kinds of users are present regarding the position on the highway.

5 Conclusions and Recommendations

Both the questionnaire and the field test show a strong decrease in amount of lane changes when ACC becomes active, especially in free flow- or capacity conditions (decrease of respectively 16,6% and 30,7%). Apparently more car-following behavior is shown by drivers when activating ACC.

Influence of ACC on Traffic Safety

According to ACC users, the risk of getting a head-tail collision reduces when using ACC. This makes them indicate that ACC leads to safer traffic conditions. However some threats occur: ACC sometimes leads to strong braking when another car merges in front of the vehicle with ACC. This is also detected in the field test: in free flow conditions the amount of strong braking actions increases when ACC is activated.

Activating Adaptive Cruise Control makes users more aware of the speed limits. They deliberately adapt the set speed of ACC to this limit. This leads to less speed limit violations. Both the questionnaire and the field test showed this.

5 Conclusions and Recommendations

5.3 RECOMMENDATIONS

Based on this research several recommendations can be made. These are described in this paragraph. First some notions about this research and how it can be improved are made, and then in two different paragraphs future scenarios will be described. First the development of ACC itself will be described, and then the advanced system CACC will be elaborated.

The conclusions of this research are based on a Field Operation Test and a questionnaire. Together these two provide a wide view on the influence of ACC on the driver, on traffic flows and on safety. But this provided only a view on ACC use in general. On a very detailed level, this research is not precise enough. For example how drivers react on certain situations when ACC is activated is not known.

Therefore further research to the alertness of the driver is necessary. The way a driver copes with for example a car merging in front of his car needs to be further elaborated to really investigate in detail how a driver reacts on certain situations when ACC is activated. This can be done by detecting the behavior of the driver himself, which is something which is not done in this research.

Also other ADAS systems need to be elaborated. Several other driving assistance systems are available, and for these systems the same goes as for ACC: further research is necessary to assess the influence of it on driver, traffic flows and safety.

5.3.1 RECOMMENDED DEVELOPMENTS OF ACC

At the moment, several car manufacturers are developing ACC even more. Visible in the newest car models is that the systems get better and better. One of the relatively new features is that ACC can be adjusted not only in terms of headway, but also in the way it reacts. Different settings are available, from a very defensive driving style to a very offensive driving style, which means the system brakes relatively late and accelerates stronger. This is very positive, since this research stated that users have very different driving styles, and to fit as much as possible with as many drivers as possible, it is very important that ACC is customizable. That way, every driver, despite his or her driving style, can alter the ACC system in such a way that it fits perfectly with his own preferences. Already algorithms are present that use the behavior of a human driver to design an improved ACC system (*Luo, 2015*). Other systems predict the behavior of the driver based on demographic characteristics and fine-tune the ACC settings based on the driving characteristics after a certain time of usage (*Rosenfeld et al., 2015*). These alterations on the ACC system are positive, but only as long as the advantages of ACC keep being present. When ACC reacts exactly the same as a human driver does, its advantages regarding flows and safety are eliminated.

Another development going on at the moment is a better integration of ACC with the other aid systems present on a car. ACC is for example often combined with lane assist, to even further relieve the driving task. But to prevent these systems from allowing the driver to lose attention, detection systems are present to ensure the driver stays alert. Especially the systems that keep the driver alert are very necessary. This research states that drivers tend to use ACC without proper preparation. This could lead to attention loss. Systems which are available to prevent that are highly recommended.

Not only the ACC system itself needs to be improved to keep the driver alert, but also the driver himself can be instructed to use ACC more wisely. The questionnaire showed that more than a fifth of the ACC users does not get any instructions, and an even larger part of the users does get only a little bit of instructions. This must be improved to guarantee safe use of the system. The development of ACC, but also of ADAS systems in general, goes very fast. Therefore it is recommended to make these systems part of the driving education novice drivers receive before getting their driving license. Users have to get used to systems which support driving.

Also devices like a head-up display can be helpful to keep the driver alert (*Rankin & Thompson, 2015*). The head-up display enables the driver to keep an eye on traffic, while at the same time having clear what the ACC settings are, and if the system is active or not.

5 Conclusions and Recommendations

The increase of the average headway decreases the capacity of the road. But despite the decrease of capacity, some advantages of ACC are related to the large headway. This research showed that the average headway becomes much more constant, and that very small headways are prevented. Also the speed becomes more constant, and under capacity and congested conditions, the amount of strong decelerations decreased. These advantages are only partly possible when the average headway of the ACC system decreases again.

Therefore there has to be a way in which the positive influence of ACC on traffic flows can be maintained, but also the average headway decreased. This is possible when ACC not only detects the predecessor, but also the car in front of the predecessor. The more vehicles ACC can detect, the better it can alter its behavior. This way, the headway can safely be decreased, and ACC will still be able to drive more smoothly and equally than a manual driver does. In the paragraph about Cooperative Cruise Control this will be further elaborated.

This functionality is not only useful to watch further ahead, but also it would mean an improvement when ACC is able to look to the right and left. This could prevent ACC from braking hard and unexpectedly when another vehicle merges in front of the car.

Several other functionalities are elaborated at the moment. An ACC algorithm which not only takes into account the predecessor but also road inclinations, speed limits and traffic information is developed (*Németh & Gáspár, 2013*). This means that ACC gets smarter and is even better able to have a positive influence on traffic flows and safety. According to the designer of this algorithm, the number of unnecessary accelerations and brakings and their durations can be significantly reduced.

Basically several alterations are possible which will make ACC even more in line with the expectations of the driver, and also maximize the positive effect of ACC on flows and safety. One of the most important ones is Cooperative ACC. This will be elaborated in the next paragraph.

5.3.2 Cooperative Adaptive Cruise Control

This research focused on ACC. But will it also be able to make predictions about CACC? CACC is an addition to ACC where cars also communicate with each other (the so called V2V, vehicle to vehicle communication). This means basically that the car becomes an active part of a larger entity of vehicles which together determines what the ideal driving behavior is. This will in the beginning of the implementation of CACC be mainly advisory, where the car advises the driver to drive in a certain lane for example, but expectations are that in the end the car take over these tasks itself.

This research showed how the driver reacts to the system. It stands out that a driver easily accepts that the car takes over control regarding maintaining speeds and headways. This will probably also be the case when ACC is replaced by CACC. Especially the group of early adopters is enthusiastic about these systems, and uses them frequently. This means that implementation of CACC is possible. The implementation of such a system does not take place instantly, but, just like ACC, first a small group of early adopters will opt for it. Then, when time passes, more and more users will get to know the system, and implementation will go on and on. And when the system is expanded with an advisory system about lane choice for example, these early adapters will easily embrace this. And when they do, the rest of the drivers will eventually follow.

Several sources indicate that CACC will perform even better than ACC, and that its influence, especially on traffic flows will be even more positive. One of the main disadvantages of ACC is the large headway, resulting in a decrease of road capacity. CACC will especially be able to more intelligently choose position, headway and speed based on other cars information. This means that the headway can be decreased, without losing the advantages of ACC like a more stable and smooth traffic stream.

Even more advantages can be achieved when several CACC-equipped cars can drive behind each other. The car in front will do the actual driving, and the other cars just follow the leading car. This means some new challenges occur, like on which lane this ‘train’ has to drive to not disturb other traffic, but the advantages are clear. Headways can become

5 Conclusions and Recommendations

very clear since the reaction time between the different cars is very small. All cars communicate, so it is possible to reduce headways and thus increase road capacity and decrease accidents and fuel usage.

Some research indicates (*Wang et al., 2012*) that it is possible to design Adaptive Cruise Control systems which are stable even when several cars with Adaptive Cruise Control are driving in a platoon, but other sources indicate that these cars could create instability (*Milanés & Shladover, 2014*, *Milanes et al., 2014*). This instability can be prevented by CACC, according to the same research. The cars all communicate with each other, and this enables them to choose the path, speed and headway in such a way that all cars drive stable.

Especially when CACC consists of several cars driving in a platoon, this research cannot be used to assess its influence. Such a system is very different compared to ACC, and drivers will react differently to it. But when CACC is implemented in the same way as ACC, the results of this research are to some extent applicable to CACC.

Also traffic characteristics can even better be taken into account. When a car is able to collect data about traffic conditions down the road, it can adjust its driving style based on this information. For example, when other cars communicate that a moving jam is approaching, the car can already autonomously decelerate to help resolve this jam (*Netten et al., 2010*).

Some authority needs to be appointed to design this system in the Netherlands. Several cars are connected to this authority. This means that this road authority can collect all data the connected cars provide, and based on that data and on roadside information, targeted information and advice can be sent to every driver. Drivers are willing to listen to this advice, and indeed change lanes for example when the system tells them to (*Van Arem, 2013*).

A lot of research is already done regarding the behavior of CACC equipped vehicles in a platoon, the most recent one being *Milanes et al., 2014*. But when CACC will be implemented, it is unlikely that it will be implemented in this way. It is impossible to install CACC systems which only can work as expected when another car with exactly the same system drives the same road. The implementation will much more likely be in the shape of an ACC system which can operate autonomously, and which can communicate with other vehicles on the highway when the opportunity is there. This means that the first commercially available CACC systems will only be able to communicate over large distances, and based on this communication and the information the cars upstream provide, advice is given.

To really assess the influence of CACC on driver behavior and to test whether the driver is willing to follow advice about his driving behavior it is necessary to conduct further research. Not only to cars with CACC driving in a platoon, but also to a type of CACC that functions as a normal ACC, only with more detailed speed, headway and lane advice based on the traffic conditions upstream. The way the user reacts to this system must be elaborated in the future. This means a research like this one, into CACC is strongly advised.

5 Conclusions and Recommendations

5.4 REFLECTION

The American philosopher John Dewey said: “We do not learn from experience … we learn from reflecting on experience”. And even researchers at Harvard found out this was true (*Di Stefano et al., 2015*). Therefore, in this paragraph, a reflection on the research will be given.

The process leading to this report consisted of several different phases. First determination of the subject was necessary. This contained research into literature to see on which subject research is necessary, and talking to professionals, and attending lectures and conferences about the subject. This was very interesting to me and I noticed I liked doing this.

Then, after determining the subject and the research outline, I started designing a questionnaire, and searching for ways to distribute that questionnaire among as much ACC users as possible. This was very practical, and I got the opportunity to work with people from Royal HaskoningDHV, the TU Delft, and ANWB. Talking to these people and learning from them was very interesting and I learned a lot from them. Also I had to design a field test. Approaching participants, determining which equipment I needed, and testing was fun. I really liked doing these practical things, and noticing this was going to work and this test provided the data I needed. Then installing the cameras in the cars, responding to the answers of the participants and anticipating on everything that went wrong was necessary. This phase of the research was really interesting and it sharpened my problem-solving skills.

Then, when enough data was provided, I needed to analyze all these data. And I have to say that this was much more work than I expected. All camera images needed to be watched and analyzed. This was a lot of work.

But when all necessary data was prepared and a proper database was designed, the statistical research could begin. This was really interesting. I knew that the database I had collected was valuable, but it turned out that a lot more information was in the database than I expected. Striving to extract a maximum amount of information with a maximum reliability was hard, but definitely very interesting. Especially the questionnaire database contained a wealth of information.

Then when all analyses necessary were executed, I started working on my report. This meant that, after all research was done, a lot of work was necessary to finish the report. It would have been wiser to start writing the report earlier on, but earlier in the process I needed all my attention to make sure the field test, the questionnaire and the data preparation went well. Therefore the last two months of my research consisted of writing the report. I have to admit this was the phase in the research I found the hardest. I am much more of a practical person, and writing the theoretical report for such a long time was challenging. I have tried my best to write the report in an understandable and clear way, and to separate results from interpretation, and so on.

Overall, I am confident with this result, and I hope this research will contribute to the knowledge available about Adaptive Cruise Control and its influence on the roads.

BIBLIOGRAPHY

Bibliography

Alkim, T., Bootsma, G., & Looman, P. (2007). The Assisted Driver - Systems that support driving. Delft: Rijkswaterstaat.

Audi. (2013). Adaptive Cruise Control. Retrieved 22-07-2015, 2015, from https://www.youtube.com/watch?v=cs7tCD3NpCg

Beggiato, M., & Krems, J. (2013). The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. *Transportation Research Part F: Traffic Psychology and Behaviour, 18*, 47-57.

Bianchi Piccinini, G., Rodrigues, C., Leitão, M., & Simões, A. (2014). Driver's behavioral adaptation to Adaptive Cruise Control (ACC): The case of speed and time headway. *Journal of Safety Research, 49*, 77.e71-84.

Bianchi Piccinini, G., Rodrigues, C., Leitão, M., & Simões, A. (2015). Reaction to a critical situation during driving with Adaptive Cruise Control for users and non-users of the system. *Safety Science, 72*, 116-126.

Blackstone, S. (2012, 28-08-2012). Adaptive Cruise Control Will Change Driving In America. *Business Insider*.

BMW. (2014). The BMW 7 Series - Owners Manual. In B. AG (Ed.). München.

Chundrlik, W.J., & Labuhn, P.I. (1991). Detroit, MI Patent No. US5014200 (A). G.M. Corporation.

Continental. (2015). Drive and enjoy relaxed driving with ACC. Retrieved 22-07-2015, 2015, from http://www.continental-automotive.com/www/automotive_de_en/themes/passenger_cars/chassis_safety/adas/acc_en.html

de Winter, J., Happee, R., Martens, M., & Stanton, N. (2014). Effects of adaptive cruise control and highly automated driving on workload and situation awareness: A review of the empirical evidence. *Transportation Research Part F: Traffic Psychology and Behaviour*.

Di Stefano, G., Gino, F., Pisano, G.P., & Staats, B.R. (2015). Learning by Thinking: Overcoming the Bias for Action through Reflection. Cambridge, MA, USA: Harvard Business School.

Dickie, D., & Boyle, L. (2009). Drivers' Understanding of Adaptive Cruise Control Limitations. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 53*(23), 1806-1810.

Donker, J. (2014). Adaptatie van Rijtaakondersteuning - Een momentopname van de Huidige Adaptatie en Verwachtingen in Rijtaakondersteunende Technologie (pp. 35). Den Haag: Ministerie van I&M.

Flemming, J.v.C.A. (2012). iCar - implementation status survey by use of OEM data - 2012 Deployment state in EU member states (pp. 44). Dresden, Germany: FSD Fahrzeugsystemdaten GmbH.

Hoedemaeker, M., & Brookhuis, K.A. (1998). Behavioural adaptation to driving with an adaptive cruise control (ACC). *Transportation Research Part F: Traffic Psychology and Behaviour, 1*(2), 95-106.

Kazi, T., Stanton, N., Walker, G., & Young, M. (2007). Designer driving: drivers' conceptual models and level of trust in adaptive cruise control. *International Journal of Vehicle Design, 45*(3), 339-360.

Kesting, A., Treiber, M., Schönhof, M., & Helbing, D. (2008). Adaptive cruise control design for active congestion avoidance. *Transportation Research Part C: Emerging Technologies, 16*(6), 668-683.

Knapper, A., Christoph, M., Hagenzieker, M., & Brookhuis, K. (2015). Comparing a driving simulator to the real road regarding distracted driving speed. *European Journal of Transport and Infrastructure Research, 15*(2), 205-225.

Larsson, A. (2012). Driver usage and understanding of adaptive cruise control. *Applied Ergonomics, 43*(3), 501-506.

Larsson, A., Kircher, K., & Andersson Hultgren, J. (2014). Learning from experience: Familiarity with ACC and responding to a cut-in situation in automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour*.

Lee, R.M. (1993). *Doing Research on Sensitive Topics*. Thousand Oaks, USA: SAGE Publications ltd.

Luo, L. (2015). *Adaptive cruise control design with consideration of humans' driving psychology.* Paper presented at the 2014 11th World Congress on Intelligent Control and Automation, WCICA 2014.

Marsden, G., McDonald, M., & Brackstone, M. (2001). Towards an understanding of adaptive cruise control. *Transportation Research Part C: Emerging Technologies, 9*(1), 33-51.

Milanés, V., & Shladover, S. (2014). Modeling cooperative and autonomous adaptive cruise control dynamic responses using experimental data. *Transportation Research Part C: Emerging Technologies, 48*, 285-300.

Milanes, V., Shladover, S.E., Spring, J., Nowakowski, C., Kawazoe, H., & Nakamura, M. (2014). Cooperative Adaptive Cruise Control in Real Traffic Situations. *Intelligent Transportation Systems, IEEE Transactions on, 15*(1), 296-305.

Mitchell, W.J., Borroni-Bird, C.E., & Burns, L.D. (2010). *Reinventing the Automobile: Personal Urban Mobility for the 21st Century*. Cambridge MA, US: MIT Press.

Németh, B., & Gáspár, P. (2013). Design of vehicle cruise control using road inclinations. *International Journal of Vehicle Autonomous Systems, 11*(4), 313-333.

Netten, B.D., van den Broek, T.H.A., & Blom, G. (2010, November 3). A270 Demo Schokgolfdemping. *Nationaal Verkeerskundecongres*.

Özkan, T., Lajunen, T., Chliaoutakis, J., Parker, D., & Summala, H. (2006). Cross-cultural differences in driving behaviours: A comparison of six countries. *Transportation Research Part F: Traffic Psychology and Behaviour, 9*(3), 227-242.

Bibliography

Pauwelussen, J., & Feenstra, P.J. (2010). Driver Behavior Analysis During ACC Activation and Deactivation in a Real Traffic Environment. *Intelligent Transportation Systems, IEEE Transactions on, 11*(2), 329-338.

Pauwelussen, J., & Minderhoud, M. (2008). *The effects of deactivation and (re)activation of ACC on driver behaviour analyzed in real traffic.* Paper presented at the Intelligent Vehicles Symposium, 2008 IEEE.

Rajaonah, B., Anceaux, F., & Vienne, F. (2006). Trust and the use of adaptive cruise control: a study of a cut-in situation. *Cognition, Technology & Work, 8*(2), 146-155.

Rakha, H., Hankey, J., Patterson, A., & Aerde, M. (2001). Field Evaluation of Safety Impacts of Adaptive Cruise Control. *ITS Journal - Intelligent Transportation Systems Journal, 6*(3), 225-259.

Rankin, A., & Thompson, J. (2015). Next-generation head-up displays. *Information Display, 31*(3).

Reason, J., Manstead, A., Stradling, S., Baxter, J., & Campbell, K. (1990). Errors and violations on the roads: a real distinction? *Ergonomics, 33*(10-11), 1315-1332.

Rosenfeld, A., Bareket, Z., Goldman, C.V., Leblanc, D.J., & Tsimhoni, O. (2015). Learning drivers behavior to improve adaptive cruise control. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations, 19*(1), 18-31.

Rudin-Brown, C., & Parker, H. (2004). Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies. *Transportation Research Part F: Traffic Psychology and Behaviour, 7*(2), 59-76.

SAE. (2014). SAE International Technical Standard Provides Terminology for Motor Vehicle Automated Driving Systems [Press release]. Retrieved from http://www.sae.org/servlets/pressRoom?OBJECT_TYPE=PressReleases&PAGE=showRelease&RELEASE_ID=2715

Schultz van Haegen, M. (2014, 16 june 2014). [Grootschalige Testen van Zelfrijdende Auto's].

Škoda. (2015). Operating Instructions Škoda Octavia. In Škoda (Ed.). Mladá Boleslav.

Strand, N., Nilsson, J., Karlsson, I.C.M., & Nilsson, L. (2011). Exploring end-user experiences: Self-perceived notions on use of adaptive cruise control systems. *Intelligent Transport Systems, IET, 5*(2), 134-140.

Suzuki, H., & Nakatsuji, T. (2003). Effect of adaptive cruise control (ACC) on traffic throughput: numerical example on actual freeway corridor. *JSAE Review, 24*(4), 403-410.

Van Arem, B. (2013). Connected Cruise Control. Delft: Agentschap NL.

van Arem, B., van Driel, C.J.G., & Visser, R. (2006). The Impact of Cooperative Adaptive Cruise Control on Traffic-Flow Characteristics. *Intelligent Transportation Systems, IEEE Transactions on, 7*(4), 429-436.

Van Eemeren, F.H., & Grootendorst, R. (1992). *Argumentation, Communication, and Fallacies - A Pragma-Dialectical Perspective*. Mahwah, USA: Lawrence Erlbaum Associates Inc.

van Twuijver, M., & Pol, M. (2004). Car Owners Experiences with In-Car Speed Controlling Systems in the Netherlands. Henley-in-Arden, UK: Association for European Transport.

Viti, F., Hoogendoorn, S.P., Alkim, T.P., & Bootsma, G. (2008). *Driving behavior interaction with ACC: results from a Field Operational Test in the Netherlands.* Paper presented at the Intelligent Vehicles Symposium, 2008 IEEE.

Volkswagen. (2013). De Nieuwe Golf - Adaptive Cruise Control. Retrieved 20-07-2015, from https://www.youtube.com/watch?v=A6t-GfxFe-w

Vollrath, M., Schleicher, S., & Gelau, C. (2011). The influence of Cruise Control and Adaptive Cruise Control on driving behaviour – A driving simulator study. *Accident Analysis & Prevention, 43*(3), 1134-1139.

Volvo. (2014). Volvo V40 Owners Manual. In Volvo (Ed.).

Wang, M., Daamen, W., Hoogendoorn, S.P., & van Arem, B. (2012, October 30-31). Modelling Driver Assistance Systems by Optimal Control. *TRAIL Beta-Congress: Mobility and logistics - Science Meets Practice*.

Wang, M., Treiber, M., Daamen, W., Hoogendoorn, S., & van Arem, B. (2013). Modelling supported driving as an optimal control cycle: Framework and model characteristics. *Transportation Research Part C: Emerging Technologies, 36*, 547-563.

Weinberger, M., Winner, H., & Bubb, H. (2001). Adaptive cruise control field operational test—the learning phase. *JSAE Review, 22*(4), 487-494.

Wells, P., Tong, S., Sexton, B., Grayson, G., & Jones, E. (2008a). Cohort 2 - A study of learner and new drivers. Volume 1 - Main report (Vol. 1). London: Department for Transport.

Wells, P., Tong, S., Sexton, B., Grayson, G., & Jones, E. (2008b). Cohort 2 - A study of learner and new drivers. Volume 2 - Questionnaires and Data Tables (Vol. 2). London: Department for Transport.

Xiong, H., Boyle, L., Moeckli, J., Dow, B., & Brown, T. (2012). Use Patterns Among Early Adopters of Adaptive Cruise Control. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 54*(5), 722-733.

APPENDIX 1

QUESTIONNAIRE WITH RESPONSES

Beginpagina

Deze enquête gaat over het gebruik van Adaptive Cruise Control. ACC is een optioneel pakket op verschillende modellen auto's. Het is een systeem dat met behulp van radar detecteert waar de voorganger van de auto zich bevindt. Op basis daarvan past hij de snelheid van de auto aan.

Deze vragenlijst is opgesteld in het kader van mijn afstudeeronderzoek. In dit onderzoek bestudeer ik de invloed van Adaptive Cruise Control op het gedrag van de bestuurder, en op de veiligheid en de doorstroming op de weg. Zo kunnen de uitkomsten van dit onderzoek meehelpen om ACC in de toekomst te verbeteren en het nog comfortabeler en veiliger te maken. En misschien kan ACC wel een rol spelen in het oplossen van files in Nederland!

Om betrouwbaar onderzoek te doen, heb ik úw hulp nodig. Hebt u ervaring met het gebruik van ACC, dan stel ik uw mening zeer op prijs! Het invullen van deze enquête kost ongeveer 10 minuten en het is volledig anoniem.

Als u de vragenlijst volledig invult, kunt u kans maken op één van de vier VVV-bonnen van €25. Wilt u meedoen, laat dan aan het einde van de enquête uw e-mailadres achter.

Bent u geïnteresseerd in de uitkomsten van mijn onderzoek? Houd dan rond juli 2015 de autopagina van de ANWB in de gaten. Daar zal een artikel met de onderzoeksresultaten gepubliceerd worden.

Alvast vriendelijk bedankt voor het invullen!

Mark Gorter

Afstudeerder bij Royal HaskoningDHV

1. Inleiding

Bent u een man of een vrouw?

O	Man	255 (94%)
O	Vrouw	12 (4%)

Wat is uw leeftijd?

O	Jonger dan 18 jaar oud	1 (0%)
O	18 - 19 jaar oud	1 (0%)
O	20 - 29 jaar oud	20 (7%)
O	30 - 39 jaar oud	21 (8%)
O	40 - 49 jaar oud	61 (23%)
O	50 - 59 jaar oud	52 (19%)
O	60 jaar of ouder	111 (42%)

Bent u in het bezit van een auto-rijbewijs (B of BE)?

O	Ja	265 (99%)
O	Nee	2 (1%)

Als Leeftijd bevat "Jonger dan 18 jaar oud" *OF Rijbewijs bevat* "Nee" ***Beëindig vragenlijst***

Hoeveel jaar bent u in het bezit van een rijbewijs?

O	0 - 1 jaar	1 (0%)
O	2 - 4 jaar	6 (2%)
O	5 - 9 jaar	10 (4%)
O	10 - 19 jaar	27 (10%)
O	20 jaar of meer	217 (83%)

Hoeveel kilometer per jaar rijdt u in totaal (zakelijk én privé)?

Om de inschatting gemakkelijker te maken, staat het aantal kilometers per week ook vermeld.

O	Minder dan 10.000 km/jaar (190 km/week)	21 (8%)
O	Tussen de 10.000 en 20.000 km/jaar (190 - 385 km/week)	79 (30%)
O	Tussen de 20.000 en 30.000 km/jaar (385 - 575 km/week)	73 (28%)
O	Tussen de 30.000 en 40.000 km/jaar (575 - 770 km/week)	46 (18%)
O	Meer dan 40.000 km/jaar (770 km/week)	41 (16%)

2. Gebruik ACC

Hebt u ervaring met Adaptive Cruise Control?

Ervaring betekent dat u regelmatig (wekelijks of vaker) een auto met ACC gebruikt.

O	Ja	230 (89%)
O	Nee ***Naar 4. Rijstijl***	29 (11%)

Hebt u ervaring met meerdere soorten auto's met ACC, vul dan deze enquete in betreffende de auto waarmee u de meeste ervaring heeft.

Van welk automerk is deze auto met ACC?

O	Audi	17 (8%)
O	BMW	24 (11%)
O	Citroën	6 (3%)
O	Ford	9 (4%)
O	Mazda	4 (2%)
O	Mercedes-Benz	12 (5%)
O	Mitsubishi	8 (4%)
O	Opel	2 (1%)
O	Peugeot	21 (9%)
O	Seat	0 (0%)
O	Škoda	4 (2%)
O	Suzuki	0 (0%)
O	Volkswagen	29 (13%)
O	Volvo	39 (17%)
O	Anders, namelijk:	50 (22%)

Heeft deze auto met ACC een automatische of een handgeschakelde versnellingsbak?

O	Automatische versnellingsbak	178 (79%)
O	Handgeschakelde versnellingsbak	47 (21%)

Heeft dit ACC-systeem een ondergrens of blijft het actief bij lage snelheden?

O	Het deactiveert onder een bepaalde snelheid (meestal rond de 50 km/u)	112 (50%)
O	Het blijft actief totdat de auto stilstaat	84 (37%)
O	Dat weet ik niet	29 (13%)

Heeft dit ACC-systeem een instelbare volgafstand?

O	Ja, er zijn verschillende standen instelbaar	208 (92%)
O	Nee, er is maar één stand mogelijk	11 (5%)
O	Dat weet ik niet	6 (3%)

Van wie is de auto met ACC die u gebruikt?

O	Het is mijn eigen auto	135 (61%)
O	Het is een (lease)auto van het bedrijf	68 (31%)
O	Het is een huurauto/deelauto	3 (1%)
O	Het is een auto van een familielid of kennis	11 (5%)
O	Anders, namelijk:	5 (2%)

Hoe gebruikt u deze auto met ACC?

O	(Bijna) alleen privé	98 (44%)
O	(Bijna) alleen zakelijk	16 (7%)
O	Privé en zakelijk	108 (49%)

Hoe lang hebt u rij-ervaring in deze auto met ACC?

O	Minder dan 3 maanden	35 (16%)
O	Tussen de 3 en de 6 maanden	33 (15%)
O	Tussen de 6 maanden en 1 jaar	32 (14%)
O	Tussen de 1 en 2 jaar	46 (21%)
O	Meer dan 2 jaar	76 (34%)

Hoeveel kilometer per week rijdt u gemiddeld in deze auto met ACC?

O	Minder dan 200 km/week	43 (19%)
O	Tussen de 200 en 400 km/week	85 (38%)
O	Tussen de 400 en 600 km/week	50 (23%)
O	Tussen de 600 en 800 km/week	29 (13%)
O	Meer dan 800 km/week	15 (7%)

Wanneer hebt u voor het laatst gebruik gemaakt van deze auto met ACC?

O	Minder dan een half jaar geleden geleden	200 (90%)
O	Meer dan een half jaar geleden	22 (10%)

Heeft u bewust voor ACC gekozen?

O	Ja, ik heb bewust gekozen voor ACC	87 (40%)
O	Ja, ik heb bewust gekozen voor een pakket waar ACC in zit	51 (23%)
O	Nee, ik heb niet bewust gekozen voor ACC	58 (26%)
O	Nee, een ander heeft gekozen voor ACC	14 (6%)
O	Anders, namelijk:	9 (4%)

Bent u voor het gebruik van deze auto met ACC voorgelicht over de werking ervan, bijvoorbeeld door een uitleg van de autodealer, of door het instructieboekje te lezen?

O	Ja, ik ben uitgebreid voorgelicht over ACC	92 (42%)
O	Ja, ik ben een klein beetje voorgelicht over ACC	69 (32%)
O	Nee, ik ben niet voorgelicht over ACC	53 (24%)
O	Dat weet ik niet meer	5 (2%)

Bent u zich bewust van de beperkingen en risico's van Adaptive Cruise Control?

O	Ja, ik ben me volledig bewust van de beperkingen en risico's	141 (64%)
O	Ja, ik weet ongeveer waar ik op moet letten	61 (28%)
O	Nee, daar houd ik me niet of nauwelijks mee bezig	14 (6%)
O	Anders, namelijk:	3 (1%)

3. Ervaring met ACC

Geef voor elk wegtype aan of u ACC prettig vindt om te gebruiken.

	Zeer onprettig	Onprettig	Neutraal	Prettig	Zeer prettig
Op wegen binnen de bebouwde kom	40 (18%)	48 (22%)	62 (29%)	48 (22%)	19 (9%)
Op provinciale wegen buiten de bebouwde kom	6 (3%)	14 (6%)	37 (17%)	77 (35%)	83 (38%)
Op autowegen	5 (2%)	11 (5%)	18 (8%)	66 (30%)	117 (54%)
Op autosnelwegen	6 (3%)	13 (6%)	15 (7%)	50 (23%)	133 (61%)

Ruimte voor een eventuele toelichting:

Deze vraag heeft betrekking op de snelweg. Geef voor elke mate van verkeersdrukte aan of u ACC fijn vindt om te gebruiken.

	Zeer onprettig	Onprettig	Neutraal	Prettig	Zeer prettig
Weinig tot geen verkeer - geen interactie met andere voertuigen.	4 (2%)	2 (1%)	19 (9%)	47 (22%)	145 (67%)
Gemiddelde verkeersdrukte - af en toe interactie met andere voertuigen.	3 (1%)	8 (4%)	22 (10%)	78 (36%)	106 (49%)
Veel verkeer - (bijna) continu interactie met andere voertuigen.	19 (9%)	50 (23%)	44 (20%)	59 (27%)	45 (21%)
Grote verkeersdrukte - langzaamrijdend verkeer of file.	44 (20%)	44 (20%)	41 (19%)	25 (12%)	63 (29%)

Ruimte voor een eventuele toelichting:

De volgende stellingen gaan over uw rijtaak wanneer u ACC aan heeft, vergeleken met wanneer u ACC niet aan heeft.

Kunt u bij elke stelling aangeven in hoeverre u het er mee eens bent?

	Zeer mee oneens	Mee oneens	Enigszins mee oneens	Neutraal	Enigs-zins mee eens	Mee eens	Zeer mee eens
Als ik ACC aan heb, kost het autorijden me minder inspanning	3 (1%)	11 (5%)	14 (6%)	20 (9%)	34 (16%)	74 (34%)	60 (28%)
Als ik ACC aan heb, hoef ik minder op het verkeer te letten	39 (18%)	78 (36%)	21 (10%)	14 (6%)	45 (21%)	18 (8%)	1 (0%)
Als ik ACC aan heb, doe ik meer activiteiten tijdens het autorijden (bellen, smartphone gebruiken, ...)	87 (40%)	68 (31%)	9 (4%)	24 (11%)	18 (8%)	8 (4%)	2 (1%)

Ruimte voor een eventuele toelichting:

De volgende stellingen gaan over de veiligheid wanneer u ACC aan heeft, vergeleken met wanneer u ACC niet aan heeft.

Kunt u bij elke stelling aangeven in hoeverre u het er mee eens bent?

	Zeer mee oneens	Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens	Zeer mee eens
Als ik ACC aan heb, loop ik minder risico op een kop-staart-botsing	4 (2%)	12 (6%)	6 (3%)	7 (3%)	41 (19%)	90 (42%)	55 (26%)
Als ik ACC aan heb, kom ik minder vaak in onveilige situaties terecht	5 (2%)	16 (7%)	16 (7%)	37 (17%)	48 (22%)	70 (33%)	23 (11%)
Als ik ACC aan heb, rijd ik minder vaak sneller dan de maximumsnelheid	11 (5%)	22 (10%)	9 (4%)	25 (12%)	22 (10%)	77 (36%)	49 (23%)
Als ik ACC aan heb, heb ik meer tijd nodig om in te grijpen door te remmen of bij te sturen als dat nodig is	35 (16%)	84 (40%)	24 (11%)	28 (13%)	19 (9%)	20 (9%)	4 (2%)
Ik zou liever hebben dat ACC alleen een melding en/of geluidssignaal gaf, in plaats van actief in te grijpen	79 (37%)	86 (40%)	13 (6%)	14 (7%)	12 (6%)	6 (3%)	5 (2%)

Ruimte voor een eventuele toelichting:

Geef aan hoe vaak de volgende situaties voorkomen als u ACC aan heeft staan.

	Helemaal nooit	Bijna nooit	Af en toe	Regelmatig	Vaak	Bijna altijd	Altijd
U geeft gas bij om de afstand tot uw voorganger kleiner te maken omdat de ACC een te grote afstand aanhoudt	30 (14%)	61 (28%)	63 (29%)	31 (14%)	21 (10%)	7 (3%)	2 (1%)
Een auto voegt in tussen u en uw voorganger, en uw auto reageert door fors te remmen	12 (6%)	36 (17%)	82 (38%)	48 (22%)	22 (10%)	8 (4%)	7 (3%)
U geeft gas bij om een andere auto in te halen, omdat uw auto anders afremt voor die auto	12 (6%)	32 (15%)	69 (32%)	47 (22%)	31 (14%)	19 (9%)	5 (2%)
In een scherpe bocht verliest de ACC van uw auto zicht op uw voorganger, en dus versnelt uw auto onverwacht	44 (20%)	79 (37%)	47 (22%)	24 (11%)	12 (6%)	8 (4%)	1 (0%)
ACC schakelt plotseling uit terwijl u het niet verwacht	112 (52%)	70 (33%)	24 (11%)	5 (2%)	3 (1%)	1 (0%)	0 (0%)
ACC remt of versnelt plotseling terwijl u dat niet verwacht	72 (33%)	77 (36%)	46 (21%)	10 (5%)	8 (4%)	2 (1%)	0 (0%)

Zijn er andere situaties die u meemaakt of meegemaakt heeft tijdens het gebruik van ACC die u als onveilig of onprettig ervaart?

Vermeld bij de situatie ook hoe vaak het voorkomt.

De volgende stellingen gaan over de doorstroming wanneer u ACC aan heeft, vergeleken met wanneer u ACC niet aan heeft.

Kunt u bij elke stelling aangeven in hoeverre u het er mee eens bent?

	Zeer mee oneens	Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens	Zeer mee eens
Als ik ACC aan heb, rijd ik gelijkmatiger (dus ik hoef minder vaak te remmen en op te trekken)	6 (3%)	15 (7%)	11 (5%)	15 (7%)	33 (16%)	92 (43%)	40 (19%)
Als ik ACC aan heb, houd ik meer afstand tot mijn voorganger	2 (1%)	8 (4%)	5 (2%)	17 (8%)	32 (15%)	104 (49%)	44 (21%)
Als ik ACC aan heb, wissel ik minder vaak van rijstrook op de snelweg	2 (1%)	30 (14%)	20 (9%)	34 (16%)	41 (19%)	72 (34%)	13 (6%)
Als ik ACC aan heb, rijd ik meer op de rechterrijstrook op de snelweg	9 (4%)	45 (21%)	21 (10%)	48 (23%)	38 (18%)	41 (19%)	10 (5%)

Ruimte voor een eventuele toelichting:

Kunt u met behulp van de schuifbalk een rapportcijfer geven aan het ACC-systeem waar u ervaring mee heeft?

(1 is buitengewoon negatief - 10 is buitengewoon positief)

Kunt u toelichten waarom u dit cijfer gegeven heeft?

Geef aan of u het eens bent met de volgende stelling:

Ik zou Adaptive Cruise Control aanbevelen aan een ander.

O	Zeer mee eens	97 (48%)
O	Mee eens	67 (33%)
O	Neutraal	23 (11%)
O	mee oneens	7 (3%)
O	Zeer mee oneens	7 (3%)
O	Dat weet ik niet	2 (1%)

Hebt verder nog andere ervaringen, opmerkingen of tips over de vormgeving en het gebruik van Adaptive Cruise Control?

4. Rijstijl

Tot slot enkele vragen om erachter te komen wat uw rijstijl is.

Deze vragen staan dus los van de vragen over Adaptive Cruise Control.

Hoe typeert u uw eigen rijstijl? Geef voor elke twee trefwoorden aan in hoeverre ze op uw rijstijl van toepassing zijn.

Langzaam	0 (0%)	2 (1%)	4 (2%)	37 (16%)	109 (48%)	61 (27%)	13 (6%)	Snel
Zorgvuldig	28 (12%)	96 (42%)	50 (22%)	24 (11%)	16 (7%)	10 (4%)	2 (1%)	Zorgeloos
Tolerant	12 (5%)	80 (35%)	63 (28%)	46 (20%)	19 (8%)	6 (3%)	0 (0%)	Intolerant
Besluiteloos	1 (0%)	3 (1%)	0 (0%)	8 (4%)	29 (13%)	129 (57%)	56 (25%)	Beslist

Geef aan hoe vaak u de volgende handelingen in het verkeer uitvoert.

	Helemaal nooit	Bijna nooit	Af en toe	Regelmatig	Vaak	Bijna altijd	Altijd
Op de snelweg zo dicht op uw voorganger rijden dat het moeilijk is om in een noodgeval veilig te remmen	52 (23%)	117 (52%)	45 (20%)	6 (3%)	3 (1%)	2 (1%)	1 (0%)
Op de snelweg harder rijden dan de maximum-snelheid	16 (7%)	77 (34%)	54 (24%)	29 (13%)	29 (13%)	17 (8%)	4 (2%)
Een boete voor een verkeersovertreding ontvangen	37 (16%)	146 (65%)	37 (16%)	5 (2%)	0 (0%)	1 (0%)	0 (0%)
Uzelf ergeren aan medeweggebruikers	1 (0%)	27 (12%)	112 (50%)	57 (25%)	20 (9%)	5 (2%)	4 (2%)
Andere activiteiten uitvoeren achter het stuur, zoals bellen, uw smartphone bedienen of roken	57 (25%)	87 (38%)	49 (22%)	19 (8%)	12 (5%)	1 (0%)	1 (0%)

Wilt u kans maken op één van de vier VVV-bonnen, vult u dan hier uw e-mailadres in. Er wordt vóór 1 juli 2015 met u contact opgenomen als u gewonnen heeft.

Afsluitende pagina

U bent aan het einde van de enquête. Bent u geïnteresseerd in de uitkomsten van mijn onderzoek? Houd dan rond juli 2015 de autopagina van de ANWB in de gaten. Daar zal een artikel met de onderzoeksresultaten gepubliceerd worden.

Vriendelijk bedankt voor het invullen!

U kunt dit scherm sluiten.

APPENDIX 2

HREC CHECKLISTS FOR QUESTIONNAIRE AND FIELD TEST

Research Ethics Checklist

1. Complete this checklist before you start your research study.
2. Send/give the completed and signed form to the Human Research Ethics Committee HREC@tudelft.nl
3. Keep a copy for your records.

Important note concerning questions 1 and 2

Some intended studies involve research subjects who are particularly vulnerable or unable to give informed consent (see question 1). Research involving participants who are in a dependent or unequal relationship with the researcher or research supervisor (e.g., the researcher's or research supervisor's students or staff) may also be regarded as a vulnerable group (see question 2). If your study involves such participants, it is essential that you safeguard against possible adverse consequences of this situation (e.g., allowing a student's failure to complete their participation to your satisfaction to affect your evaluation of their coursework). This can be achieved by ensuring that participants remain anonymous to the individuals concerned (e.g., you do not seek names of students taking part in your study). If such safeguards are in place, or the research does not involve other potentially vulnerable groups or individuals unable to give informed consent, it is appropriate to check the NO box for questions 1 and 2. Please describe corresponding safeguards in the summary field.

Delft University of Technology
ETHICS REVIEW CHECKLIST FOR STAFF AND PhD RESEARCH

This checklist should be completed for every research study that involves human participants. Before completing it please refer to the Central Committee on Research Involving Human Subjects (CCMO): http://www.ccmo.nl/en/
This checklist must be completed fully and submitted before potential participants are approached to take part in your research study.

Project title:	**The influence of Adaptive Cruise Control on driver behaviour, traffic flows and safety**
Name(s) of researcher(s):	**Mark Gorter, st.nr. 4087267**
Job title(s) of researcher(s):	**Graduate Student**
Name of supervisor (if applicable):	**Bart van Arem, CiTG, TU Delft**
Role of supervisor (if applicable):	**Chairman of Graduation Committee**

	Yes	No
1. Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g., children, people with learning difficulties, patients, people receiving counselling, people living in care or nursing homes, people recruited through self-help groups)	☐	■
2. Does the study use participants who are in a subordinate position to the researcher(s)? (e.g. students being supervised by the researcher)	☐	■
3. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places)	☐	■
4. Will the study involve actively deceiving the participants? (e.g., will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study)	☐	■
5. Will the study involve discussion or collection of information on sensitive topics? (e.g., sexual activity, drug use, mental health)	☐	■
6. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants?	☐	■
7. Will blood or tissue samples be obtained from participants?	☐	■
8. Is pain or more than mild discomfort likely to result from the study?	☐	■
9. Does the study risk causing psychological stress or anxiety or other harm or negative consequences beyond that normally encountered by the participants in their life outside research?	☐	■
10. Will financial inducement (other than reasonable expenses and compensation for time) be offered to participants?	☐	■
11. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children or students)?	☐	■

12. Will the experiment collect and store videos, pictures, or other identifiable data of human subjects? ☐ ■
    a. If "yes", you have to ensure that collected data is safeguarded physically and will not be accessible to anyone outside the study. Furthermore, the data has to be de-identified if possible and has to be destroyed after a scientifically appropriate period of time.
13. Will the experiment involve the use of devices that are not "CE" certified? ☐ ■
    b. If "yes", was the device built in-house? ☐ ☐
        i. If "yes", was it inspected and certified safe by a safety expert at TU Delft? (please provide records of the inspection) ☐ ☐
        ii. If "no", was it inspected by some other, qualified authority in safety and approved? (please provide records of the inspection) ☐ ☐

14. Has or will this research be submitted to a research ethics committee other than this one? (if so, please provide details) ☐ ■

Name of Committee:

Date of submission:

Submission or approval number (if known):

If you have answered NO to all questions above (excluding sub-questions) above (i.e., a more detailed submission to an ethics committee is not required), please very briefly (100-200 words) summarise your research, stating the question for the research, who will participate, the number of participants to be tested and the methods to be used.

For example:

To investigate whether playing violent video games leads to violent ideation, recruited subjects will be requested to provide information regarding their video game habits, and any violent thoughts or episodes they have recently been involved in. This questionnaire will typically take no more than 15 minutes to complete. To confirm informed consent, the system will allow participants to complete the questionnaire only after they have checked a box verifying that they have read a brief description of the study which appears at the top of the questionnaire. After completing the questionnaire participants will receive an email which will explain the purpose of the research and thank them for their participation.

Write or type your summary here:

This research regards a questionnaire distributed amongst users of Adaptive Cruise Control. This can be completed on-line. The questionnaire is highlighted in an article on the website of the ANWB. In this article, users of ACC are asked to fill in the questionnaire. This is voluntary.
The questionnaire contains questions about the experiences users have with ACC. Questions are asked about general characteristics of the users (gender, age group, driving style), and about the way they use and perceive ACC. Completing the questionnaire is anonymous. No personal information is stored.
At the end of the questionnaire, users are asked if they want to win a tourist voucher of €25. If they want, they have to fill in their e-mail addresses. Four of these vouchers are distributed randomly amongst the contributors who leave their e-mail addresses. This is done to encourage people to complete the questionnaire.

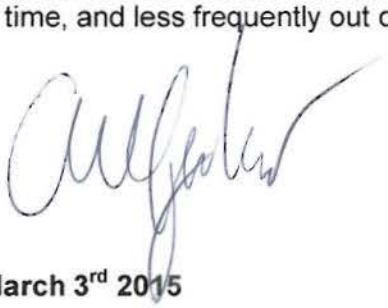
Send the completed and signed form to Human Research Ethics Committee: HREC@tudelft.nl

If you have answered 'NO' to all questions you can proceed with your study.

If you have answered 'YES' to **any of the questions above**, you will need to submit an application for ethics approval, including sample consent documents to this committee.

To submit your research proposal for consideration by the Human Subjects Research Ethics Committee, use the ethics approval application form available on Blackboard. This Committee meets monthly during term time, and less frequently out of term time.

Signature(s) of researcher(s)



Date: **March 3rd 2015**

Signature research supervisor (if applicable):

Date:

Research Ethics Checklist

1. Complete this checklist before you start your research study.
2. Send/give the completed and signed form to the Human Research Ethics Committee HREC@tudelft.nl
3. Keep a copy for your records.

Important note concerning questions 1 and 2

Some intended studies involve research subjects who are particularly vulnerable or unable to give informed consent (see question 1). Research involving participants who are in a dependent or unequal relationship with the researcher or research supervisor (e.g., the researcher's or research supervisor's students or staff) may also be regarded as a vulnerable group (see question 2). If your study involves such participants, it is essential that you safeguard against possible adverse consequences of this situation (e.g., allowing a student's failure to complete their participation to your satisfaction to affect your evaluation of their coursework). This can be achieved by ensuring that participants remain anonymous to the individuals concerned (e.g., you do not seek names of students taking part in your study). If such safeguards are in place, or the research does not involve other potentially vulnerable groups or individuals unable to give informed consent, it is appropriate to check the NO box for questions 1 and 2. Please describe corresponding safeguards in the summary field.

Delft University of Technology
ETHICS REVIEW CHECKLIST FOR STAFF AND PhD RESEARCH

This checklist should be completed for every research study that involves human participants. Before completing it please refer to the Central Committee on Research Involving Human Subjects (CCMO): http://www.ccmo.nl/en/
This checklist must be completed fully and submitted before potential participants are approached to take part in your research study.

Project title:	**The influence of Adaptive Cruise Control on driver behaviour, traffic flows and safety**
Name(s) of researcher(s):	**Mark Gorter, st.nr. 4087267**
Job title(s) of researcher(s):	**Graduate Student**
Name of supervisor (if applicable):	**Bart van Arem, CiTG, TU Delft**
Role of supervisor (if applicable):	**Chairman of Graduation Committee**

	Yes	No
1. Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g., children, people with learning difficulties, patients, people receiving counselling, people living in care or nursing homes, people recruited through self-help groups)	☐	■
2. Does the study use participants who are in a subordinate position to the researcher(s)? (e.g. students being supervised by the researcher)	☐	■
3. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places)	☐	■
4. Will the study involve actively deceiving the participants? (e.g., will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study)	☐	■
5. Will the study involve discussion or collection of information on sensitive topics? (e.g., sexual activity, drug use, mental health)	☐	■
6. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants?	☐	■
7. Will blood or tissue samples be obtained from participants?	☐	■
8. Is pain or more than mild discomfort likely to result from the study?	☐	■
9. Does the study risk causing psychological stress or anxiety or other harm or negative consequences beyond that normally encountered by the participants in their life outside research?	☐	■
10. Will financial inducement (other than reasonable expenses and compensation for time) be offered to participants?	☐	■
11. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children or students)?	☐	■

12. Will the experiment collect and store videos, pictures, or other identifiable data of human subjects? ☐ ■
    a. If "yes", you have to ensure that collected data is safeguarded physically and will not be accessible to anyone outside the study. Furthermore, the data has to be de-identified if possible and has to be destroyed after a scientifically appropriate period of time.
13. Will the experiment involve the use of devices that are not "CE" certified? ☐ ■
    b. If "yes", was the device built in-house? ☐ ☐
        i. If "yes", was it inspected and certified safe by a safety expert at TU Delft? (please provide records of the inspection) ☐ ☐
        ii. If "no", was it inspected by some other, qualified authority in safety and approved? (please provide records of the inspection) ☐ ☐

14. Has or will this research be submitted to a research ethics committee other than this one? (if so, please provide details) ☐ ■

Name of Committee:

Date of submission:

Submission or approval number (if known):

If you have answered NO to all questions above (excluding sub-questions) above (i.e., a more detailed submission to an ethics committee is not required), please very briefly (100-200 words) summarise your research, stating the question for the research, who will participate, the number of participants to be tested and the methods to be used.

For example:

To investigate whether playing violent video games leads to violent ideation, recruited subjects will be requested to provide information regarding their video game habits, and any violent thoughts or episodes they have recently been involved in. This questionnaire will typically take no more than 15 minutes to complete. To confirm informed consent, the system will allow participants to complete the questionnaire only after they have checked a box verifying that they have read a brief description of the study which appears at the top of the questionnaire. After completing the questionnaire participants will receive an email which will explain the purpose of the research and thank them for their participation.

Write or type your summary here:

This research regards a Field Operation Test consisting of eight cars driven by Royal HaskoningDHV employees, equipped with ACC. These cars are leased by these employees. Equipment is installed in the cars, and then the participants use their car like they always do. Data will be logged for four weeks per participant.
The equipment to be installed (all CE certified) are an OBD2-data recorder and two cameras: one installed on the inside of the windscreen facing towards the road in front of the vehicle, and another one installed on the dashboard facing the speedometer of the car. The equipment does not have any negative influence on the driving task of the participant.
The participants are handed out a user manual in which all elements of the FOT are discussed, as well as privacy and safety issues. Also they are asked to sign a consent form.

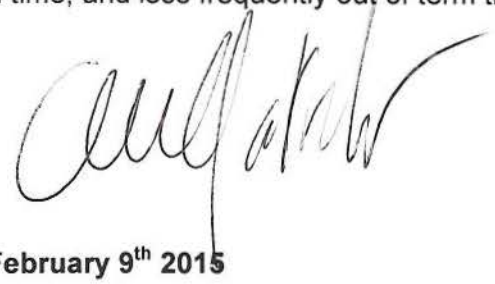
Send the completed and signed form to Human Research Ethics Committee:
HREC@tudelft.nl

If you have answered 'NO' to all questions you can proceed with your study.

If you have answered 'YES' to **any of the questions above**, you will need to submit an application for ethics approval, including sample consent documents to this committee.

To submit your research proposal for consideration by the Human Subjects Research Ethics Committee, use the ethics approval application form available on Blackboard. This Committee meets monthly during term time, and less frequently out of term time.

Signature(s) of researcher(s)



Date: **February 9th 2015**

Signature research supervisor (if applicable):

Date:

APPENDIX 3

NEWS ARTICLE ON ANWB.NL WEBSITE WITH REFERENCE TO QUESTIONNAIRE

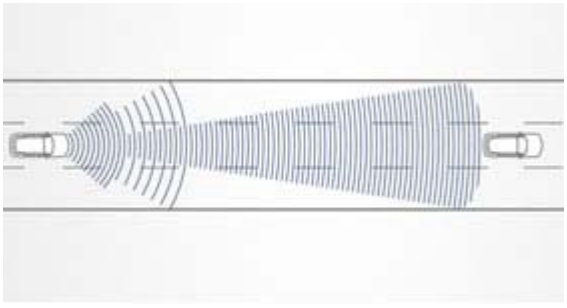
Onderzoek Adaptive Cruise Control

Deel je gebruikerservaring en win een VVV-bon!

16 maart 2015 - Adaptive Cruise Control is een systeem dat aanwezig is in de nieuwere auto's van dit moment. De auto wordt uitgerust met een radarsysteem dat voorgangers 'ziet'. Op basis van deze gegevens is de auto in staat om zelf gas terug te nemen of te remmen. Zo wordt het anticiperen op andere auto's voor de bestuurder een stuk gemakkelijker gemaakt. Wij willen jouw mening weten over dit systeem.

ACC neemt taken uit handen van de bestuurder. Maar betekent dit dat de alertheid van de bestuurder dan ook omlaag gaat? Dat zou een negatieve invloed hebben op de verkeersveiligheid. En wat is de invloed van ACC op de doorstroming? Zou het kunnen helpen om het fileprobleem op te lossen, of worden ze alleen maar erger?
En de meningen over ACC zijn niet alleen positief. Een veelgehoord bezwaar is bijvoorbeeld dat de auto teveel afstand houdt tot de voorganger. Zo geef je ruimte aan andere weggebruikers om voor je in te voegen. De radar ziet nu dat de volgafstand veel kleiner is en reageert door te remmen. Zo beweegt de auto als het ware naar achteren in de file.

Onderzoek



Zo blijkt dat Adaptive Cruise Control nog lang niet is uitontwikkeld. Tot nu toe is vooral ook onderbelicht of en hoe de bestuurder van de auto zijn gedrag aanpast aan ACC. Daarom doet ingenieurs- en adviesbureau Royal HaskoningDHV, in samenwerking met de Technische Universiteit Delft en de ANWB, hier onderzoek naar.

Zo kun je helpen

Deel van het onderzoek is een enquête over Adaptive Cruise Control. Zo worden de ervaringen van gebruikers van ACC in kaart gebracht. Op basis hiervan kan het nut en gebruiksgemak van ACC worden vergroot. Daarom een oproep aan alle autobestuurders die ervaring hebben met Adaptive Cruise Control. Jouw ervaringen als gebruiker zijn van belang! Klik hier om naar de enquête te gaan. Het invullen kost maximaal tien minuten. Daarbij maak je, als je je e-mailadres doorgeeft, kans op een van de VVV-bonnen van €25!

Lees meer over (adaptive) cruise control

APPENDIX 4

USER MANUAL FOR PARTICIPANTS OF THE FIELD OPERATIONAL TEST

Handleiding Veldtest Adaptive Cruise Control

Afstudeeronderzoek Mark Gorter

Dit document beschrijft alles wat u weten moet over het deelnemen aan de veldtest. Het is belangrijk dat u deze goed doorleest. Er staat in beschreven wat er in uw auto geïnstalleerd wordt en waarom. Ook wordt er ingegaan op uw privacy en veiligheid. Tot slot is er een toestemmingsverklaringsformulier opgenomen. Zou u deze na het lezen van de handleiding willen tekenen en inleveren bij het begin van de veldtest?

Ik wil u alvast vriendelijk bedanken voor het meewerken aan de veldtest!

1. Contact

Mochten er vragen of onduidelijkheden zijn, schroom dan niet met mij contact op te nemen. Mijn begeleiders binnen Royal HaskoningDHV zijn Pieter Prins en Evert Klem. Hebt u vragen of opmerkingen die u met hen wilt delen, dan staan hun contactgegevens hier ook bij.

- **Mark Gorter** **088 348 55 32** **06 29 49 85 48** **Mark.Gorter@RHDHV.com**
- Pieter Prins 088 348 29 64 06 54 24 50 73 Pieter.Prins@RHDHV.com
- Evert Klem 088 348 31 69 06 52 01 87 13 Evert.Klem@RHDHV.com

2. Inhoud veldtest

De veldtest houdt in dat er apparatuur in uw leaseauto geïnstalleerd zal worden. Deze apparatuur is in staat om uw rijgedrag te registreren. Dit wordt gedaan om inzicht te krijgen in uw rijgedrag, in het bijzonder wat betreft het gebruik van Adaptive Cruise Control.

Mijn onderzoek focust zich op hoe Adaptive Cruise Control u als bestuurder beïnvloedt. Er wordt bijvoorbeeld onderzocht bij welke verkeerscondities (rustig, druk of file) u ACC activeert of juist deactiveert. Ook wordt er onderzocht of u sneller of juist langzamer rijdt met ACC aan, of u meer rechts houdt of juist niet, enzovoort.

Het is van belang dat u uw rijgedrag niet aanpast nu u aan de test deelneemt, maar dat uw rijgedrag zo natuurlijk mogelijk is. Hierom zorg ik dat er door u geen extra handelingen uitgevoerd hoeven te worden. U kunt dus gebruik maken van uw auto zoals u dat altijd doet, en u hoeft uw rijgedrag (dus ook uw gebruik van Adaptive Cruise Control) niet te veranderen.

3. Apparatuur

Er worden drie apparaten in uw auto geïnstalleerd, namelijk een CarChip OBD2 data-recorder, en twee camera's. Zowel de camera's als de CarChip zijn CE gecertificeerd.

2.1 CarChip Pro

De CarChip Pro is een kleine data-recorder, die in de OBD2-plug van uw auto gemonteerd zal worden. Deze plug is verbonden met de motormanagement-module van uw auto. Dit stelt de CarChip in staat om een aantal parameters te registreren. De CarChip wordt automatisch geactiveerd zodra u uw auto start. De volgende parameters zullen door de CarChip opgeslagen worden:

- Snelheid (km/h)
- Toerental van de motor (Toeren per minuut)
- Positie van het gaspedaal (in % van de maximale positie)
- Motorvermogen (in % van het totale vermogen)

De CarChip is alleen in staat om parameters uit te lezen uit de auto, en niet om instellingen in het motormanagement te veranderen. Het gebruik van de CarChip beïnvloedt het presteren van de auto dus op geen enkele manier.

2.2 Camera's

In de buurt van de binnenspiegel zal een camera geïnstalleerd worden. Deze camera filmt door de voorruit de weg voor de auto. De andere camera wordt geïnstalleerd op het dashboard van uw auto, en is gericht op uw snelheidsmeter. Dit wordt zodanig gedaan dat u daar zo min mogelijk last van heeft. Deze camera is nodig om te zien wat er op en rond uw snelheidsmeter aangegeven wordt. Zo is voor mij zichtbaar of u ACC geactiveerd heeft of niet.

De camera's zijn bevestigd met een plaklaag. Deze plaklaag zorgt ervoor dat de camera's niet kunnen bewegen. Na het verwijderen van de camera's zal gezorgd worden dat er geen lijmresten achterblijven in de auto. Eventuele schade veroorzaakt door het aanbrengen van de camera's zal vergoed worden door de afdeling Transport NL van Royal HaskoningDHV.

De voeding van beide camera's wordt verzorgd door de 12v-aansluiting in de auto (de sigarettenaansteker dus). Dit betekent dat er twee draden van de camera's naar de 12v-aansluiting zullen geleid worden. Deze zullen weggewerkt worden met behulp van tape. Ook dit tape zal zorgvuldig verwijderd worden na gebruik, zodat er geen sporen achterblijven.

Verder is er een verdeler nodig, zodat er twee camera's op één 12v-aansluiting aangesloten kan worden. Mocht u het gebruik van de 12v-aansluiting niet kunnen missen voor bijvoorbeeld het opladen van uw telefoon, dan zullen er twee verdelers nodig zijn.

De camera's zijn zo ingesteld dat ze geactiveerd worden zodra ze stroom krijgen, zodra de auto start dus. Ze gaan weer uit als de auto uitgezet wordt. U hoeft de camera's dus niet aan- of uit te zetten. Bij het (de)activeren van de camera's is een kort geluidssignaal te horen.

4. Tijdsduur

De test heeft een totale lengte van vier tot vijf weken.

Aan het begin van de veldtest zal er twee uur nodig zijn om de apparatuur in uw auto te installeren. Dit kan door mij zelfstandig gedaan worden. Toch is het handig als u hiermee even meekijkt, zodat ik de apparatuur zodanig kan installeren dat het u het beste uitkomt.

Als de apparatuur geïnstalleerd is, begint de veldtest. Er wordt data verzameld. Elke week zal de verzamelde data uitgelezen worden. Dit betekent dat er elke week een afspraak gemaakt moet worden. Het uitlezen van de data zal ongeveer een kwartier in beslag nemen. Ik voer hier geen aanpassingen aan uw auto uit, dus het is niet per sé nodig dat u hierbij aanwezig bent.

In de vijfde week van de test is er voldoende data verzameld. Dan zal de apparatuur uit uw auto verwijderd worden en is de test afgerond.

Na het afronden van de test zal ik u vragen een enquete in te vullen. Hierin komen onderwerpen aan de orde als persoonskenmerken, rijstijl, ervaringen met ACC en een terugblik op deze test. De enquete zal maximaal een kwartier tijd kosten.

5. Privacy

Ik ben me ervan bewust dat u op vrijwillige basis gegevens verstrekt. Dit betekent dat uw privacy zo goed mogelijk gewaarborgd wordt. De volgende maatregelen hebben we daarvoor genomen:

1. Mocht u om wat voor reden dan ook een rit in de auto maken waarvan u niet wilt dat die gefilmd wordt, dan kunt u eenvoudig de voeding van de camera's uit de 12v-aansluiting halen. De camera's gaan dan uit, en er wordt niet gefilmd. Voor de CarChip is het demonteren iets minder eenvoudig, maar hier geldt dat buitenom de parameters genoemd in paragraaf 2.1 niets opgenomen wordt. Dit is dus vrijwel niet privacy-gevoelig.
2. U als bestuurder wordt niet in beeld gebracht tijdens het rijden in de auto. Verder geldt voor beide camera's dat er uitsluitend beeld opgenomen wordt, en geen geluid. De gesprekken die u in de auto voert worden dus niet opgenomen.
3. De apparatuur is niet uitgerust met GPS- of andere communicatieapparatuur, dus buitenom de filmbeelden is niet te traceren waar u gereden heeft.
4. Dit onderzoek focust alleen op de snelweg. Daarom worden bij het downloaden van de beelden als eerste alle beelden die niet op de snelweg opgenomen zijn, verwijderd.
5. De opgenomen data wordt opgeslagen op een beveiligde server van Royal HaskoningDHV. Uitsluitend de direct betrokkenen bij dit project hebben daar toegang toe. De data wordt ook alleen gebruikt voor dit onderzoek. De gegevens zullen niet binnen Royal HaskoningDHV of andere partijen buitenom Royal HaskoningDHV verspreid worden. Na afronding van het onderzoek zal alle privacygevoelige data verwijderd worden.
    - Uitzondering hierop betreft het kleinschalig gebruik van de beelden bij het presenteren van het onderzoek aan de afstudeercommissie van Mark Gorter aan de Technische Universiteit Delft en het publiceren van het onderzoeksrapport. Hierin zal alle data echter volledig geanonimiseerd weergegeven worden, en uiteraard heeft u inzicht in het uiteindelijk op te leveren onderzoeksrapport. Dit zal in juli 2015 af zijn.
    - Tweede uitzondering is in geval van calamiteiten. Op het moment dat onverhoopt uw deelnemende auto betrokken wordt in een calamiteit, kan de verzamelde data, alléén op verzoek van de bestuurder, getoond worden aan politie, verzekeringsmaatschappij of andere belanghebbende. De verzamelde data kan dan gebruikt worden als bewijsmateriaal.
6. Op verzoek is het altijd mogelijk uw eigen verzamelde data in te zien.
7. Ik respecteer uw privacy en zal ervoor zorg dragen dat de persoonlijke informatie die u mij verschaft vertrouwelijk wordt behandeld. Privacygevoelige informatie wordt zo goed mogelijk geanonimiseerd, en bij het publiceren van de resultaten van dit onderzoek zal er voor gezorgd worden dat de gegevens zo min mogelijk terug zijn te leiden tot u als test-deelnemer.
8. Mocht u om wat voor reden dan ook beslissen om u terug te trekken uit dit onderzoek, dan zal daar altijd ruimte voor zijn. De apparatuur zal dan zo snel en goed mogelijk verwijderd worden, en op verzoek verwijder ik ook de tot dan toe verzamelde data.

6. Veiligheid

De apparatuur wordt zodanig geïnstalleerd dat de prestaties van uw auto er op geen enkele manier door verminderd wordt. Verder is de apparatuur zo ingesteld dat uw gedrag als bestuurder niet beïnvloed wordt. Ook uw zicht wordt niet beperkt. Zo wordt uw veiligheid niet verminderd ten opzichte van het normale gebruik.

Toestemmingsverklaringformulier

Titel onderzoek:	De invloed van Adaptive Cruise Control op rijtaak, veiligheid en doorstroming
Verantwoordelijke onderzoeker:	Mark Gorter

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en de risico's en belasting van het onderzoek. Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk aan derden bekend gemaakt zullen worden. Mijn vragen zijn naar tevredenheid beantwoord.

Ik begrijp dat videomateriaal of bewerking daarvan uitsluitend voor analyse en/of wetenschappelijke presentaties zal worden gebruikt.

Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Naam deelnemer: ……..……

Datum: ……..…… Handtekening deelnemer: …...……..…….……

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Eventuele schade veroorzaakt door het aanbrengen van de meetapparatuur zal vergoed worden door de afdeling Transport NL van Royal HaskoningDHV.

Naam onderzoeker: ……..……...

Datum: ……..…… Handtekening onderzoeker: …...……..…….……

Royal HaskoningDHV

Enhancing Society Together