Stepping over the Threshold - Linking Understanding and Usage of Automated Driver Assistance Systems (ADAS)

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Stepping over the threshold linking understanding and usage of Automated Driver Assistance Systems (ADAS)

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ABSTRACT

Automated Driver Assistance Systems (ADAS), which aim to enhance safety and comfort while driving, are becoming increasingly popular in vehicles today. However, ADAS are not yet operative in every situation due to technical limitations, and therefore do not cover all driving situations, traffic, weather and/or road conditions. In order for drivers to use these systems in a safe manner, they need to understand the different modes of operation, as well as the limitations of the systems, or they will not be able to build appropriate trust and adequate usage strategies.

Therefore, the purpose of this study was to investigate the factors influencing user understanding of ADAS by implementing an Explanatory Sequential Mixed Methods design. This was done by triangulating data from a Naturalistic Driving (ND) study (132 vehicles) with explanations and reflections from in-depth interviews of purposefully selected participants (12 drivers from the vehicle pool) who were showing different usage patterns.

The results show that users' understanding is influenced by preconceptions about the system, as well as the perceived system performance and usefulness, leading to different levels of trust that affect the users' engagement with the ADAS. It was found that the driver's perception of a system does not just change over time, but changes through different situations presented, challenging the expected events and the users' mental model of the interaction with the system. Therefore, to gain trust and appropriate usage strategies for the ADAS the user needs to overcome potentially negative experiences and challenge the current understanding of the ADAS, by stepping over the threshold.

1. Introduction

Automated Driver Assistance Systems (ADAS), which aim to enhance safety and comfort while driving, are becoming increasingly popular in vehicles today. Manufacturers including Tesla, Cadillac and Volvo are competing to deliver improvements. Adaptive Cruise Control (ACC), and more advanced functions like Pilot Assist (PA) in Volvo vehicles are examples of such ADAS functions. ACC is designed to offer a supplementary driving aid for longitudinal control (speed control and maintenance, distance keeping), while PA supports by assisting in longitudinal and lateral control (speed control and maintenance, distance keeping, lane keeping assistance) of the vehicle. Both functions can be used anytime and independently, and as vehicles with several automated driving functions become increasingly common, the interaction with the ADAS also becomes increasingly complex. It becomes harder for drivers to build up a comprehensive mental model of the system functionalities. This poses a problem for the design of ADAS functions like ACC and PA, since they are not yet operative in every situation due to technical limitations, and therefore do not cover all driving situations, traffic, weather and/or road conditions.

In order for drivers to use the systems in a safe manner, they need to understand the different modes of operation, as well as the limitations of the systems, or they will not be able to construct adequate usage strategies (Seppelt and Lee, 2007; Beggatio and Krems, 2013). Nonetheless, empirical evidence shows that many drivers do not fully comprehend the system limitations or functionalities, underlining the importance of looking further into this aspect (McDonald et al., 2018). A survey by Boelhouwer et al. (2020) showed that almost a quarter of the drivers do not receive any information about the ADAS they bought, and of the few who got information only 9% actually got to try out the systems. A simulator study by Forster et al. (2019) showed that the mental model of the drivers was significantly improved by

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prior education through a manual or interactive wizard. However, surveys by Jennes et al. (2008) and Larsson (2012) show that most drivers are not aware of the manufacturers' warnings about system limitations, and if aware they have difficulty in transferring their knowledge from the manuals to the actual driving task. Both studies showed that the drivers prefer to learn as they go rather than read the manual.

In any case, the necessary level of driver involvement in the interaction with the system requires very good comprehension from the user about how the system works. As vehicles offer different modes of operation and the functions are getting more and more complex, drivers need to understand the limitations in order to use the system in a safe manner (Beggatio and Krems, 2013). To understand the limitations of the system, the driver has to build up a mental model – an abstract representation of the mechanisms underlying the interaction. A correct understanding of ADAS functionalities is therefore important in the construction of adequate usage strategies (Seppelt and Lee, 2007).

In the preceding paper on the same study (Orlovska et al., 2020), we concluded that the driving context affects ADAS usage through system performance, showing that the limitations of the ADAS design affect the drivers' trust and willingness to use the systems over a long period. The findings indicated a threefold interrelation that includes driver behaviour, system performance, and driving context. The results showed that usage of the systems differed between drivers, leading to categorisation of different driver types. Usage was highly dependent on context, but there was also a strong connection to the perceived system performance. These findings showed that the users' understanding of the system and their interaction with it differs and, furthermore, that there might be incomplete understanding.

However, these findings have not been reported in the preceding paper (Orlovska et al., 2020) and therefore the authors wanted to investigate the underlying factors that impact why users understand the system the way they do, and what factors in the users' perception contribute to their understanding. By 'understanding' we mean the way the users interpret the system, how it works and how they are supposed to, or can, use it. Therefore, the overall aim of this paper is to further explore the body of data and acquire knowhow about which factors in the users' understanding affect their usage of Automated Driver Assistance Systems. This paper should be regarded as a direct continuation of the preceding one (Orlovska et al., 2020), which aimed to understand how the driving context influences driver behaviour, by means of the triangulation of data gathered through a Naturalistic Driving (ND) study and a consecutive interview study.

2. Methods

An Explanatory Sequential Mixed Methods (Creswell, 2014) approach was adopted and modified to fit with the scope of this research. The sequential use of quantitative and qualitative approaches (see Fig. 1) aims to facilitate an integrated interpretation regarding the effect of the drivers' perception on the usage of ADAS.

To collect the quantitative data a Naturalistic Driving (ND) study was utilised. ND study usually refers to a study where data collection is not constrained by a strict experimental design (Fridman et al., 2019), and the data is gathered in a natural driving context and under various driving conditions, closely resembling real-driving situations. The ND study in this analysis enabled a time-efficient and reliable way for undertaking quantitative assessment of system and driver performance, in combination with contextual information including weather conditions, road conditions, and data indicating the traffic conditions on the roads.

In order to clarify the sensor-based findings, in-depth interviews with the study participants were subsequently held, with the aim of identifying and explaining the effect that driver perception has on the usage of ADAS functions. The subsequent design of the qualitative phase has to be structured in such a way that it follows from the results of the quantitative phase and explains emerging phenomena. The qualitative study design is therefore based on clarification of the subjective reasoning of the drivers in the detected target groups, in order to understand their specific user behaviour and needs, and so as to be able to map out the interdependencies that influence system usage. It was decided that in order to reach this goal, semi-structured in-depth interviews with the drivers of the vehicles from which the quantitative data was gathered was the most suitable method.

The data in this study was collected with the informed consent of all drivers, regarding all collected data points and their prior agreement to participate in this research project. The retrieval, storage and processing of the collected data was performed strictly according to the European General Data Protection Regulations (GDPR). This data is processed confidentially, and all participant identities are kept strictly anonymous.

2.1. Quantitative data collection

Quantitative evaluation in this study provided precise measurements of driver and system performance in various driving conditions. The ND data helped identify different use patterns regarding the evaluated functions and indicated trends regarding driver behaviour.

2.1.1. Study design and procedure

For the quantitative data collection, data from 132 vehicles was collected and subsequently analysed. All vehicles had the same version of the two evaluated systems; ACC and PA. Driver behaviour and system performance were categorised and measured, so as to be able to evaluate them separately and examine their effect on each other. Data points enabling the understanding of the driving context for ADAS were included in the assessment. To evaluate traffic conditions, speed limits, driving speed, time of activation/deactivation of functions, data, and GPS location were used. For road conditions assessment, lane marks reading, speed limits, GPS location, and ambient temperature were considered. For weather condition identification, wiping status, fog illumination, ambient temperature, data, and GPS location were measured. Analysis of this data makes it possible to see in what context the driver performed activations or deactivations of the ADAS functions. The ND study was conducted over a period of seven months from April to October 2018.

Data collection was undertaken using the external wireless communication and data acquisition unit that was installed in every test vehicle. The external data acquisition system enabled management of the data from the vehicle fleet by keeping track of map-based positioning, mileage, uptime and diagnostic codes. Table 1 provides a summary of the measured signals.

The raw data consisted of data from the CAN-bus data and was collected for every single Drive Cycle (DC). By the term 'single DC', a driving activity that begins when the engine is turned on, and ends when the engine is turned off, is meant. The automated start-stop function does not lead to a fully turned off engine, and therefore is not counted as an end of a DC. Thus, all DCs, including DCs with no activations relating to the evaluated functions, were included in the evaluation. Every DC was recorded and documented with a unique file name to be able to connect the vehicle to its data and evaluate it at a later stage.

In the data pre-processing step, incomplete, inaccurate, inconsistent, duplicated, and irrelevant data was detected and removed from the dataset. Then the data was synchronised in time, providing the order and structure for the initial dataset.

2.1.2. Data analysis

For the main phase of the quantitative analysis, a confirmatory approach was adopted to triangulate the performance data with the interview data to show the correlation of these data and the reliability of the quantitative results. The data analysis was performed with

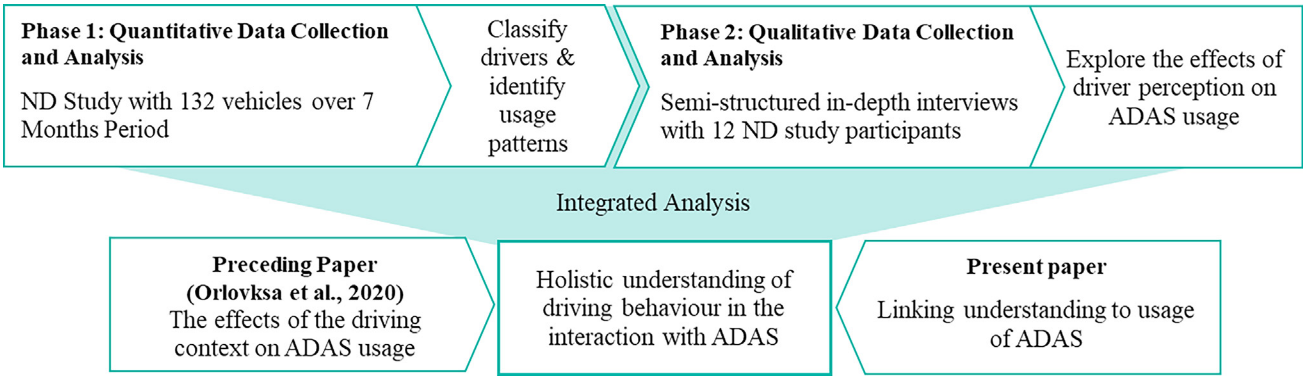


Fig. 1. Explanatory Sequential Mixed Methods design.

Table 1
Summary of measured signals for the assessment of the ADAS usage and driving context.

Traffic condition variables	Description
Speed limits	to identify the allowed speed (0-130 km/h)
Driving speed	to see the deviation from speed limits (0-198 km/h)
Braking/acceleration	to determine the distance between changes (frequency)
Time of activation/deactivation	to consider possible rush hour (t, h)
Data	to distinguish the workday from the weekend/holidays etc. (date)
GPS location	to clarify the traffic conditions in historical data (Latitude/Longitude)
Road condition variables	
Ambient temperature	to exclude slippery road conditions (-2°C $< t >2$°C)
Lane marks reading	to secure ADAS performance on the road (On/Off)
Speed limits	to identify the road type (0-130 km/h)
GPS location	to consider issues like a crossing of the country borders, big road constructions, etc. (Latitude/Longitude)
Weather condition variables	
Wiping status	to detect heavy rain or snow: wiper statuses 5-7 (overall range 0-7)
Fog illumination	to control bad visibility conditions (e.g. fog, mist) (On/Off)
Ambient temperature	to clarify precipitation (t,°C)
Data	to record the seasonal change (date)
GPS location	to clarify the weather conditions in historical data (Latitude/Longitude)
ADAS signals (PA & ACC)	
PA status is on	to identify when the system was in use (PA_act)
PA activation is requested	to identify the driver's requests for function activation (PA_req)
PA status is stand-by mode	to identify the situation when the system is not providing support (PA_stb)
PA status is off	to identify when the system was not used (PA_off)
ACC status is on	to identify when the system was in use (ACC_act)
ACC activation is requested	to identify the driver's requests for function activation (ACC_req)
ACC status is stand-by mode	to identify the situation when the system is not providing support (ACC_stb)
ACC status is off	to identify when the system was not used (ACC_off)

Power BI. The data was analysed at four different levels of abstraction: overall assessment (based on the average calculation for all users), group assessment (based on the comparison of user behaviour between different user groups), one-driver evaluation (focused on in-depth user behaviour evaluation of the same driver), and single DC evaluation (zoom-in analysis if something indicated unusual or interesting user behaviour that was worth investigation).

2.2. Qualitative data collection

Subsequently, in-depth interviews were performed to obtain explanations and reflections on the recorded driver behaviour during the ND study, helping to identify the human factors that impact driver behaviour and system usage.

2.2.1. Participants

The interview study consisted of 12 participants, 2 females and 10 males, with an age range of 31–62 years (Mean 52.4, SD = 9.0). The participants were recruited via an email newsletter directed only at members of the vehicle fleet that was analysed in the ND study. Therefore, the criteria for inclusion in the study were set through participation in the fleet. Thus, every interested member located in the Gothenburg area was potentially a valid participant.

All participants commuted every day, with 5 participants accounting for an annual mileage of more than 30,000 km, 4 participants driving between 20,001 km and 30,000 km per year, and three covering between 10,001 km and 20,000 km. All the participants were long-term users of Volvo vehicles. According to their own estimates nine of the participants were the sole or main drivers, sharing the vehicle only 0–10% of the total driving time. Two drivers shared their respective vehicles up to 20% of the time, and one driver up to 35% of the total driving time. From the quantitative data collection, it was known that participants have a different level of usage and engagement with the systems. All participants were Volvo Cars employees, while no participant who is involved in development of the functions was accepted for the interview study.

2.2.2. Study design and procedure

The investigation and validation of the quantitative data was performed by means of in-depth semi-structured interviews to explore the individual experience and understanding of the systems. Interviews as a data collection method are a valid and reliable choice when aiming to obtain knowledge about driving behaviour, user perception and the users' mental model of the driver assistance system (Beggatio and Krems, 2013).

The interview study was conducted between December 2018 and February 2019. All the interviews were audio-recorded with the participants' consent. The interview comprised four sections: Contextual Information; System Usage and Scenarios; Perception and Experience with the System; Information Display and Controls. Thus, a set of open-ended questions was developed, based on the four main themes. The structure of the interview and the interview questions were based on the initial results of the quantitative study.

In addition, a questionnaire focusing on self-assessment of usage in different driving contexts was handed out to the participants after the interview. The questionnaire consisted of Likert type (Likert, 1932) scenario-based statements with four response categories, without a neutral category. Finally, the participants' background information such as age, gender, car model and year, commute behaviour and kilometres driven per year were mapped. All sessions were conducted individually, face to face and in English.

The interview was conducted using the developed topic guide. However, the interview was not limited to the sample questions and the participants were encouraged to elaborate on their experiences and provide more descriptive insights. Each session lasted about one hour including interview and questionnaires. The participants were reimbursed with a cinema voucher for attending the interview.

2.2.3. Interview analysis

All interviews were carefully transcribed verbatim, coded and analysed with NVivo 12 software. The first transcript was analysed by author 1 and author 2 in cooperation, by first categorising the transcripts into the corresponding topics and questions. Since the interview structure and content was based on the initial results of the quantitative analysis, the categories were already determined, leaving the researchers to identify different themes and their meanings within the categories. In a subsequent step the themes were reviewed and discussed in order to determine coherence and reliability. Afterwards, the interviews were coded by each researcher separately and a final session was held, where open questions and themes were discussed to review the quality of the coding.

2.3. Integrated analysis

After transcription of the interviews, statements where participants described their use of the ADAS ACC, and PA functions were extracted. This helped explain the vehicle data-based observations and identified relevant aspects of the driving context influencing the drivers' usage of ADAS.

For the evaluation of the results a deductive coding approach (Hsieh and Shannon, 2005) was applied, correlating with the predetermined results and themes from the quantitative data evaluation and interview structure. This sought to investigate if the identified trends from the quantitative study were supported by the qualitative data. An inductive approach was also applied in the next step to assess the themes and discover new insights beyond the quantitative results that were not covered by the initial analysis.

The analysis resulted in three themes: Usage and Pre-Conception, Perceived Usefulness, and Trust and Acceptance. The integrated analysis was conducted with regard to the findings identified during analysis of Paper A (Orlovska et al., 2020), and was guided by the aim of identifying the factors in the users' understanding that affect their usage of ADAS, which surfaced as a research question during the analysis. Afterwards, the findings were contextualised so as to contribute to augmentation of the identified factors.

3. Findings

This chapter describes the synthesis and analysis of the quantitative and qualitative findings, with the aim of identifying the effect of driver understanding on ADAS function usage.

3.1. Usage and pre-conceptions

Analysis of the quantitative data reveals the existence of various levels of usage for the system functions. Some drivers show a clear commitment to ACC over PA, while others prefer PA to ACC.

To investigate this phenomenon more deeply, the data of all 132 drivers was investigated and four groups of drivers were identified, based on the drivers' use preferences regarding the functions. The first group consists of drivers who do not use ACC and/or PA regularly and who did not activate the system more than four times, during the entire period. According to the categorisation, this group consists of 10 drivers and is equivalent to 7.6% of the total. The second group includes the drivers who use ACC to a very high extent, and above average of the total usage in the pool, which is 24.7%. At the same time these users use PA very little; at least three times less than ACC. This group consists of 21 drivers and equals 15.9% of the total. The third group includes drivers who use PA more than ACC, consisting of 24 drivers and equalling 18.2% of the total. The fourth group includes 77 drivers, equivalent to 58.3% of the total. These drivers do not show any preference over on function to the other, seemingly using both functions according to the driving situation.

Despite the fact that the majority of drivers used the system in response to the driving context, it appears that some drivers have clear preferences regarding the evaluated functions. The identified groups were analysed further to understand how the preference of one ADAS function affects the usage of the other function. Fig. 2 graphically represents two groups of drivers, those who prefer ACC to PA, and those who prefer PA to ACC.

As Fig. 2 reveals, drivers who prefer ACC to PA show a higher use level of ACC, compensating for the low usage of PA. For two drivers this can be classified as "no usage" (drivers 142 and 231). On the other hand, drivers who prefer PA to ACC demonstrate a very high use level of PA, and somewhat rare use of the ACC function on its own.

These results correlate with the statements of the twelve participants, where the different individuals declare clear preferences for one function or the other. However, overall the participants preferred using ACC and one even stated, *"I use it almost all the time […]"*. Few participants stated that they use PA as much as ACC, but overall PA was less favoured. One participant even stated specifically that he uses *"PA half as much as I use ACC"*.

Another finding regarding the usage patterns is the consistent level of engagement the drivers have with the ACC and PA functions. Most of the drivers did not show any increase or decrease in their level of usage of the functions. During the seven months of data collection, the data shows that PA and ACC were used to a different extent by different drivers, but the usage level of one single driver remained the same (see Fig. 3).

For example, the driver of vehicle 19 makes very high usage of ACC/PA, reaching up to 75.9% of all DCs for ACC and 50% respectively for PA. The driver of vehicle 20, on the other hand, decided during the first months to not use any of the functions, after a few attempts at driving with them. The driver of vehicle 197 showed very high usage of ACC, reaching 88.4% of all DCs, and moderate usage of PA, reaching 26.1%.

As Fig. 3 illustrates, most of the drivers from the vehicle pool did not show any significant variation in their usage level regarding the functions. This consistency is an indicator that the exploration process has been completed. However, the usage level among drivers remained very diverse, indicating different outcomes from the learning

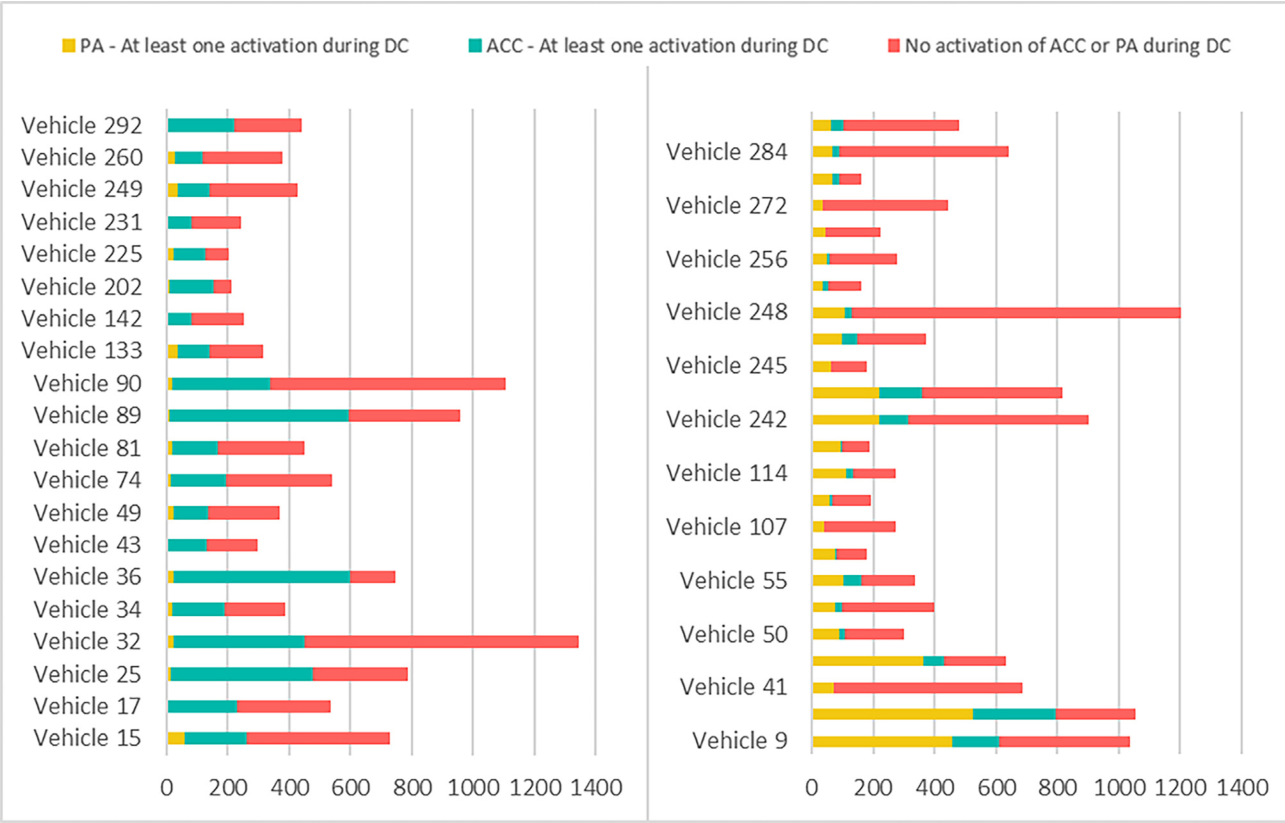


Fig. 2. Group of drivers who prefer ACC to PA (left) and group of drivers who prefer PA to ACC (right).

process. From the setup, it is known that all drivers were located in the same geographical area, which means they had the same weather conditions, road structure, and similar traffic and road situations during the whole study period.

To follow up on this observation the respondents were asked about their learning experience. All of them stated that it was easy to learn how to activate and deactivate both functions, and also to understand what the interface was communicating to them. In fact, the majority had learned how to use the systems by themselves, and only two participants stated that they had a look in their vehicle's manual or quick guide to read up on it.

"I knew that the function was there. So, of course I wanted to know how to engage it with the buttons on the steering wheel. That was pretty straightforward."

However, two of the drivers stated that they got extra support from someone who knew the functions and experienced that as a great help in understanding how to interact with them. In this context it was also pointed out that actual practice with the functions was decisive in the learning process, indicating that a description or demonstration on its own is not enough. The majority who had learned it by themselves based a lot of their knowledge and learning experience on systems they had used previously in other vehicles.

"I tried it with the supervisor, and it was really nice. It was very easy to use, when I had it in my own car."
"Learning by doing with some support really. You need to experience it yourself, because you need to experience how it feels if you don't brake, when the car is getting closer. Scary in the beginning, but then you get used to how the car acts."
"I didn't have an introduction. I think the ACC is kind of used a bit intuitively. I had a V40 before and it was kind of the same with the button on the steering wheel."

These statements show that the learning process is influenced by a preconception of the system, which builds the basis for understanding how to interact with it.

Looking back at the results illustrated in Fig. 2, which presented the drivers preferences of the different functions, it seems that the drivers do not evaluate the driving situation every time during every new drive cycle, but that they apply the use patterns they have learned and stick to them. This is an indication of a more static mental model of how the system works and how to interact with it. Therefore, it appears that after learning how the system works and creating sufficient understanding of the interaction, the mental model is not revised or does not continue to develop.

This assumption is also supported by the expectations the participants expressed about the systems before the first usage. When asked what was expected from the system, the answers varied, so the result was either disappointing or a positive surprise depending on the expectations the drivers had beforehand. These expectations play an important role in how or whether the driver chooses to use the system. In particular, those respondents who expressed high expectations that were not met, seemed to be rather disappointed and chose to use the systems less.

"I thought more of it in the beginning. […] I needed to adjust to its behaviour."

"I had higher expectations and the reality did not match those expectations. But on the other hand, I also knew about [the limitations], kind of. But I still wanted to test it. I just thought 'OK, I will not use it.'"

Those whose expectations were met, or even exceeded, seemed to have an easier time with testing and figuring out how to use the function, and therefore engaged with the system in ways that led to higher usage.

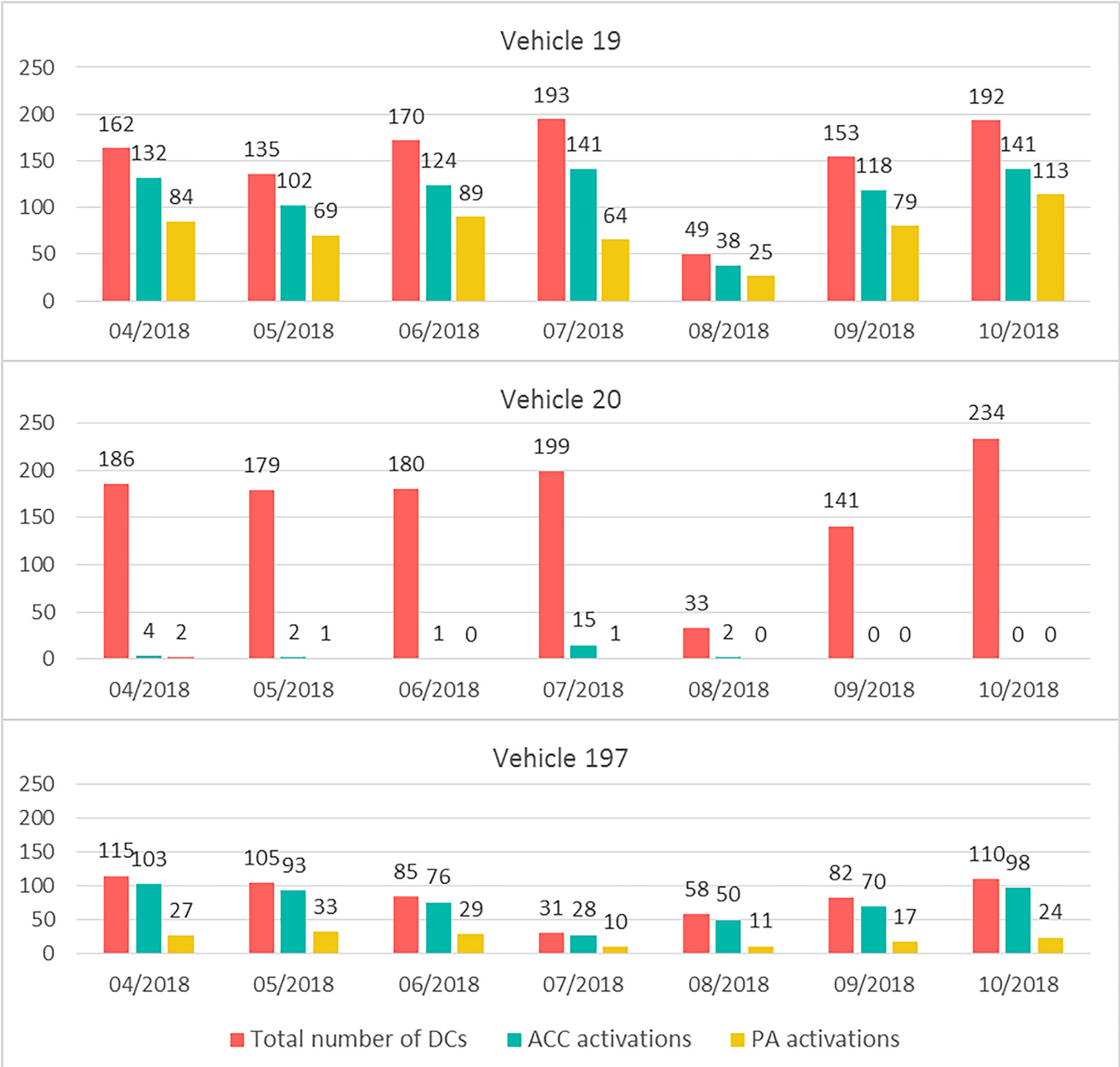


Fig. 3. Different use levels regarding ACC and PA for drivers of vehicles 19, 20 and 197.

"I didn't have any expectations because I thought ACC should work as it always has done, and it does."

"Yes, my expectations correlate. So, it was easier to begin to use the system right away. So, I started to use it immediately, when I bought the car."

"If you have high expectations, maybe you think it is a kind of auto pilot or more, then I believe you will of course be disappointed. But I went into it with the knowledge that it is a driver support system and not an auto pilot. So, I have to be engaged even though it helps me up to certain limits."

In summary, the results point towards established mental models that are not revised after being considered sufficient. It appears that if these preconceptions are not challenged, then there is no change in behaviour and no adjustment of the mental model, or interaction with the system. This led the authors to question what factors can challenge the driver's perception of the system, leading to deeper analysis of the perceived value, since a difference between expected and perceived value might change the current perception of the functions.

3.2. Perceived usefulness

Even though all the participants found the functions easy to learn and use, some had trouble seeing the benefits of using them, or simply did not find the support they were looking for in the functions. Nevertheless, all the respondents agreed that ACC as well as PA are comfort functions that provide support with the simple tasks of accelerating, braking, maintaining a safe distance and keeping below the speed limit. The drivers particularly value the comfort that comes with being relieved of the more demanding driving tasks, such as maintaining a safe distance to the car in front. Furthermore, all drivers express more relaxation when using the systems, because they experience a lower workload in addition to the physical relief.

"It's relaxing, because I don't need to take care of certain rather annoying parts, like keeping a safe distance to the car in front of me and so on. It definitely helps, it takes away certain…maybe not the responsibility, but a certain burden."

"But at the same time, regarding mental workload or whatever, it clearly takes away certain small part, like permanently keeping the lane. I don't say it is difficult, but still it is something I need to be focused. And that part goes away when I use PA or gets reduced at least."

Another aspect which seems to be an important factor for relaxation is that many of the respondents explain that their driving behaviour is altered, from a very active style to a more passive and calm driving behaviour. The participants state that while using the system, they tend to follow the traffic flow rather than overtaking and picking their own speed, which results in less aggressive driving, which is also perceived as safer.

"Activating the system, independently if it's ACC or Pilot Assist, puts you in a smoother, more…calm behaviour in the traffic […]. Actually, if I drive without, I increase speed or reduce speed a lot more than that, and maybe I tend to change lanes a bit more when I'm driving by myself.

"It makes me drive, I believe, safer. A little bit slower with the better distance to the car in front of me."

Safety is another major value the participants attribute to the system. Many of the respondents say they feel more comfortable using the infotainment system, for instance changing the radio station or a playlist, or concentrating on a phone call or meeting, when Pilot Assist is engaged. Some of the respondents even state that they specifically activate it in those situations and disengage the system after they finish their task. Furthermore, drivers who tend to use the PA function during long drives perceive this function as an extra safety support on long and *"boring"* drives, where they feel they lose concentration or vigilance.

"If I want to do some settings in the centre stack display, or something where I know that I will not be as observant of the traffic. It feels like a safety feature, that I could put on Pilot Assist and I know I will get some extra support when I am not as observant as I could be."

"It's a clear support. Like, yesterday morning I started at five o'clock. And of course, maybe you're not 100% awake at five o'clock in the morning and, and then I have it as an extra safety function."

Another group of respondents see an extra level of safety in stop-and-go situations or in heavy traffic, where not only physical relief is achieved but also support in safely following the stream of traffic without running into the vehicle in front, which otherwise would need their full attention. The participants state that in these slow-moving situations, they tend to engage in secondary tasks to be more productive or pass the time.

In summary, all the respondents regard the Adaptive Cruise Control and Pilot Assist functions as convenient and supportive functions which relieve them of mental workload and support a relaxed experience. In addition to this experienced comfort, they also see increased safety when using the functions, since they regard them as an additional pair of eyes or quick reflexes that will provide support in situations where they themselves are not as attentive. The safety and comfort factors are clearly perceived as positive values, enabling usage of the functions.

3.3. Trust and acceptance

Even though it appeared that all drivers perceived the functions as useful and could find value in them, different usage patterns could be observed from the quantitative data. Therefore, in order to further investigate the different usage patterns, two drive cycles that occurred in identical driving contexts were studied more closely. Fig. 4 depicts two different drives, performed by two different drivers at the same time and in the same geographical area. Both drivers belong to different usage groups. With a few minutes of time difference, two vehicles took the same route for their commute home. This fact confirms the presence of the same weather and road conditions for both vehicles. Moreover, judging by the fact that both vehicles maintain speeds of between 22 and 45 km/h on the route, which had speed limits of between 50 and 80 km/h, it can be assumed that both vehicles were in a congested traffic situation.

However, even though both drivers covered the same route, at approximately the same time and driving vehicles equipped with the same system version, one of the drivers chose to activate the ADAS, while the other drove the same route without any activation. From the compared cases, it emerges that besides the driving context (road or traffic conditions) and the perceived value, there are other factors that affect the drivers' acceptance and perception of the ADAS functions.

Therefore, the respondents were asked to describe how they used the system during their everyday drives. The drivers mentioned different reasons, some of them relating to system performance. More specifically, examples were given where the functions did not act as expected, which put them in uncomfortable situations and therefore caused them to refrain from usage. One of the examples cited was the lane keeping behaviour of Pilot Assist. The drivers reported that the system does not follow the lanes smoothly because the system tends to correct the vehicle's position too much, causing discomfort. Looking further into the interviews, more examples regarding the perception of system performance were identified. One example that was mentioned is when the system conducts an action that the drivers did not anticipate. One situation many of the respondents described was the vehicle accelerating when the driver did not expect that, because the traffic situation called for another action.

"First time I experienced the acceleration, for instance, which was too much acceleration compared to the traffic situation, and I was bit: 'What's happening?"

"I had some problems with ACC, when it was out of control for a couple of seconds, because I was trying to override it, but I didn't, so I was thinking: 'Wowowow! What's happening?' before I got control over the system again."

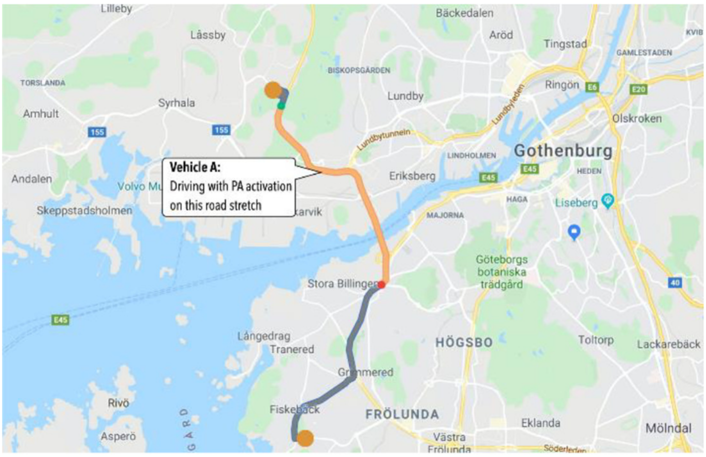
Another uncomfortable situation that was reported by the respondents was when the PA function switched to standby. In this situation accelerating, braking and adapting speed to the car in front still works, but lane keeping support is deactivated. According to all the participants, visual indication about the system status is often not noticed, causing potentially critical situations where the drivers are not prepared for the lack of steering support.

"I was not prepared when the system was deactivated, because I thought it was on and suddenly the car didn't follow the road."

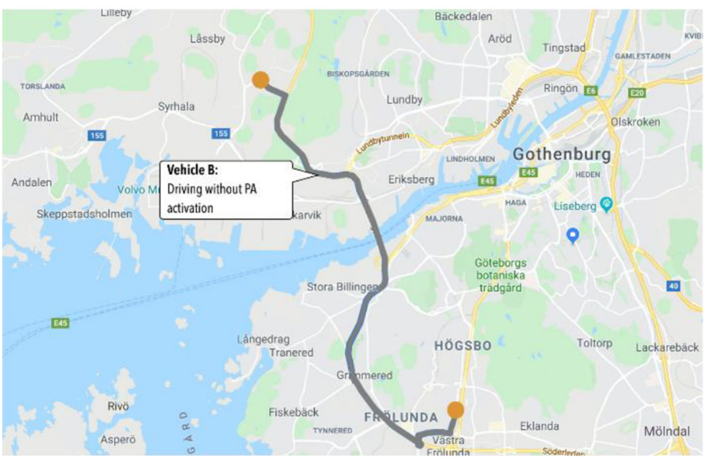
"I've been annoyed or surprised by the system switching off from the green steering wheel to the grey one. And sometimes I haven't noticed really that it's changed."

"It happened that you thought it was on and then when you think: 'I should change something in the navigation', and then you look up and you're sort of in the middle, between two lanes."

These descriptions show that the feedback provided about the system status is not obvious enough, leading to situations where the drivers are taken by surprise. However, this also shows that there is excessive trust in the system. Even though most drivers describe the system as a support function, they still expect the driving aid to have the same abilities as human drivers and to be responsive to different situations. These experiences can create a sense of unreliability, which may cause drivers to not trust the system and prefer one function over



a) Drive Cycle parameters: Vehicle A*
Date: 20/09/2018
Start point: Torslanda
Start time: 15:29
Destination point: Fiskebäck
Stop time: 15:42
Driving distance: 13 km
ACC/PA activation: from Hisingsleden to Västerleden



b) Drive Cycle parameters: Vehicle B*
Date: 20/09/2018
Start point: Torslanda
Start time: 15:25
Destination point: Frölunda
Stop time: 15:44
Driving distance: 13 km
ACC/PA activation: no activation

Fig. 4. Difference in ADAS usage under the same driving conditions: DC with ACC/PA activation DC without ACC/PA activation* For data protection reasons the vehicle numbers in this picture are coded.

the other, distinguishing between different conditions and the system performance in which they feel comfortable using the functions, or they may choose not to use the functions altogether.

"If you put trust into it and rely on the assistance, you think is activated, but then it's not. Then of course the trust level goes down."
"It was a point when I decided not to use it in complicated traffic situations."
"But I was really prepared all the time as it did not act as I expected, so I stopped using it completely."
"So, if I rely on the system and then all of a sudden it's not there, then I prefer to not have it engaged at all. If I see that it goes back and forth, on and off, then I prefer it off, because it gives me a kind of false safety that it's supposed to work, but it doesn't."

When asking the respondents to describe their trust in the system functions, a clear perspective on the perceived reliability of the system emerged. One of the most important factors mentioned was the consistency they experienced during the usage of the system.

"I would say consistency helped my trust. It does the same things all over and over again. It doesn't surprise me like PA does."
"I think continuous behaviour of the system is important. The system may not be perceived as doing different in similar occasions, because then you wonder 'Why?' and you don't trust it."
"With PA I don't feel as comfortable as I should be, to really rely on it 100%. I'm still…with my foot and my hands prepared to act. But I trust especially ACC a lot."

It emerges that acceptance of ACC and PA differs based on how much the drivers think they can trust the system, which they seem to base on system performance. This seems to explain the preferences for ACC versus PA, as some of the drivers specifically state that they do trust one of the functions over the other. Further, the respondents mentioned that they distinguished between different situations and conditions and said that there were different expectations of the system functions. These expectations seem to be dependent on how much trust the drivers have in the function.

"Basically, you need to be in full control. The clearer the road is, the better the road is, the less traffic it is, the more you can trust the system."

"I have trust in the system and know the limitations. So, I wouldn't drive through a 90 degree turn with ACC or PA, with my hands off the steering wheel. […] I always need to be there, I always need to be in control."

"I have to say that I only use it in save situations, where assistance failure wouldn't be too severe. I mean, on the straight road, if it suddenly doesn't work anymore, then it maybe looks a bit weird, but nothing really happens."

This shows that some of the drivers seem to be more aware of system limitations and choose to use and trust the system in those situations. This leads to the assumption that the better the user understands the system capabilities and limitations, the better their expectations are met, and trust can be developed under these specific terms.

Further, the respondents state that they had to build trust in the system over time, which supports the comments above that the drivers choose to use the systems in situations where they deem the system to be reliable, or situations that they consider it safe to try. There seems to be a clear learning curve, in which the user either builds enough trust to accept the system performance for what it is, and use the system, or the user experiences too many negative situations or inconsistencies they cannot explain, and they never reach a state of acceptance, and therefore refrain from using the system.

> *"You need to build trust. I think you need to have some good experiences to start that journey. I think, if you try it maybe in the beginning, during the wrong circumstances, then you…it doesn't work. And then you maybe never try to activate it."*
>
> *"[…] but once you get to know the system, if it does what I assume it will do, then you build trust."*

In summary, these findings make it clear that perceived system performance during different experiences influences driver trust and acceptance. This will influence how and if the system is used, and how much the user relies on it in any given situation. Further, it emerges that negative experiences can cause users to refrain from using the system altogether, especially when they cannot rely on its performance, or understand certain system behaviour. This uncertainty about the system's behaviour is an indicator that there is limited understanding of the system's limitations and capabilities.

3.4. Linking understanding and usage to trust

In the present findings, we described which factors affect usage of ADAS, more specifically what role user understanding plays in this regard. We presented trends that were detected during a naturalistic driving study, and elicited insights from chosen participants about their perception of the systems, to gain more in-depth knowledge about the observed behaviour.

The results demonstrate three things.

First, usage is determined by the preconception the user has about the system. Second, the overall perception of the system is influenced by preconceptions and system performance, which will reflect on the value and usefulness the users ascribe to them. Third, trust in and acceptance of ADAS, and therefore willingness to use it, are determined by the ability of the user to understand its limitations and capabilities.

From the findings, three driver types with different levels of trust in the system could be identified, as depicted in Table 2. The different types will be discussed in more detail in the following sections.

3.4.1. The Sceptic

Driver type 1, the 'Sceptic', does not use the functions, which can mainly be explained by the fact that system performance is not perceived as reliable, and such drivers feel uncomfortable during use of the functions. The perceived system performance is strongly linked to the expectations the users had before and how much they match the actual state. Further, if these users are not willing to explore the function and achieve a certain level of knowledge about how to use it, they will not be able to perceive any benefits. This especially occurred with drivers who had a strong negative experience, and therefore refrained from further exploring the functions. Hence, they will never reach a point where they become comfortable enough to trust the system and harvest the benefits of using the functions.

Table 2
Different levels of trust determining usage of ADAS.

	Type 1: The Sceptic	Type 2: The Conscious	Type 3: The Enthusiast
Trust	No trust	Appropriate Trust	Over-Trust
Usage	No Usage	Situational Usage	"All the time"-Usage
Motive	Perceives system performance as unreliable, so does not receive any benefits	Perceived safety and comfort are valued high, but balanced through perceived system performance in different contexts	Perceived safety and comfort are valued high, along with high technology acceptance, therefore inclined to engage at all times

3.4.2. The Conscious

Driver Type 2, the 'Conscious' driver, opts to use the functions in certain situations only, and differentiates the usefulness of each function according to the situations encountered. The 'Conscious' driver has seemingly identified the strengths and weaknesses of the functions and has built up an appropriate level of trust in the functions within the contextual settings where they have assessed the system as reliable. This driver type might prefer one function over the other, depending on personal experience, or sees usefulness in both functions depending on the driving context. This type of driver has explored the functions to the extent that he or she consciously chooses when to use each function and maximises the benefits of using them, for instance on long trips there is the physical relief obtained through activation of ACC, or in traffic jams extra support through PA's lateral aid. Consequently, one can assume that this driver type does not fully trust the system functions but has built up a situational trust, which is calibrated through system performance in a specific driving context.

3.4.3. The Enthusiast

The third driver type, the 'Enthusiast', finds himself on the opposite side compared to the 'Sceptic'. This driver is characterised by excessive trust in the system, moreover using the functions in a way that is not intended, such as using PA as a hands-free system or eyes-off-road function, when they want to engage with the infotainment system or use the phone. This type of driver sees and values the benefits that the functions offer as very high and tries to engage the system whenever possible. This excessive trust and willingness to explore can be explained by high technology acceptance from the user, which could account for high expectations beforehand. However, such drivers might potentially end up in critical situations, like the ones reported in later sections, where they rely on the system too much and encounter a situation when the system is not capable of performing adequately because the sensors do not have sufficient vision.

Comparing the three driver types, it appears that the 'Conscious' driver has understood the system's capabilities and limitations best, in contrast to the 'Sceptic' who has little or no understanding, and the 'Enthusiast' who occasionally seems to over-estimate the system's capabilities. These findings support the conclusion that usage is influenced by understanding the system's capabilities and limitations, which is crucial for building up the necessary trust that is needed in interaction with the ADAS. However, trust is calibrated throughout the usage process and can be affected through experiences whether positive or negative, leading to users adjusting their expectations of the system and therefore their usage strategies.

4. Discussion

This section discusses the contextualised findings, linking understanding and usage to each other, and highlights the importance of designing a guided learning experience that supports the user in stepping over the threshold.

4.1. Perceived usefulness is dependent on understanding

The findings regarding the perceived usefulness that users ascribe to the system clearly show that, overall, both functions are regarded as comfort and safety enhancers. The users value the fact that the functions reduce physical as well as mental workload, which promotes greater relaxation while driving. Nonetheless, some users feel that

Pilot Assist did not behave consistently or that they do not feel they can rely on it, leading to the users preferring to drive themselves.

However, the relief in physical and mental workload was reported to have an overall positive impact on driving behaviour. The users explain that the functions prompt a slower and less aggressive driving behaviour, which is therefore perceived as safer. They tend to change lanes less often and follow the traffic flow, and keep a safer distance to the car in front. This result ties in well with the results of a focus group study by Strand et al. (2010), where the participants reported similar examples and found that the use of ACC had a positive safety effect on their driving behaviour, resulting in a calmer and less stressful driving style.

From the data collected from vehicles, we can see that there is no change in usage patterns over a seven-month period. This indicates that the users form an opinion about the system's capabilities and limitations early on, which determines how they subsequently use it. Further, the users state that interaction with the function – its usage – is easy to learn, which creates a low threshold regarding engagement with the system. From the interviews, we know that these statements refer to the activation and deactivation process, as well as situations when the users think the system works. A field operational test by Weinberger (2001) supports this finding, where he found that users form a model of how and when to use the systems already after two weeks of usage. However, our findings also show that even though users understand the systems well enough to find value in using them in different situations, they do not fully understand the limitations of the systems. Even though the manufacturers clearly state in the manual that the systems are not recommended for use in demanding driving conditions, such as city driving or other heavy traffic situations, in slippery conditions, when there is a great deal of water or slush on the road, during heavy rain or snow, during poor visibility, on winding roads, or on highway ramps (Volvo Car Corporation, 2019), some users try to use the systems in these situations and are consequently disappointed by the system's performance. It therefore appears that users are willing to explore and try the systems, but their perception of the systems does not change. These indications are supported by a driving simulation experiment conducted by Stanton and Young (2005), which aimed to analyse driver behaviour during interaction with ACC functions. They found that the systems fulfil their respective roles as a comfort and convenience device, but that the benefits did not support better understanding of the systems' limitations.

The study shows and extends the results from other research presented above, that all drivers seem to perceive these types of systems as useful and that they support their driving activity by providing physical and mental relief. Further, the respondents of the study report a more stress-free experience when driving with ADAS functions like ACC or PA. However, it becomes clear that the drivers do not need to fully understand the system capabilities and limitations in order to be able to perceive any usefulness of the functions. Nonetheless, it seems that a basic understanding of the functions is needed to perceive value, while better understanding will elevate that perception of the system even more. This study highlights that the drivers stick to chosen usage scenarios and do not spend their cognitive resources on re-evaluating their own performance. Some individual ADAS performance and the way some drivers use ADAS functions can be seen as not optimal. The diversity of chosen use scenarios showed that drivers need different levels of system support to be able to understand the system interaction.

4.2. Inconsistencies lead to better understanding

In addition to trust, another emerging factor governing use or non-use of the systems is user comprehension of the system. It poses the question of whether the user's preconceptions and expectations influence the learning process, leading to the application of pre-defined and possibly ill-defined use patterns, preventing them from updating their mental model of system usage and/or causing them to refrain from using the functions. Therefore, it is worth investigating how user preconceptions of ADAS are shaped and what role they play in the adoption process of new systems. Kazi et al. (2005) explain that it is necessary to develop acceptance of the system in order to engage with it. In order to do so, the user needs to understand the limitations of the system by building up a mental model – an abstract representation of the mechanisms underlying the interaction. The mental model directly influences the interaction and cooperation between driver and system. It allows the driver to describe, explain and predict the current and future state of the system during usage (Rouse and Morris, 1986).

It seems that after the user has formed a mental model of a system that is regarded as sufficient, it does not evolve any further. One explanation for this phenomenon could be that the study participants are located in the same geographical area throughout the study and the tracked data refers to everyday situations, for instance the commute to work. This implies that the users are most likely not presented with unknown environments, so their use patterns are not challenged or questioned. This argument is in line with previous research which aims to investigate how drivers use ACC in an on-road study, and if changes in usage occur over time. The results showed that becoming familiar with the system's function is a quick process but learning about the system's limitations depends on the experiences encountered as well as the driving environment (Pereira et al., 2015). Forster et al. (2019) could see similar effects in a simulator study, where the results showed that the preference-performance relationship remained stable after just a short time of interacting with the driving automation system. According to Festinger (1957) our attitudes and behaviour will not change as long as we experience consistency regarding our beliefs and the actual state of affairs. Considering our results, this means that if no cognitive dissonance occurs, for example a new situation where the users are forced to re-evaluate their interaction with the system, there will be no change in behaviour. Therefore, one can assume that users build up a certain image of the system's capabilities and limitations which are sufficient for their use and which may not fully apply to the actual occurrences. It remains unclear to what degree the mental model evolves and is updated, and how much it is influenced by pre-existing concepts the users have created from other systems.

4.3. Understanding leads to trust

It is evident, however, that users trust the functions to different degrees. The preference of ACC over PA in connection with different driving contexts, such as road types or traffic situations, indicates that there are situational aspects involved in the perception of system performance and reflects the degree of user trust in the function in those specific situations. This finding is in line with Ekman et al. (2019), who concluded that trust is the result of a combination of the information provided, for instance through in-car interfaces or through the behaviour of the system, and the way these factors relate to the driving context. This highlights the fact that the continuous building of trust is connected to several factors in combination, and each situation is evaluated individually.

This is an indicator that users have various levels of trust within one interaction. While some users seem to have found many ways to engage with the systems and do so in various situations and under various conditions, others do not seem willing to further explore the system and its capabilities. The findings show that the drivers stick to chosen usage scenarios and do not re-evaluate their usage behaviour. This unwillingness to explore seems to be connected to the trust the users have in the specific function, which they seem to base on the experiences they have during the learning phase. Further, the diversity of chosen usage scenarios showed that drivers need different levels of system support. On the other hand, over-trust can lead to misuse (Parasuraman et al., 2008), as was also seen from some examples during the study where the drivers trusted the system as more than just a driver support and ended up being taken by surprise. The users may try the systems and, in this way, understand the limitations better. However, if there is no exploration phase and the system simply does not live up to their expectations, the lack of trust will lead to disuse.

Therefore, one can surmise that in order to learn the limitations of a system, the user actually has to experience its limitations. However, negative experiences and inconsistencies seem to have a deep impact on acceptance. This was also argued by Lee and See (2004) who stated that predictability is a significant trust formation factor. This statement was proven to be true during the interviews, where the users complained about the system not acting in a consistent way, leading them to perceive the system as unreliable and causing them to refrain from using it. This shows the need for clearer communication from the system to the user.

Compared to other research, this study highlights that users need to overcome those negative experiences in order to better understand the systems and gain the benefits of their functionality. Having said that, the design of the communication between drivers and ADAS often does not imply explicit communication. The lack of system feedback to the driver therefore often results in poor understanding of how the system is performing and what limitations it has, leading to misuse or disuse of the systems.

4.4. Stepping over the threshold

From the findings it is evident that extensive comprehension of the system's capabilities and limitations is a key factor for acceptance and therefore usage of ADAS functions. This study especially highlights that a driver's perception of a system does not change just over time, but also through different situations, challenging the expected events and the users' mental model of the interaction with the system. From the results it emerges that drivers build situational trust that is dependent on the function and the context of use, showing that trust is layered and that users have different levels of trust for certain usage scenarios within each system interaction.

The contribution of this study to the research body is to point out that trust leads to usage and how it is connected. But, to gain trust one needs to overcome potentially negative experiences and gain full understanding of the system's capabilities and limitations. In previous research it has not been acknowledged that users need to encounter negative experiences in order to be able to understand the system's constraints. It highlights the need for stepping over the threshold to be able to build a good understanding of system performance and to therefore gain enough trust to be able to build appropriate usage strategies.

These findings support the notion that a guided exploration of ADAS during the learning stages needs to be investigated further. In the preceding paper (Orlovska et al., 2020) the authors argue that a more direct communication and feedback between vehicle and driver can facilitate the interaction with the system. A smart agent could support system usage, or explain system deactivations in various driving conditions, gradually supporting the understanding of the system.

The implication for designers of ADAS is that the interaction needs to be organised in such a way that the learning experience is guided throughout the process. There is a need to design for experience in order to help change the level of trust by the 'Sceptic' and the 'Enthusiast' to an appropriate level, and to support the driver in developing a good understanding of and appropriate usage strategies for ADAS.

5. Conclusion and future research

The results of this study show that users' understanding is influenced by preconceptions about the system, as well as the perceived system performance and usefulness, leading to different levels of trust that affect the users' engagement with the ADAS. It was found that the driver's perception of a system does not just change over time but needs to be challenged. It is important to highlight, that only challenging the expected events and the users' mental model of the interaction with the system leads to change of the mental model. Therefore, to gain trust and appropriate usage strategies for the ADAS the user needs to overcome potentially negative experiences and challenge the current understanding of the ADAS, by stepping over the threshold.

The results presented here are of interest for system development, but first and foremost they are relevant for further research. For instance, it would be valuable to use the elicited insights as a basis for a study that investigates mental models, to further identify factors that influence the user's understanding of ADAS.

Furthermore, the results demonstrate that it is crucial to design a guided learning experience in order to avoid deeply negative experiences, and to support users in overcoming the threshold of using ADAS and support them in using these systems in the intended ways. In summary, better support for users in understanding system capabilities and limitations will forge acceptance of ADAS, and this accordingly needs to be investigated in order to identify design strategies that will enhance the learning experience.

CRediT authorship contribution statement

Fjollë Novakazi: Writing - original draft, Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Visualization. **Julia Orlovska:** Writing - review & editing, Methodology, Conceptualization, Investigation, Data curation, Formal analysis, Investigation. **Lars-Ola BligÔrd:** Writing - review & editing, Methodology, Conceptualization, Supervision. **Casper Wickman:** Writing - review & editing, Supervision, Project administration.

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