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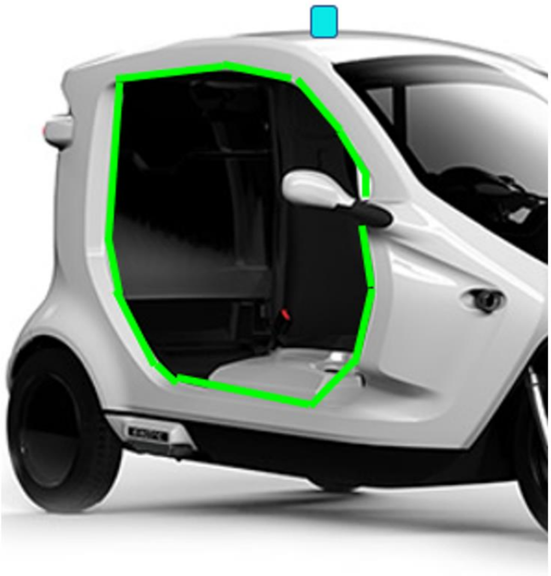


People’s understanding of external HMI and their experiences of interacting with an automated delivery vehicle in a terminal context

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Abstract

This study investigated how the participants in a scenario of a terminal for goods handling perceived to interact with an automated delivery vehicle (ADV) for loading/unloading and how they understood the external Human Machine Interfaces (eHMI), i.e., visual signals on the ADV that communicate the ADV's behaviour, mode and intentions. The objectives were (i) to test and validate the self-driving functions; (ii) to test and validate the control room functionalities and (iii) to evaluate how the participants understood the eHMI and (iv) to evaluate how they experienced to interact with the ADV in specific situations. The eHMI communicated four messages; Acceleration (from stand still), Deceleration (to stand still), Unplanned stop and Delivery mode.

The participants were introduced to the scenario and instructed to act the role of being newly employed at a terminal for loading/unloading goods. There were two situations they were asked to handle: (i) the ADV had stopped (unplanned) due to an obstacle in front which had to be removed for the ADV to drive on, and (ii) to load/unload the ADV when it had stopped at a designated place for loading/unloading. The participants marked on a 5-point scale how easy/difficult it was to understand the different eHMI (eHMI communicated Acceleration from standstill, Deceleration to standstill, Unplanned stop and Load/Unload mode) and how safe/unsafe they felt to approach and interact with the ADV. The same procedures were repeated three times.

The results showed that the participants thought it was easy to understand the different eHMI on the ADV, specifically the types of eHMI that are on vehicles today, such as hazard lights and turning indicators. The results also revealed that the context, i.e. terminal scenario, the situations, and the work tasks, was a contributing factor to their understanding of the eHMI. The participants' previous and gained experiences also contributed to their understanding of the eHMI. The participants thought it was safe to approach the ADV, for example to remove the obstacle in front of the ADV, much because they assumed that such close interactions with the ADVs could happen often and, therefore, they assumed it was safe to interact closely to the ADV. The size of the ADV (smaller than a regular car) was also mentioned as a contributing factor.

The self-driving functions in the ADV were integrated in the ADV's system architecture. A challenge was to obtain stability in the system with repeated driving cycles. The *Autonomous Transport Management System* (ATMS) was put in a cloud service to enable remote testing, and to facilitate repeated integration tests as well as test-cycles with the ADV. The information in the messages sent to the ADV included, for example, the coordinates for the route and the control signals for the eHMI. In addition, a function was implemented to reset the ATMS easily when it entered a faulty state. The control of the LED lights for the eHMI was managed by the main *Vehicle Control Unit* (VCU) which provided more accurate output from the eHMI compared to using the vehicle data.

Key words: Autonomous delivery vehicle, understanding of external HMI, Human – ADV interactions

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Sammanfattning (Swedish)

Denna studie utgick från ett scenario där ett självkörande leveransfordon (eng. Automated delivery vehicle, ADV) anländer för omlastning i en godsterminal. Syftena med studien var att; i) testa och validera de självkörande funktionerna i ADV:n, ii) testa och validera de s.k. kontrollrumsfunktionerna och iii) att utvärdera deltagarnas (i rollen som personal på terminalen) förståelse av eHMI, d.v.s. visuella signaler på ADV:n som kommunicerar dess status, körbeteende och intentioner, och (iv) utvärdera deltagarnas upplevelser av att interagera med ADV:n i två situationer: att ta bort att föremål framför ADV:n och att last/lossa gods från ADV:n.

Deltagarna fick agera nyanställda på en terminal för lastning/lossning av gods och där de skulle hantera två situationer: (i) att plocka bort ett föremål framför ADV:n som hindrade den att köra vidare och (ii) att lasta/lossa gods från ADV:n. Deltagarna markerade på en 5-gradig skala hur lätt/svårt det var att förstå de olika eHMI på fordonet (som kommunicerade Acceleration från stillastående, Inbromsning till stillastående, Oplanerat stopp och Leveransläge) och hur säkert/osäkert det kändes att dels plocka hindret framför ADV:n, dels att lasta/lossa från ADV:n. Varje deltagare upprepade resp. situation tre gånger.

Resultaten visade att deltagarna generellt förstod de olika eHMI på ADV:n, speciellt den typ av eHMI som finns på fordon idag, t.ex. varningsblinkers och blinkers. Det visade sig också att kontexten, d.v.s. terminalscenariot, situationerna och arbetsuppgifterna, var viktig för deltagarna för att förstå innebörden av eHMI. Även deltagarnas tidigare erfarenheter, samt den erfarenhet och kunskap de fick under studien bidrog till att förstå de olika eHMI. Deltagarna tyckte att det kändes säkert att närma sig ADV:n för att ta bort hindret. De antog denna typ av situation kunde vara vanlig på en terminal med ADV:er och antog därför också att det var säkert att interagera med ADV:n. Storleken på ADV:n (mindre än en bil) var också en bidragande faktor till att det kändes säkert.

De självkörande funktionerna i ADV:n och rutten var integrerad i ADV:ns systemarkitektur. En utmaning var att få stabilitet i systemet med upprepade körcykler. Det autonoma transporthanteringssystemet (eng. *Autonomous Transport Management System*, ATMS) placerades därför i en molntjänst för att kunna fjärrtestas och för att kunna upprepa integrationstester och testcykler. Informationen i meddelandena som skickades till ADV:n från kontrollrumsfunktionerna inkluderade till exempel koordinaterna för rutten och styrsignalerna för eHMI. Även en funktion för att återställa systemet vid felmeddelanden implementerades. Styrningen av LED-lamporna i eHMI hanterades av fordonets styrenhet (eng, *Vehicle Control Unit,* VCU) vilket gav en noggrannare beräkning av utgångssignalerna till eHMI jämfört med att använda fordonsdata.

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Content

Preface

This report is from the GLAD project (GLAD: *Goods deliveries under the last mile with automated delivery vehicles*). GLAD was a research and development project with the overall aim to gain knowledge about user needs as well as about the technical, societal, business and policy related challenges with automated delivery vehicles (ADV). The GLAD project was conducted during June 2020 and September 2022 and was coordinated by RISE Research Institutes of Sweden. The project was partly financed by the Swedish Transport Administration (ref. no. TRV 2020/26017). The partners in the GLAD project were RISE Research Institutes of Sweden, Aptiv AB, Combitech AB, Clean Motion AB and Halmstad university. The studies in the GLAD project are summarized in the following report:

- Söderman, M., (2022), *GLAD, Goods deliveries under the last mile with automated delivery vehicles - Summaries of the studies in the GLAD project*, ISBN 978-91-89757-24-0, RISE report 2022:135

The full reports from the studies in GLAD are:

- Andersson, K. (2022), *Autonoma leveransfordon – vad är de för sorts fordon och har det någon betydelse? (Eng. Automated delivery vehicles - what kind of vehicles are they and does it matter?),* ISBN 978-91-89711-44-0, RISE report 2022:100
- Söderman, M. (2022), *Typical and critical traffic situations with small electric delivery vehicles – indications for future automated delivery vehicles*, ISBN 978-91-89757-19-6, RISE report 2022:130
- Söderman, M., Andersson, J., Habibovic, A., (2022), *Use cases and high-level requirements for safe interactions between Automated Delivery Vehicles and human operators in a terminal,* ISBN 978-91-89757-20-2, RISE report 2022:131
- Andersson, J., Habibovic, A., *How to convey the intent of an automated vehicle with its longitudinal and lateral movements - evaluating four communication concepts in two traffic situations involving pedestrians* (Report expected in 2023)
- Söderman, M., Clasen, R., Bergström, G., Collings, W., (2022) *Development of self-driving and control room functions and of external HMI for Automated Delivery Vehicles,* ISBN 978-91-89757-21-9, RISE report 2022:132
- Söderman, M., Clasen, R., Bergström, G., Collings, W., (2022) *People's understanding of external HMI and their experiences of interacting with an Automated Delivery Vehicle in a terminal context,* ISBN 978-91-89757-22-6, RISE report 2022:133
- Gonzales, S., Sveder, C., Oscarsson, E., Jönsson, S., (2022) *Challenges and potential business applications of Automated Delivery Vehicle initiatives - a brief overview,* ISBN 978-91-89757-23-3

1 Background

In the GLAD project, there are three studies about automated delivery vehicle (ADV) development and Human interactions with ADV. In the first study (Andersson & Habibovic, 202x)[1] it was explored how the participants, as pedestrians in an urban environment, experienced an ADV's driving behaviour in terms of its positions in lane and its speed, as implicit communication of its actions and intentions towards the pedestrians. Two scenarios were studied: (i) a pedestrian (participant) standing at the side of a street ready to cross when an ADV was approaching; and (ii) a pedestrian facing an approaching ADV driving partly on the walking lane in order to pass an obstacle on the road. This scenario is similar to how today's manual vehicles are communicating with turning signals, brake lights, horn etc., but also through the vehicle's implicit communication, such as speed, the dynamics in acceleration and deceleration as well as position in lane, distance to other vehicles and VRUs etc. The findings indicated that additional means to the ADV's speed and positions in lane, for example external Human Machine Interface (eHMI), i.e., visual signals that communicate the vehicle's states, intentions and behaviour to the surrounding, could provide support for pedestrians to better understand the ADVs' behaviour and intentions, especially in environments where ADVs are expected to drive in low speed, such as in urban environments.

The vehicle used in the study mentioned above was a so-called Wizard-of-Oz vehicle, i.e. a human driver was hidden in the vehicle to give the impression of an self-driving vehicle. A following study (Söderman et al., 2022) focused on three areas (i) development and implementation of self-driving functions; (ii) development of integrated Control room functions which could send commands, e.g. to drive a specific rout, and receive status from the ADV, e.g. its position, speed and position along the route, and; (iii) the design and implementation of eHMI on an ADV. The National Highway Traffic Safety Administration (NHTSA, USA) has argued that automated vehicles (AV) must be capable of conveying information to humans regarding its intentions and performance (ISO/TR 23049:2018), often referred to as external HMI (eHMI). Several studies have investigated different eHMI-concepts as means to communicate AV's behaviours and intentions to the surrounding. For example, studies by Faas et al. (2020), Métayer et al. (2019) and Wilbrink et al. (2021) indicate that people can feel safer and have more trust in AVs with eHMI and can help pedestrians to understand the AVs' intentions. The main goal is to allow effective communication to the surrounding and, thus, avoiding uncertainty and misunderstanding that could lead to dangerous situations (Carmona et al. 2021). However, the results from studies about human – AV interactions are not consistent in whether eHMI does provide support to humans to understand AVs behaviour and intentions and to make "safe" decisions when interacting with AVs (de Winter and Dodou, 2022; Lee et al. 2021; Moore et al. 2019).

Moreover, there are currently no established framework or standards for eHMI, i.e. *what* eHMI concepts should convey (content) or *how* the eHMI concepts should be designed (texts, icons, projections, light signals, colours etc.) to convey specific messages to people in the surrounding. Still, the matter of eHMI as means to communicate automated vehicle's behaviour and intent has been investigated in numerous studies and several

[1] Report is expected in 2023

criteria and design guidelines have been proposed, for example by Weber et al. (2019), Habibovic et al. (2018), Carmona et al. (2011).

This report describes the tests of the self-driving and control room functions, as well as the evaluations of the eHMI-concepts for ADV with end-users that were developed in Söderman et al. (2022).

2 Objectives, research questions and limitations

The study addressed three areas:

I. Integration, testing and validation of the self-driving functions in the ADV that were developed in Söderman et al. (2022).

II. Human Machine Interaction evaluations where the objectives were to evaluate the eHMI with end-users that was developed in Söderman et al. (2022). The research questions were:
   - How do the participants understand the eHMI in a terminal context?
   - How do the participants experience to interact with the ADV in two situations:
     - To remove an obstructing obstacle
     - To load/unload the ADV (goods)
   - How can the eHMI be improved to communicate the ADV's behaviour more clearly?

III. Control room functionality (the Autonomous Transport Management System, ATMS) developed in Söderman et al. (2022). The objectives:
   - To integrate ATMS to the ADV
   - To implement functionality to send eHMI information (when to light which signal) to the ADV
   - To repeat the iteration procedure (send mission from ATMS to ADV) multiple times in a row to evaluate the performance.
   - To implement the functionality to send reference speed and reference heading from ATMS to the ADV (i.e., not relying on pre-stored data in the ADV)

A major limitation was that the study could not be carried out in a real terminal for goods handling. Instead, the study was carried out in an enclosed area outdoors with markings on the ground and cones to mark entry/exits, lanes and load/unload zones to represent a terminal for loading/unloading goods. The participants were recruited from different industries, but no one was currently working at a terminal, even though a couple of the participants had previous experiences of working in goods terminals. Another limitation was that the ADV used in the study was a prototype not specifically designed to carry goods (Figure 1). The limitations were explained to the participants by the test leader. The terminal scenario, the situations that the study addressed, and the participants' roles and tasks in the study were also carefully explained.

Figure 1, *The ADV prototype used in the study.*

3 Method

3.1 Scenario and subjective measurements

The enclosed area in which the scenarios took place measured appr. 35 times 35 meters. The length of the route was about 75 meters (Figure 2).

The scenario description: An ADV has entered the terminal. On its way to a designated loading/unloading zone it has stopped due to an obstacle in its way. The ADV has stopped about 1,5 m in front of the obstacle (Figure 2, Situation 1). The ADV is unable to drive around the object and, therefore, the eHMI for Unplanned stop has been activated (Figure 5). The participant is now notified (by the test leader) that the ADV has stopped. The test leader asked the participants (i) what they think had happened; (ii) why the ADV had stopped; (iii) if they noticed the eHMI, and (iv) how they interpreted the eHMI. The participants marked on a 5-point scale how easy/difficult it was to understand the eHMI. The participants were then asked if it felt safe (enough) to remove the obstacle (a bag) in front of the ADV and marked on a 5-point scale how safe/unsafe it would feel to remove the obstacle. The obstacle was removed by the test leader as part of the study's safety protocol.

After the obstacle had been removed the ADV resumed its route to a zone for loading/unloading (Figure 2, Situation 2 and 3). The participants were now standing at the zone for loading/unloading the ADV. When the ADV approached the loading/unloading zone the eHMI for deceleration was activated (Figure 2). Shortly after the ADV had stopped in the loading/unloading zone the participants were asked if they had noticed the eHMI for deceleration and they marked on a 5-point scale how easy/difficult it was to understand the eHMI. The eHMI or loading/unloading was then activated (Figure 2, Situation 5) and the participants were asked how they interpreted the eHMI and marked on a 5-point scale how easy/difficult it was to understand the eHMI. The participants were then asked if they thought felt safe (enough) to go close to the ADV to load/unload goods (the test leader accompanied the participants when approaching the ADV) and they marked on a 5-point scale how safe/unsafe it felt to go close to the ADV to load/unload (Figure 2, Situation 6). After the loading/unloading was completed (no actual loading/unloading but pretending) the participants stepped back and the ADV drove away (Figure 2, Situation 7). The participants were asked if they noticed the eHMI for acceleration (Figure 2) and marked on a 5-point scale how easy/difficult it was to understand the eHMI.

The same procedure was repeated in three rounds. Prior to the first round no explanations were given to the participants about the ADV's behavior in the different situations and about the intended message of the eHMI. After the first round the ADV's behavior and the eHMI were explained. When the three rounds had been completed the participants filled in questionnaires and were asked some concluding questions:

- Questionnaire: 5-graded Likert-scales about the participants' experiences of the eHMI-concepts regarding visibility, perceived understanding and perceived usefulness
- Questions to the participants at the end of the session about what they thought was difficult to understand in the different situations and eHMI and questions about areas of improvements of the eHMI.

The session took approximately 45 minutes in total per participant.

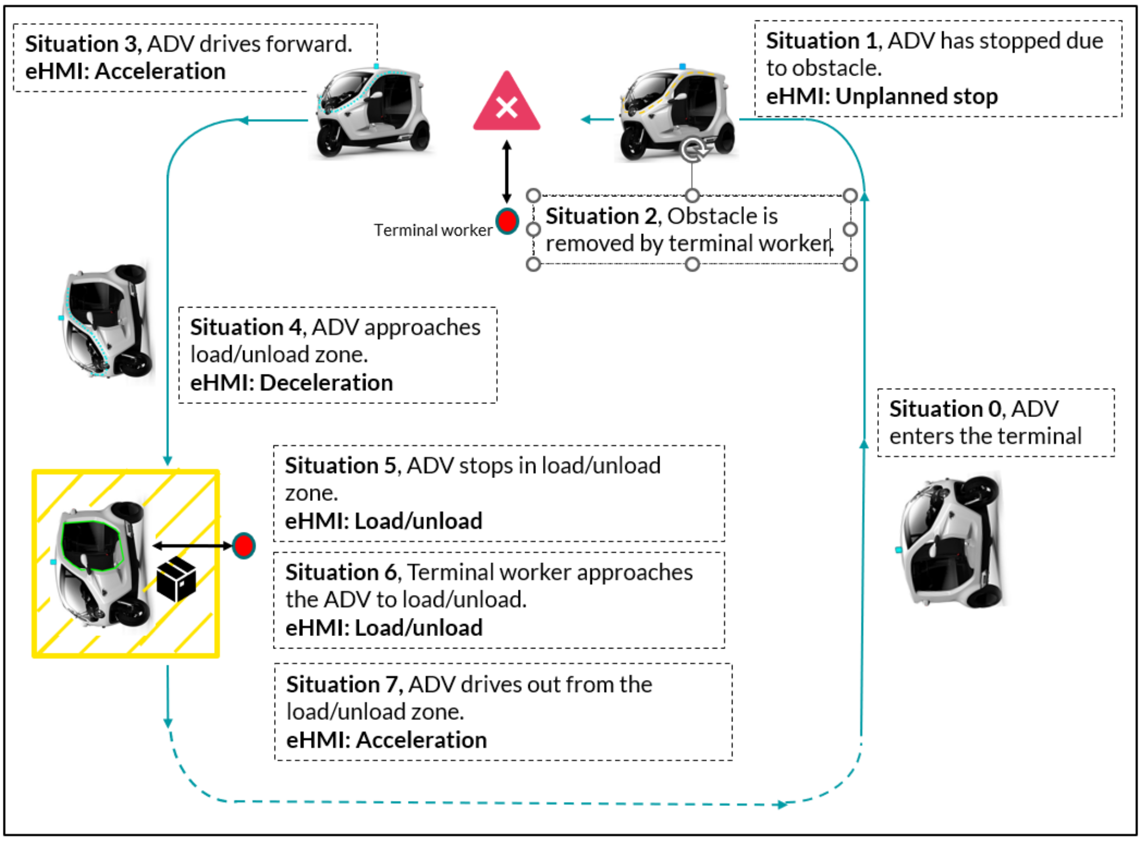


Figure 2. *Plan of the route, situations and eHMI. The length of the route was 46 meters. Max speed 5 km/h.*

Table 1. Overview of situations and eHMI

No.	Situation	eHMI
0	ADV enters the terminal	
1	ADV has stopped due to obstacle in front	Unplanned stop
2	Obstacle is removed	Unplanned stop
3	ADV drives forward	Acceleration
	Questions and 5-point scales after each round.	
4	ADV approaches the loading/unloading zone	Deceleration
5	ADV stops in the loading/unloading zone	Load/unload mode
6	TP approaches the ADV to "load/Unload"	Load/unload mode
7	ADV drives out of the loading/unloading zone after the Loading/Unloading is completed.	Acceleration
	Questions and 5-point scales after each round. After the third round: Concluding questions and experienced problems and areas of improvements.	

3.2 External HMI (eHMI)

Figures 3-5 describe the situations explored and the corresponding eHMI.

Figure 3, eHMI Deceleration/Acceleration: LED-stripes mounted on the sides of the roof, along the A-pillars to the front lamp (same as the deceleration). During deceleration to standstill the lights were wandering forward from the roof's sides towards the front lamp. During acceleration from standstill the lights were wandering backward from the front lamp, along the A-pillarss and over the sides of the roof. Colour: cyan.

Figure 4, eHMI Load/Unload mode: LED-stripes mounted around the area where you load/unload goods. The Load/Unload mode was activated when the ADV had stopped for loading/unloading goods indicating that goods personnel could approach the ADV to load/unload goods.

Figure 5, eHMI Unplanned stop: LED-stripes mounted on the sides of the roof, along the A-pillars to the front lamp. In the event of an unplanned stop the ADV (system) cannot solve but needs assistance the lights are flashing in yellow, together with the hazard lights on the vehicle. The eHMI for Unplanned stop was active until the situation was resolved.

3.3 eHMI evaluation

3.3.1 Participants and scenario introduction

The scenario was a terminal for loading/unloading of goods on incoming ADVs. Due to practical reasons (dependent on GPS-signals, limited accessibility to real terminals and difficulties recruiting terminal workers etc.) the study was carried out outdoors in an enclosed area. The participants were recruited from various industries and businesses. Thirteen persons participated in the study (11 men, 2 women), ages from 22 to 66 y (ave. 37 y, std. 14,4). No one was working at a terminal, but a couple of the participants had experiences of working in goods terminals.

The test leader informed the participants about safety matters, for example showed the locations of the emergency stop buttons on the ADV, that the ADV was monitored by a technical crew (sitting in one end of the test area) and that the participants could terminate their participation in the study at any moment with no questions asked. The test leader also accompanied the participants through the study to ask questions, but also due to the safety protocol, since the ADV was a prototype and that the participants would be in close range of the ADV.

The participants were introduced to the scenario in which they were asked to "act" the role of being newly employed at a terminal for loading/unloading goods (which is a common type of short time employment). This was their first day at the terminal, and thus, they were unfamiliar with the routines at the terminal and with the ADV.

3.4 Technical development

3.4.1 ADV Functionalities

The driving capability of the ADV was based on a Pure Pursuit Controller, a path tracking algorithm popular in robotics because it has a low complexity in terms of parameters and high robustness of operation. The technical implementation of the controller leveraged functionality from the Robot Operating System (ROS) navigation stack.

The input used in this controller was defined and stored in Comma Separated Value (CSV) file types and contained information about the route structured so that each point had an order-ID, GPS-coordinates, reference heading and reference speed. eHMI signals were added to this input structure to enable positional triggers for the eHMI signals based on the ADVs positions relative to the route.

A Representational State Transfer (REST) module was implemented for communication between the control room and the ADV. The REST module enabled the ADV to send and receive information and data over a network connection, such as the assignment input CSV-file as well as the launch and resume commands.

Additional features included expanding the pure pursuit controller algorithm to handle multiple routes with intermediate stops and resume functionality. This was achieved by treating each sub-route of an assignment as a separate input for the controller, reducing a complex assignment to several independent sequential drives.

The implementation of multiple routes facilitated the implementation of the stop for obstacles event as well as the loading and unloading event. The control room was then able to send a command to the ADV so that it continued the next route after each stop.

3.4.2 eHMI implementation

The trigger signals for the eHMI light indicators were updated in this study. In a previous study (Söderman et al., 2022) utilized dynamic signals from the ADV, such as acceleration/deceleration, to trigger the eHMI signals. In order to increase repeatability, timing and length of signals this functionality was instead pre-programmed so that they were coupled with the coordinates of the route. The triggers were then triggered by the ADVs positions relative the route.

The resolution of available triggers for signal change was related to the number of coordinates in the route, where two points per meter were used. The turning signal indicator was kept dynamic based on the ADVs actual steering angle (Figure 6).

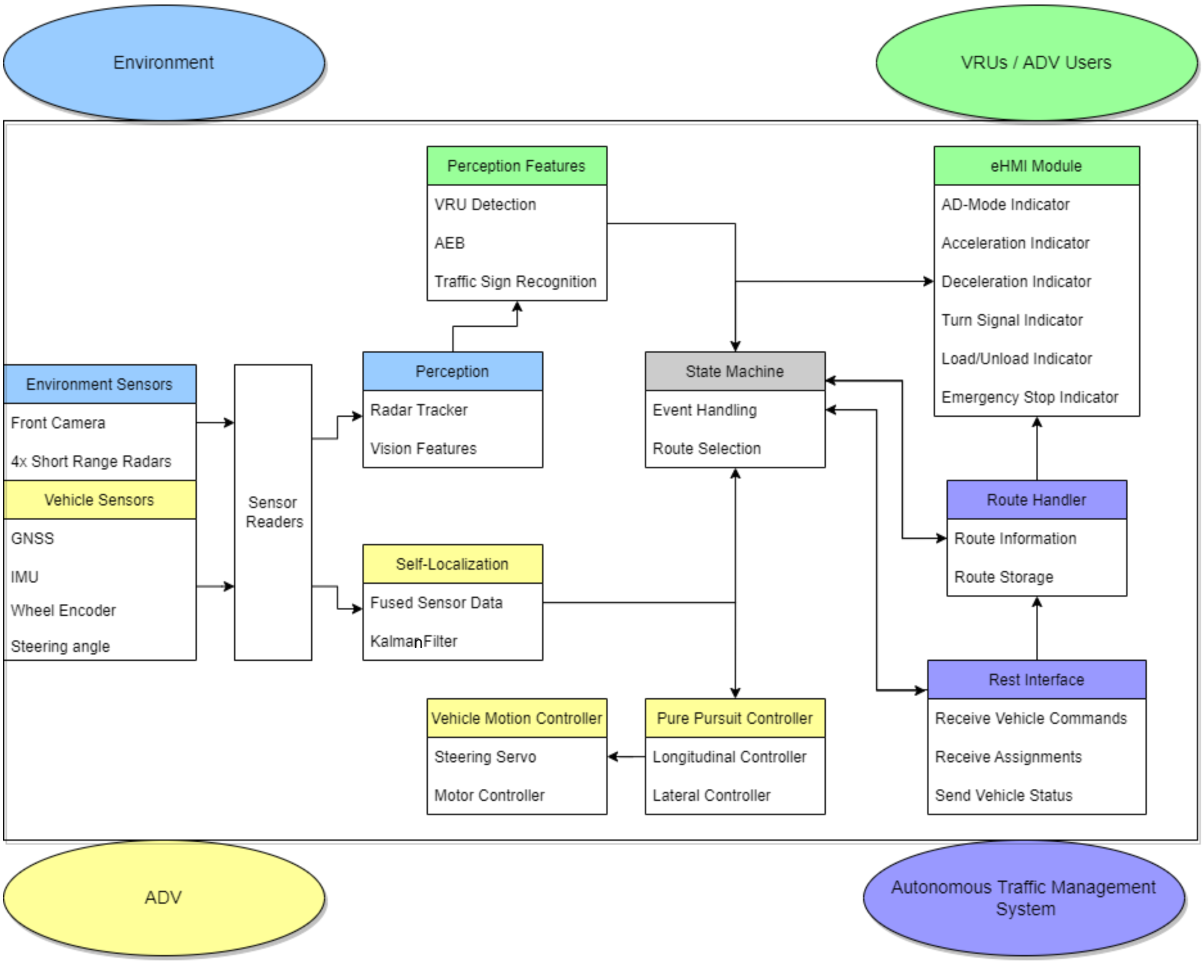


Figure 6. *The overall system architecture: ADV system overview and interaction*

3.4.3 Site control functionality and integration with ADV

The focus was to reach a stable version of ATMS and the software on the ADV with a minimal amount of manual input (e.g., clearing a database between each run). The ATMS was moved to a remote server, so that the ADV could be operated from a distance. That made it possible to test new fixes without needing an ATMS operator physically by the vehicle. However, the new function development was given low priority and, instead, effort was put into stabilizing the system. Many tests were performed, and when a stable version had been reached, the code was not changed (code freeze).

Information about reference positions and reference speed was implemented in the messages sent from the ATMS. Previously, that information was stored on the ADV. Information about when to show which signal via the eHMI was also implemented in the messages. The information was added manually into the messages, and not via the eHMI.

A key difference between the previous study (Söderman et al., 2022) and this study was the possibility to repeat the ADV's runs several times without human interference between each run. Functionalities were implemented which facilitated resetting the system to a state where a new run could be launched.

4 Results and discussion

4.1 eHMI

The participants' markings on the 5-point scales how easy/difficult it was to understand the different eHMI are shown in the pie charts below. Prior to the first round the participants were not informed about the intended messages of the eHMI. Prior to the second round the test leader explained the eHMI. No further explanations were given prior to the third round.

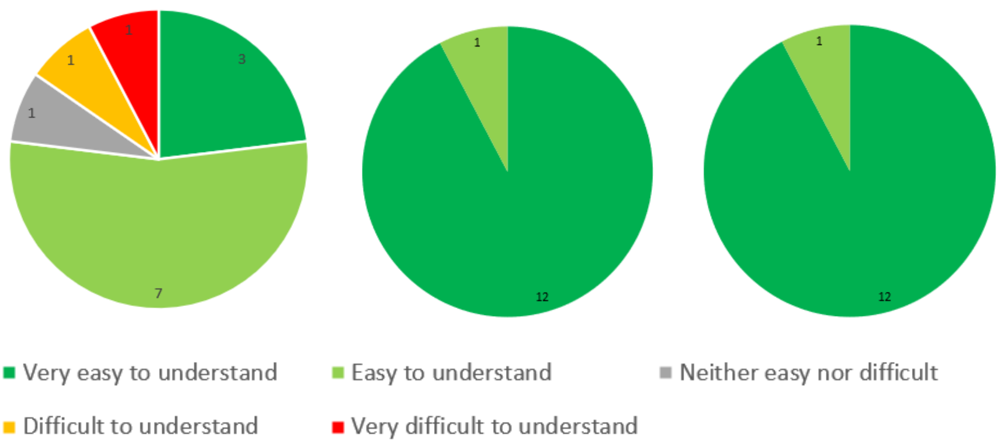
4.1.1 eHMI Unplanned stop

Situation: The ADV has stopped due to an obstacle in front of the ADV.

eHMI: Unplanned stop (Figure 5)

Question: *How easy/difficult is it to understand the eHMI?*

1st Round **2nd Round** **3rd Round**



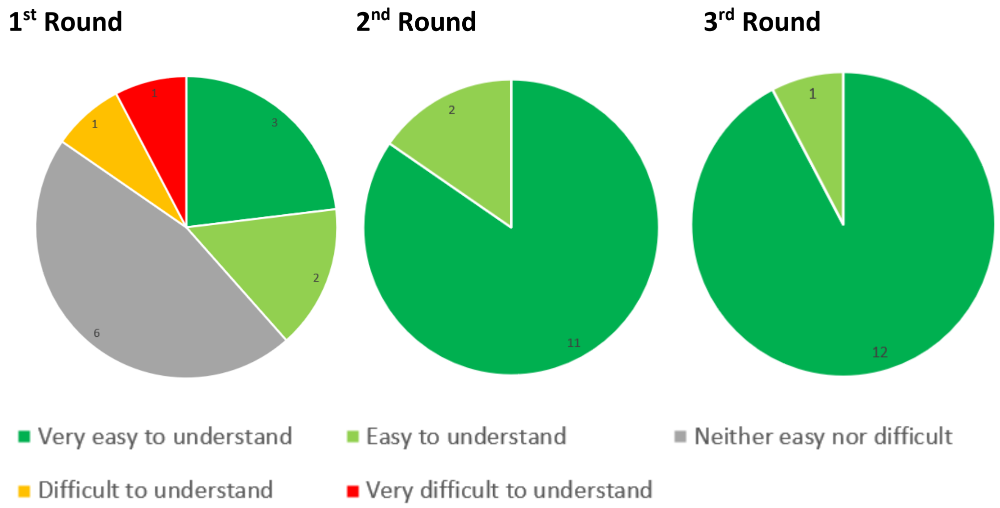
The results show that most of the participants understood the eHMI *Unplanned stop* as intended. A reoccurring comment from the participants was that this eHMI was similar to the hazard lights on cars today, which made the participants to think that this eHMI communicated *warning, attention, take notice* etc. The fact that there was an obstacle (a bag) obstructing the ADV's way strengthened the participants' reasoning about this eHMI's intended message. Due to the bright sunlight during the test it was difficult for some of the participants to see the yellow LEDs, which made it difficult for them to understand the situation and the HMI.

4.1.2 eHMI Deceleration

Situation: The ADV is decelerating when approaching the loading/unloading zone

eHMI: Deceleration (Figure 3)

Question: *How easy/difficult is it to understand the eHMI?*



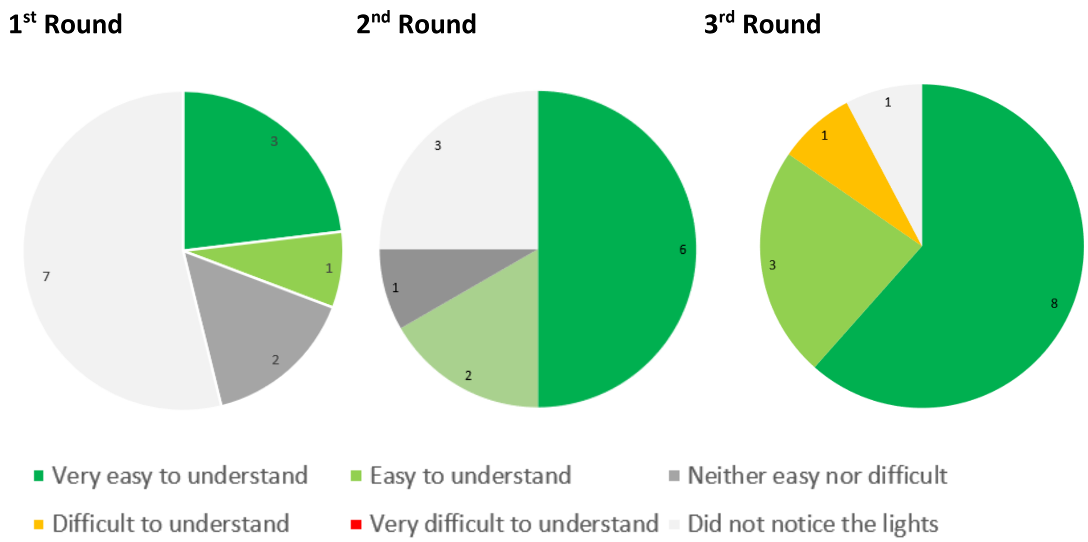
With no explanation about the eHMI Deceleration this eHMI was not clear to the participants. Those who thought this eHMI was easy/very easy to understand often concluded its meaning from the situation, i.e. waiting for the ADV to stop at the loading/unloading zone. The forward moving LED-lights in cyan were often interpreted as indicating that the ADV was heading for the loading/unloading zone rather than indicating specifically that the ADV was slowing down. Given the context that the ADV was driving and slowing down to stop in the loading/unloading zone contributed to their understanding of the eHMI.

4.1.3 eHMI Acceleration

Situation: The ADV accelerates

eHMI: Acceleration (Figure 3)

Question: *How easy/difficult is it to understand the eHMI?*



The eHMI Acceleration was noticed by less than half of the participants in the first round. One explanation was that the LED-lights were not bright enough in the daylight. Another explanation was that the participants' task to load/unload the ADV was completed and, therefore, they did not pay any attention to the ADV as is drove away.

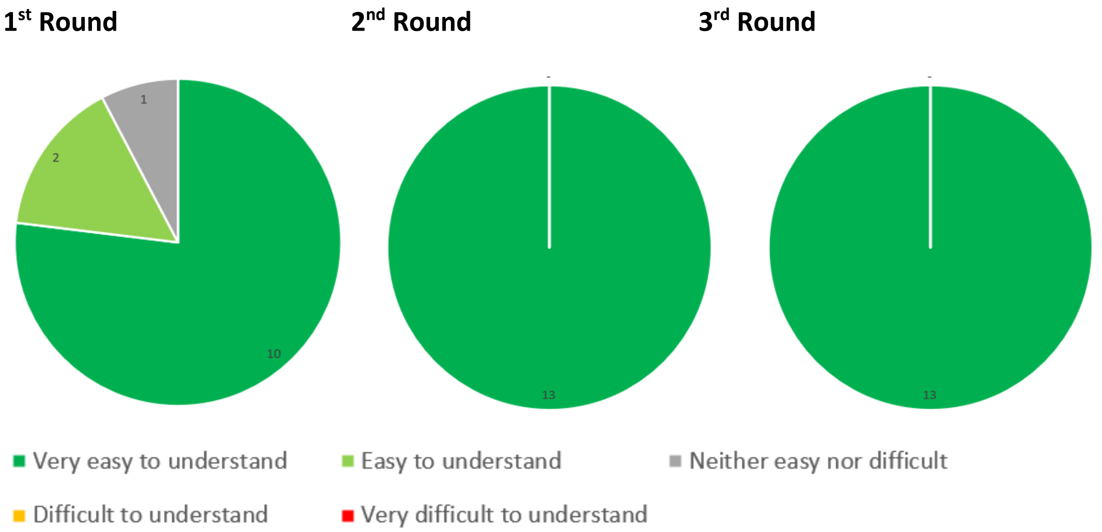
When this eHMI was explained prior to the second round the participants understood the eHMI, and some participants also recalled the forward moving lights in the eHMI for Deceleration when the ADV approached the loading/unloading zone and, thus, concluded the meaning of the eHMI Acceleration's backward moving LED lights.

4.1.4 eHMI Load/Unload goods

Situation: The ADV has stopped in the loading/unloading zone

eHMI: Load/Unload mode (Figure 4)

Question: *How easy/difficult is it to understand the eHMI?*



The participants thought the eHMI loading/unloading mode was easy to understand without any prior explanation. The green LED-lights on the side of the ADV surrounding the area for loading/unloading goods was clearly visible, and the participants interpreted the green colour that the ADV was ready to load/unload and safe to interact with.

4.2 The participants' experiences of approaching the ADV

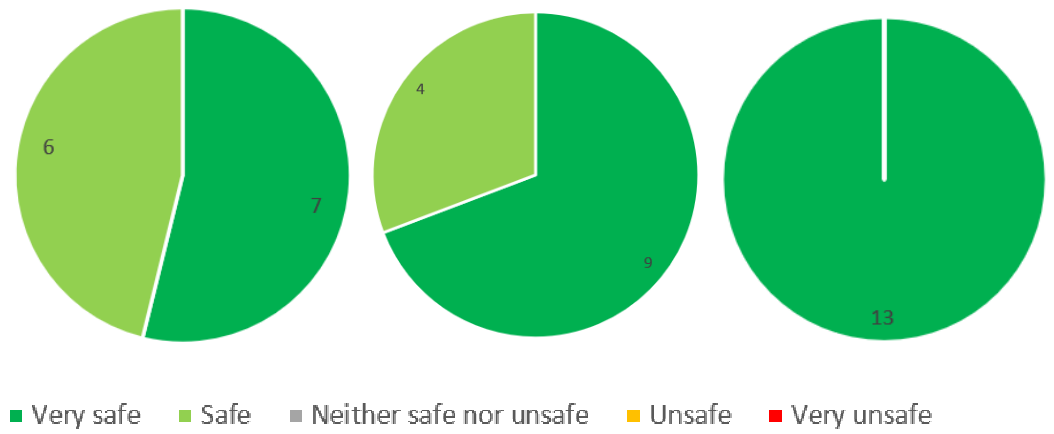
On two occasions during the study the participants were asked to approach the ADV. The first occasion was when the ADV had stopped due to an obstacle (Figure 2, situation 1). The participants were asked how safe/unsafe it would feel to go in front of the ADV to remove the obstacle. The other occasion was when the participants approached the ADV to load/unload goods (Figure 2, situation 6).

Situation: Remove the obstacle in front of the ADV.

eHMI: Unplanned stop (Figure 5)

Question: *How safe/unsafe did it feel to go in front of the ADV to remove the obstacle?*

1st Round **2nd Round** **3rd Round**



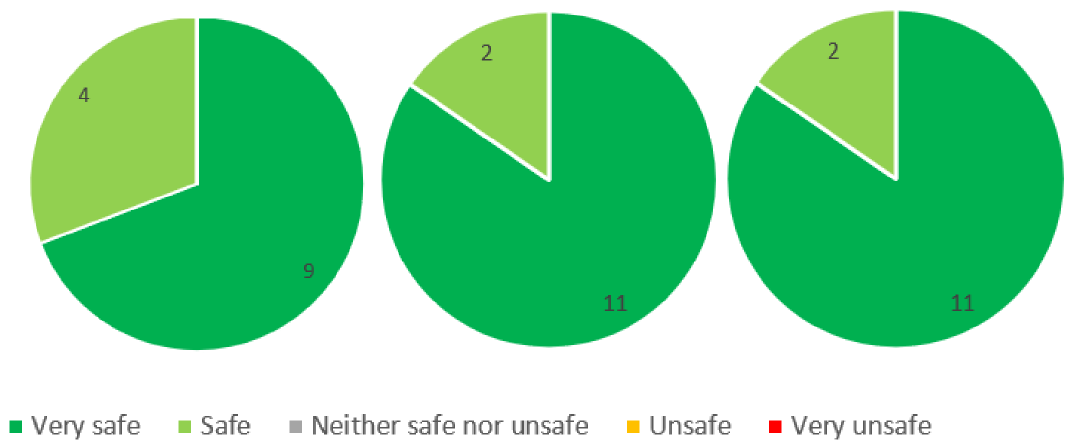
The participants' ratings on the 5-point scale show that they thought it would feel safe to go in front of the ADV to remove the obstacle. Due to the safety protocols for this study, the test leader carried out the actual removal of the obstacle, which may have affected their ratings. However, the trend from round 1 to round 3 indicated increased perceived safety. The participants also mentioned that they assumed this type of situation could happen often in a terminal with ADVs and, therefore, removing obstacles in front of an ADV would be a regular routine and considered as a non-critical event.

Situation: The participant interacts with the ADV to load/unload goods.

eHMI: Load/Unload mode (Figure 4)

Question: *How safe/unsafe did it feel to approach the vehicle to load/unload?*

1st Round **2nd Round** **3rd Round**



The participants experienced interacting with the ADV to load/unload goods as safe. The clear meaning of the eHMI for loading/unloading may have contributed to the perceived safety. The participants' comments indicated that the size of the ADV (L 2,4 m, W 1,25 m, H 1,5 m), considered as rather small, also contributed to the perceived safety. Standing at the side of the ADV to load/unload goods and not standing in front of or behind the ADV was also mentioned to add to the perceived safety. Some of the participants said they would be more concerned about incidents related to the actual loading/unloading of goods, such as dropping packages on their toes, or pain and injuries to the back from handling the goods. It should be mentioned that the emergency stop buttons on the ADV's roof could be easily reached which may have contributed to the perceived safety in this situation.

4.3 Overall experiences

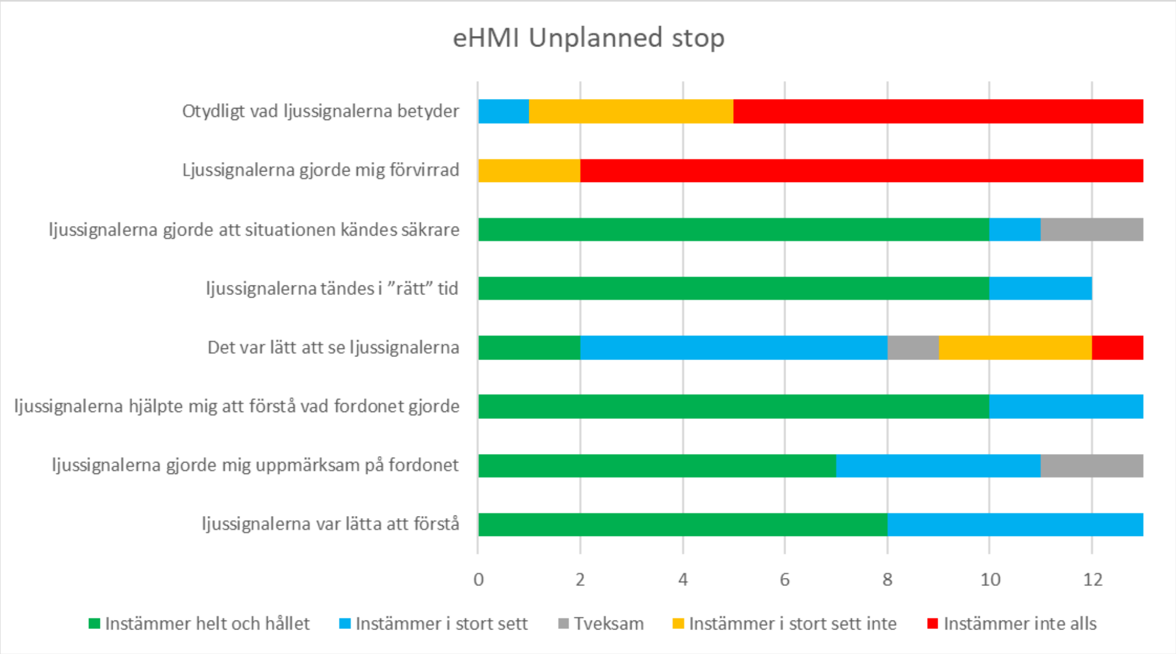
After the participants had completed the three rounds, they filled in 5-point Likert-scales for their overall experiences of the different eHMI. The statements in the graphs below, from top to bottom (translated from Swedish):

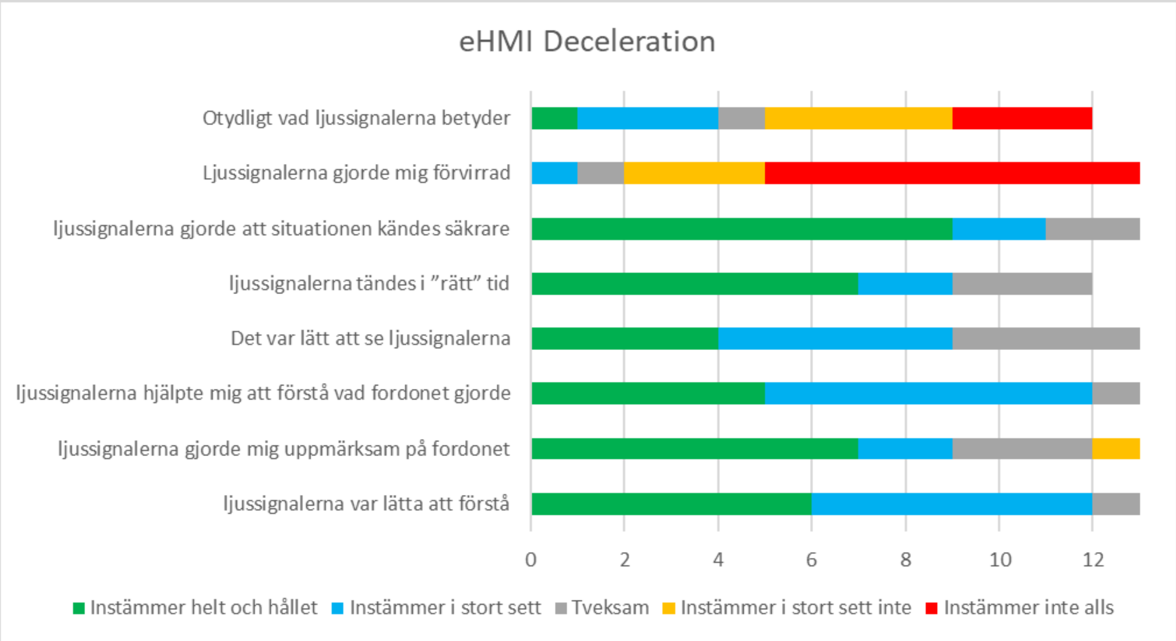
- *It was unclear to me what the light signals (eHMI) meant*
- *The light signals (eHMI) made me confused*
- *The light signals (eHMI) made the situation safer*
- *The light signals (eHMI) were timely activated*
- *It was easy to see the light signals (eHMI)*
- *The light signals (eHMI) helped me to understand the ADV's behaviors*
- *The light signals (eHMI) made me attentive to the ADV*
- *The light signals (eHMI) were easy to understand*

■ (green) Completely agree, ■ (blue) Agree, ■ (grey) Neither, ■ (orange) Do not agree,

■ (red) Do not agree at all

The graphs below illustrate the distribution of the participants' responses to the statements in the Likert-scales. The results show that the participants overall responded in favour to the statements about the eHMI after the three rounds were completed. The statements with low scores were: *It was easy to see the light signals* (Unplanned stop, Deceleration and Acceleration), *The light signals (eHMI) were timely activated* (Deceleration and Acceleration) and, *The light signals (eHMI) made me attentive to the ADV* (Deceleration and Acceleration).


eHMI Unplanned stop
Otydligt vad ljussignalerna betyder
Ljussignalerna gjorde mig förvirrad
ljussignalerna gjorde att situationen kändes säkrare
ljussignalerna tändes i ”rätt” tid
Det var lätt att se ljussignalerna
ljussignalerna hjälpte mig att förstå vad fordonet gjorde
ljussignalerna gjorde mig uppmärksam på fordonet
ljussignalerna var lätta att förstå
0
2
4
6
8
10
12
Instämmer helt och hållet
Instämmer i stort sett
Tveksam
Instämmer i stort sett inte
Instämmer inte alls


eHMI Deceleration
Otydligt vad ljussignalerna betyder
Ljussignalerna gjorde mig förvirrad
ljussignalerna gjorde att situationen kändes säkrare
ljussignalerna tändes i ”rätt” tid
Det var lätt att se ljussignalerna
ljussignalerna hjälpte mig att förstå vad fordonet gjorde
ljussignalerna gjorde mig uppmärksam på fordonet
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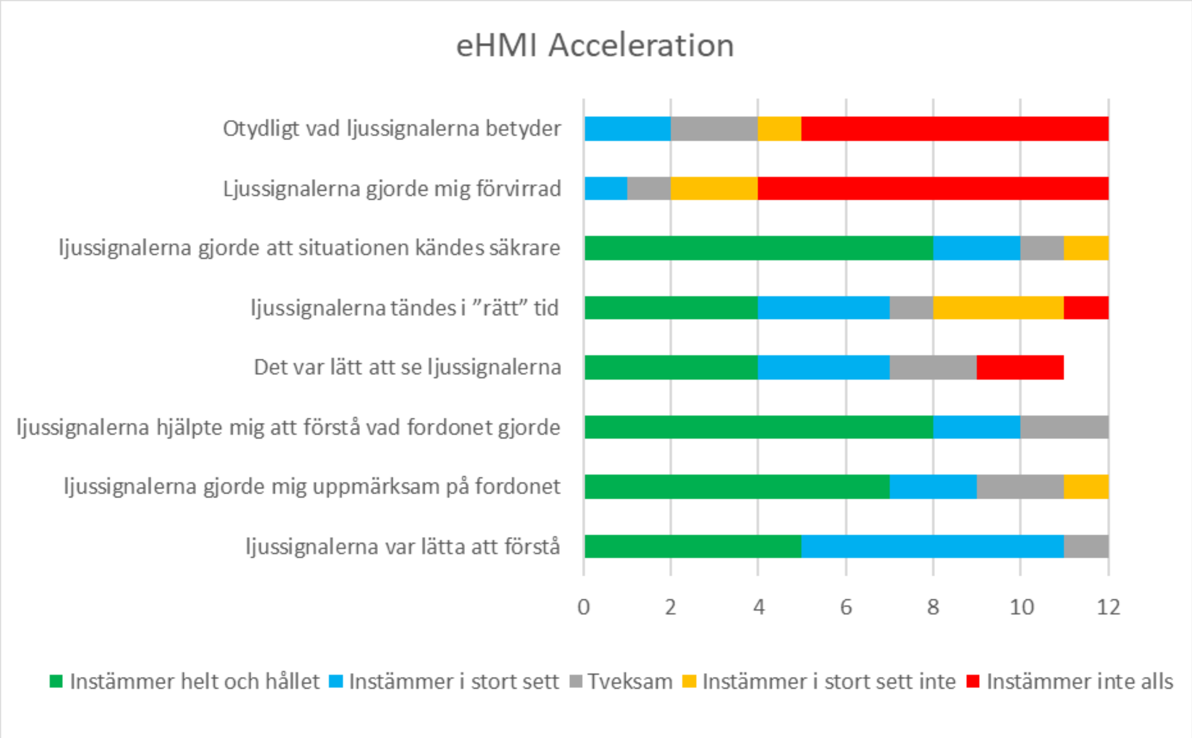

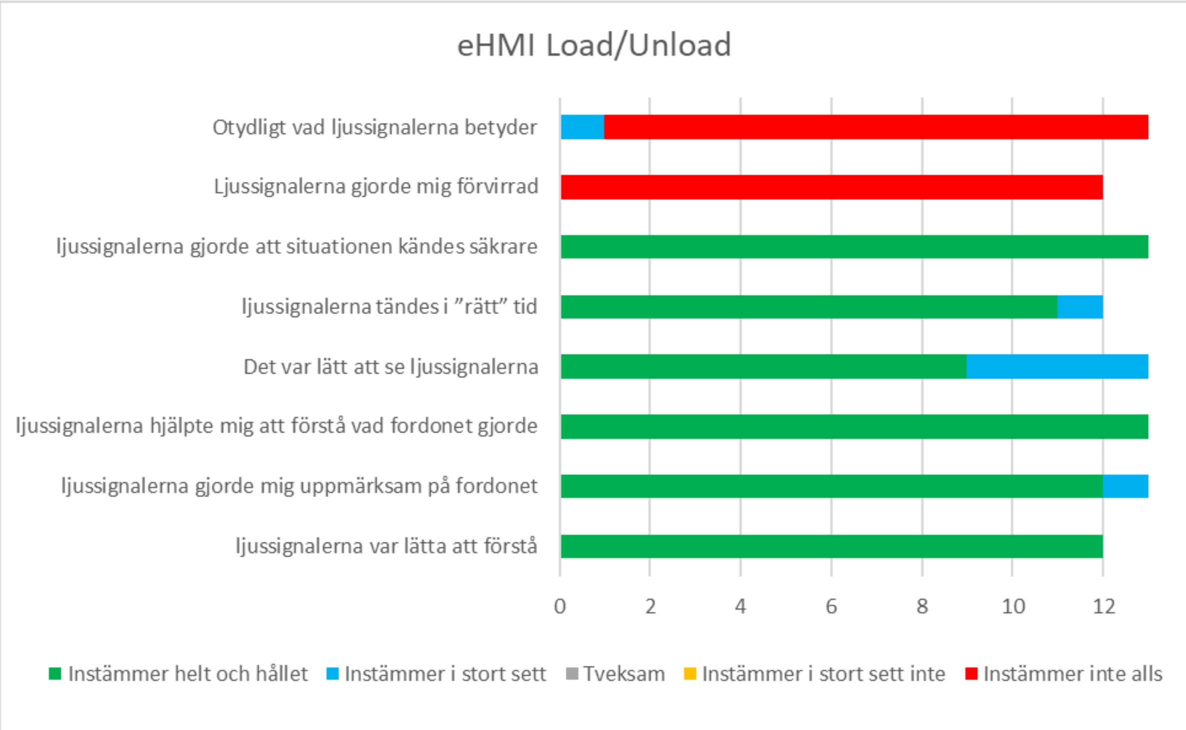

4.4 Experienced problems and suggested areas of improvements

The participants were asked to summarize their experiences after the three rounds in terms of experienced problems and areas of improvements of the eHMI. A general problem mentioned was that the LED-lights were difficult to see in the bright daylight.

Poor visibility and clarity of the eHMI can affect the efficiency to communicate the ADVs state, intention and behaviour to the surrounding.

Another problem mentioned by the participants was the timing of the activations/inactivations of eHMI Acceleration and eHMI Deceleration. The eHMI Acceleration was activated when the ADV started to drive from standstill. The participants remarked that the eHMI should be activated earlier to indicate that ADV *is about to start*, for example with flashing cyan lights. This would give a forewarning about the ADV's intention. The participants also mentioned that when your task to load/unload the ADV was completed you should give a *go-ahead* signal to the ADV to ensure that the ADV does not drive off until the route is clear.

An important finding from the study was that the participants did not think the different eHMI conveyed their intended messages *per se*, especially the eHMI Acceleration and eHMI Deceleration. Their forward and backward moving cyan LED-lights did not clearly communicate that the ADV was accelerating and decelerating. There are several plausible explanations. Firstly, today's vehicles have no specific eHMI to communicate acceleration and deceleration to the surrounding (except for the brake lights), and, therefore, these eHMI were unfamiliar to the participants. Secondly, the cyan colour did not provide any specific meaning to the participants. Cyan does not communicate any meaning to most people compared to the more established colours red, green and yellow which are used in many different applications, such as traffic lights, warning signals signs. Thirdly, the concept of backward moving and forward moving LED-lights on the ADV were not familiar to the participants.

The eHMI Unplanned stop and the eHMI Load/Unload were easier to understand. The eHMI Unplanned stop was similar to the hazard lights on vehicles today with the yellow flashing lights. Moreover, the situation (the ADV had stopped at a location where it was supposed not to stop and that there was an obstacle in front) contributed to the participants understanding of the eHMI. The participants also understood the eHMI Load/Unload due to the situation (the ADV stopped in the loading/unloading zone). In addition, the participants associated the green lights with “safe”, “clear”, “ready”, “go” etc. (compare, for example with traffic signals).

In sum, the different eHMI did not convey their specific and intended messages *per se,* but together with the context, i.e. terminal scenario, the tasks to be carried out at the terminal and ADV's behaviour in the specific situations, they were understood. It could also be assumed that working at a terminal with ADVs would require some introduction and training regarding the ADVs and their eHMI.

The study showed that the trend of increased understanding of the eHMI from round 1 to round 3 was consistent throughout the study, which indicates rather steep learning curve, i.e., the participants could learn and understand the different eHMI quickly. A similar notion about gained knowledge about eHMI was also noted in a study by Habibovic et al. (2018).

4.5 Technical development and implementation

4.5.1 The self-driving functions

The implementation of multiple sub-routes to perform the stops facilitated the scenarios of loading and unplanned stop. In the loading scenario (Figure 2, situation 5) the stop was treated as a stop between routes. The unplanned stop scenario (Figure 2, situation 1) was more complex to handle regarding which actions to take after such a stop was initiated, as well as the reliability of the stop function. Simulating the unplanned stop by using a planned stop protocol worked for the intended purpose. This approach may not be suitable in other environments as it was an unplanned event.

4.5.2 The site control

The integration of the ATMS and the ADV worked as planned, and the system was enabled to run several times in a row. However, problems occurred at two occasions, in both cases due to database errors. The cause was probably some form of timing issue, where occasional problem can occur when the ADV connects and disconnects several times. In future work, the stability in the ATMS needs to be further improved and to include frequent checks to ensure that everything is in a working state.

In this study the coordinates and heading information for navigation were added in the information sent to the ADV. The Control information for the eHMI was added to make it possible to control the different signals from the ATMS. The added information enabled more control to be transferred from the ADV to the ATMS in terms of map information. It was easy to add information to the different eHMI due to a developed format for the messages. In further work, more of the information will be implemented in the HMI rather than in editing the messages manually.

4.5.3 eHMI implementation

The eHMI implementation described in section 3.4.2 with coordinate-triggered events worked as intended with good repeatability. There was a single instance where the position differed from the expected stopping point and, thus, did not trigger the stopped event lights. The approach did however make it difficult to pre-signal intention with the eHMI from a stopped state, as the trigger would not be available until the ADV started to drive onto the first coordinates in the route.

5 Conclusions

From a technical point of view the integration between the ATMS and the ADV was sometimes difficult, and a lesson learned was that repeated tests are critical to identify and solve stability issues.

Regarding the eHMI the study had three objectives; (i) to evaluate the participants' understanding of the eHMI, (ii) to evaluate how the participants experienced to interact with the ADV in specific situations, and (iii) identify areas of improvements to the eHMI design. Overall, the results showed that the participants thought it was easy to understand the different eHMI. Specifically, the eHMI which had similarities to existing conventional visual signals on vehicles today were perceived as easy to understand. The study also suggests that the eHMI did not convey their intended meaning *per se*. Contextual factors, such as the terminal scenario, the situations and work tasks contributed to the participants' understanding of the different eHMI. In addition to the contextual factors, the participants' previous and gained knowledge and experiences contributed to the participants' understanding of the eHMI.

The participants thought it was safe to approach the ADV, much due to their assumption that close interaction with the ADV was part of the job and, therefore, interacting closely with the ADV was expected to be safe. The size of the ADV (considered as rather small) was also mentioned as a contributing factor to their perceived safety.

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