CHALMERS
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Intelligent Light Communication from Automated Vehicles to Other Road Users

Communicating Intent for a Safer and Smoother Transport

Master's thesis in Product Development

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Gothenburg, Sweden 2019

Master's thesis 2019:51

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Master's Thesis 2019:51
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Cover: Sketch of proposed concept showing new light communication on a Volvo FH truck.

Printed by Chalmers Reproservice
Gothenburg, Sweden 2019

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Abstract

The development of AVs (automated vehicles) is moving rapidly and many automakers are including more and more ADAS (Advanced Driver Assistance System) in their vehicles as steps towards full autonomy. However, there are many aspects to consider before AVs can function on public roads. One important topic is how these AVs will communicate with other road users, which is what this master thesis project aims to investigate.

The project is in collaboration with Volvo GTT (Group Trucks Technology) and focuses on external light communication from automated HGVs (Heavy Goods Vehicles) to other road users. A survey, answered by 111 participants, was used to investigate in what situations additional light communication is needed. Additionally, a need for AVs to be able to act assertive just as human drivers do in certain situations to help the overall traffic flow was identified. Based on this, a scenario where an HGV needs to merge from a highway on-ramp into traffic congestion was chosen for further investigation.

When analysing the chosen scenario, three primary needs for additional light communication were identified: (1) communicating that the HGV has to merge, (2) communicating the urgency of the situation and (3) communicating when the HGV will initiate the turn.

A concept was developed consisting of long LED-strips mounted on the cab together with a modified flash sequence of the light. The new sequence consists of three phases, the first being the same steady turn signal used today. In the second phase, the light flashes in a double pattern, similar to a heartbeat, to communicate urgency. In the third phase, which is activated just before the turn is initiated, the light flashes with higher frequency to catch even more attention from the other road users.

The concept was tested using a VR-simulation of the chosen scenario where eleven participants drove a passenger vehicle and had to interact with a merging HGV equipped with the proposed concept. The evaluation confirmed the hypothesis that the larger LED-strips attracted more attention than traditional turn signals. When interviewed about the new flash sequences, the majority of the participants understood its meaning and thought that it would help an AV to communicate the urgency of the situation.

Keywords: automated vehicle, heavy goods vehicle, turn signal, road users, visual communication, external communication.

Acknowledgements

We would like to take the opportunity to thank everyone who have contributed and influence our work in this project.

To start, we want to express our gratitude towards Volvo GTT and especially everyone at the Ergonomics & Driver Interface group who have welcomed us and helped us along the way. A special thanks to Christer Lundevall for creating our specified test environment in virtual reality and for your help during the test phase. Your commitment to our project helped us taking it further than we could have hoped for.

We would also like to thank everyone who participated in our survey and concept testing. You have all sacrificed valuable time to help us understand how vehicle communication is perceived and how it can be improved. We are truly thankful for your time and participation.

To our supervisor Felix Dumont at Volvo GTT, thank you for guiding and inspiring us throughout the whole project. Without your experience, dedication and support, this project would have never been possible. Thank you.

Lastly, we would like to thank our examiner Marco Dozza for always being available for guidance and support.

Thank you!

Henrik Karlsson & Anna Lidman Olsson

Gothenburg, June 2019

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1
Introduction

Intelligent Light Communication from Automated Vehicles to Other Road Users is a Master's Thesis Project within Product Development at Chalmers University of Technology carried out by two students at Volvo GTT (Group Trucks Technology). The thesis work is carried out during the spring of 2019 with the aim of investigating how to improve communication between automated HGVs (Heavy Goods Vehicles) and other road users.

1.1 Background

There are approximately 26.000 road fatalities each year within EU and 15% of these accidents are HGV related [6]. One of the most common factors for a road accident is miscommunication, mostly one of the road users had trouble understanding what the other user was going to do [7]. According to Volvo Trucks Safety Report, 90% of the accidents are caused due to human errors [6], something AVs probably could change. Studies and research suggest that the number of accidents in traffic will be reduced when AVs will be put to use [8]. In addition to increased safety, AVs may also help to reduce costs for hauliers and decrease fuel consumption [9].

Today, pedestrians and drivers can communicate with each other by, for instance, seeking eye contact and/or different hand gestures. This kind of communication will be non-existent when the driver is removed and how this will affect traffic in the future is unknown. Data regarding AVs is very limited and therefore it is difficult to predict what risky situations that can arise. The already existing features to communicate with external lights from the HGV are the turning signals, the reverse lights combined with repeatedly sound signals and the brake lights. But if the HGV is to be automated, the existing communication may not be enough for the future challenges. Therefore, it is of interest to investigate how AVs will behave in traffic in the future, but also how other road users will respond to vehicles with no driver. Exactly how the implementation of AVs will be executed in the society is unclear. However, it is a fact that there will be a time where human driven vehicles will interact with automated ones [10] which means that the need to communicate will remain.

1.2 Aim

The aim of this project is to investigate how light communication can be used by automated HGVs in order to improve communication to other road users and thereby contribute to a safer and more efficient transportation environment. In detail, the project aims to answer the following research questions:

- When should the information be communicated?
- What type of information should be communicated?
- How should the information be communicated?

Furthermore, the project aims to develop a concept for a specific traffic scenario according to the answers from the stated research question. The concept will be tested and verified using VR (Virtual Reality).

1.3 Limitations

To narrow down the scope of the project, the following limitations were stated:

- Based on gathered data, one scenario where the road user safety can be improved will be chosen and a solution to improve the safety via light communication will be developed for that specific situation
- The project will prioritise European trucks and also European laws and regulations if differences that are affected of geographical locations occur
- Generated ideas and concepts should be compatible with a Volvo FH truck
- The development will be to such degree that testing and verification of the concept can be made. Any further design, placement location and ergonomics investigations will be passed on for future research

2
Literature review

In this chapter, information gathered from the pre-study together with benchmarking of existing and upcoming solutions within the field is presented.

2.1 Autonomous vehicles

Automated technologies are being developed at an accelerated pace and automakers are all researching the area of self-driving vehicles. Even companies that are not traditional automakers, such as Google and Uber, are conducting their own research and testing of AVs. It is the development of the advanced technology of sensors, microprocessors and information systems that makes this development possible [11].

SAE (Society of Automotive Engineers) International has published a standard that defines six levels of automation in vehicles ranging from level zero (driver in full control of vehicle all the time) to level five (vehicle in full control all the time) [11]. The standard specifies to what extent a human driver needs to interact with the vehicle at the different levels of automation [12]. At level zero, there is no automation at all. The vehicle's performance needs to be entirely controlled by a human driver [12]. At level one, the vehicle is still controlled by the driver but some driving assisting features may be included in the vehicle design such as steering or braking. However, only one ADAS (Advanced Driver Assistance System) can be active at the time [12, 13]. In level two, the vehicle have multiple assisting features that can be active simultaneously, e.g. steering and acceleration, but the driver needs to be engaged with the driving task and monitor the conditions at all times [12, 13]. At the third level, the vehicle can perform all driving functions under some circumstances. In these situations, a driver is no longer required to monitor the environment but must be ready to take control of the vehicle with notice from the ADS (Automated Driving System). The driver has control of the vehicle under all other circumstances [12, 13]. It is first in level four that the vehicle is capable to perform all driving functions under certain conditions without the need of a driver to pay attention. At level five, the vehicle is fully autonomous and capable of performing all driving functions during all conditions. The driver may still have the option to control the vehicle [12, 13].

There has been concerns regarding the safety of level three since having active ADAS have been shown to increase the driver reaction time if they need to take control of the vehicle [14]. One study showed that it takes drivers about 4.2-4.4 seconds to retake full control of a highly automated vehicle in noncritical scenarios [15]. This is far too long since most authorities recommend a minimum time headway of 1-2 seconds and in reality, drivers tend to leave an even shorter headway of less than one second [16].

2.2 Autonomous vehicle acceptance

Before AVs will dominate the roads, practical and ethical issues have to be solved. What laws and regulations that will be obtained regarding autonomous traffic are still unknown. The number of AVs in traffic is expected to increase as much as to over a million within 10 years [17]. Some issues that have to be dealt with are for example ethical dilemmas; how should the vehicle act when it finds itself in a specific situation and who should be responsible if an accident actually occurs? Surveys that have been made show that people are sceptical regarding safety when talking about driverless vehicles [18]. Even though AVs still are under development, accidents involving automated cars have already occured. An example is the fatality that occurred in Arizona in March 2018 when a women was about to cross the road leading a bike when an automated Uber car was approaching and resulted in a collision [19]. The Uber cars are provided with an operator that is supposed to pay attention at all time while the car is on automated mode [20]. There are also some accidents involving Tesla cars that have caught attention regarding their Autopilot function. Tesla explains that the Autopilot feature can be seen as a tool that can steer, accelerate and brake for other vehicles and pedestrian in the same lane but the driver still has the top responsibility for all of the vehicle's actions [21]. In one accident the car crashed into a concrete highway lane divider while the Autopilot feature was active which lead to death for the driver. But in this case, the Autopilot system had recorded that no hands were detected on the steering wheel just before the crash [22]. Another example is an accident where a Tesla car drove straight into a truck with a semitrailer which resulted in a fatality [23]. The Autopilot system failed to recognise the trailer of the truck against the bright sky and therefore no actions were made from the Autopilot system [24].

Another challenge for AVs is to detect bicyclists since they are both fast and relatively small [25]. Technology that identifies 3D object from 2D images exists, but one study has shown even the most successful technology in identifying bicyclists only succeed in 74% of the cases and it can only predict the direction the bicycle is facing 59% of the times. [25]. The accidents with automated systems and the issues with detecting bicycles show that AVs are not ready to hit the roads just yet. And when they come, they will still be affected by human actions like programming of the vehicle and other human road users. Since human behaviour can be unpredictable, this can be a challenge for the AVs. In a survey, the attitude towards AVs was tested and showed that people were more positive to be a pedestrian around an AV than being a passenger of one. [26].

2.3 Road user behaviour

From a previous master thesis project regarding visual communication between truck drivers and the surroundings, some interviews with truck drivers were presented. According to the interviews, the truck drivers thought that car drivers lack understanding for trucks and that they show no respect for them [1]. Also, according to the interviews, the truck drivers thought that the cyclist were careless and behaved as they could just follow the same rules as the pedestrians and that the pedestrians were absent since they spent their attention to their phones or wore earphones [1]. As cellphones get more frequently used, accidents involving pedestrians texting, taking calls and listen to music gets more common [27]. A pedestrian is not able to pay full attention to the surroundings and the traffic when distracted by its phone and is therefore at a higher risk of being involved in an accident. A pedestrian that uses the phone while crossing a road tend to walk slower and also to look left and right fewer times before crossing [28].

During a research, it was investigated what factors that influenced whether the pedestrian understood that the driver was going to yield or not. Some of the indications mentioned were if the car did slow down or stopped completely and non-verbal gestures such as eye contact or flashing the head lights [29].

2.3.1 Assertive behaviour

Humans have different driving styles that are influenced by not only traffic situations but also emotions and motivation [30]. These can be categorised into eight different styles, namely: dissociative, anxious, risky, angry, high-velocity, distress reduction, patient and careful [31]. Furthermore, these driving styles have been proven to be influenced by age, gender and driving history as well as personality measures of self-esteem, need for control, sensation seeking and extraversion [31].

As AVs are being developed and rolled out to real world traffic conditions, mixed levels of automation will use the same roads simultaneously [32]. Today, vehicles in SAE level zero (e.g. 2018 Honda Fit) are already sharing the road with vehicles in level one (e.g. Kia Stinger GT) and level two (e.g. Tesla Model S) [33]. This means that an AV will have to interact not only with other AVs but also with vehicles driven by humans that have different driving styles.

When mixed levels of automation exist, problems concerning traffic behaviour may arise. If some vehicles have advanced sensor technologies that are programmed to assure that the vehicle never hit anything, this can be taken advantage of by other road users. There are already examples of VRUs playing the game of chicken with AVs since they feel confident that the vehicle will register their presence and yield in time [34]. The reason that people do not walk straight out on a cross walk today even though they have right of way, is the small probability of the driver being inattentive, intoxicated or sociopathic in which case the VRU will be at most risk [35]. However, with the introduction of AVs, VRUs and other road users could exploit the predictable and safe behaviour of AVs [35].

Imagine the following scenarios where the safe behaviour of AVs could cause problems and safety issues:

- An AV has detected a stream of pedestrians just exiting a sports venue that are about to cross the road. Naturally, the vehicle yields to let the pedestrians pass. However, thousands of pedestrians are pouring out of the venue and other vehicles are lining up behind. Should the vehicle wait for all pedestrians to cross or should it start to slowly drive through the stream of people?
- An autonomous HGV has just entered the highway and wants to merge into traffic. However, there is a traffic jam and all other vehicles are inching forward at a slow pace with minimal gap in between. Since the other road users know that the HGV will yield in all situations, no one decides to let it merge. Should the HGV wait forever, or should it start to slowly merge anyway?

2.4 Autonomous HGVs

Vera, see Figure 2.1, is an autonomous electric concept vehicle by Volvo Trucks with both low noise and emission levels. It is controlled and monitored via a control centre and is designed for closed areas such as harbours and logistics centres. It has systems to locate its position within centimetres, analyse other road users and conditions and it communicates with all other Vera vehicles in the system. A solution like Vera allows for continuous around the clock operations and a more optimal flow compared to today's solutions that rely on human drivers and daytime work hours [36].

Figure 2.1: Vera - autonomous electric vehicle[1]

Volvo Trucks, together with Brønnøy Kalk AS, have also initiated a project where six autonomous FH16 trucks, see Figure 2.2, transport limestone along a five kilometre stretch between the mine and a crusher. A wheel loader operator calls on the truck, stops the truck and then fill it up with limestone. The truck is then sent on its way through an open pit and tunnels until it reaches the crusher site. Here, the truck is reversing and unloading the limestone into the crusher all by itself. The testing began in 2018 and the plan is to become fully operational by the end of 2019 [37].

[1]Figure from `https://images.volvotrucks.com/` [Accessed 1 March 2019].

Figure 2.2: Autonomous Volvo FH16 trucks[2]

Einride is another Swedish company that develops autonomous electric HGVs, see Figure 2.3. Their vehicles have no driver's cab but can be remote controlled when needed. They also offer increased loading capacity since goods can be placed where the cab is usually located. The vehicles are equipped with radars, LIDAR's and cameras which gives a full 360-degree awareness of the surroundings [38]. Einride says it aims to deliver a complete transport system between Gothenburg-Helsingborg in Sweden by 2020 [39].

Figure 2.3: Einride Autonomous HGVs. (1) T/Pod and (2) T/Log[3]

2.5 Communicating intent

Today, there are two types of lights that communicate driving intentions to other road users: the turn signals and the reversing light. All other lights are either on or off (like head lights) or are activated in the same instance as a certain action performed (like break lights). The turn signals are used to notify others road users that the vehicle is about to make a turn and should be activated some time before the actual turn takes place. The reversing lights are activated at the same time as the reverse gear is put in place, indicating that the vehicle is about to reverse. For an HGV, an acoustic warning is also added to reinforce the intent to reverse. Other ways of communicating driving intentions include non-verbal cues such as eye contact and gestures between the driver and other road users, for example at cross walks or in intersections determining who will go first [40].

[2]Figure from `https://images.volvotrucks.com/` [Accessed 5 March 2019].
[3]Figure from `https://www.einride.tech/press/` [Accessed 1 March 2019].

In AVs with no driver, the informal ways of communicating will disappear and several studies and suggestions have been made on how to replace this type of communication. One suggestion is the AVIP-system (Autonomous Vehicles' Interaction with Pedestrians) [41]. It is a concept developed for passenger cars which consist of a LED-strip mounted above the windshield communicating four different signals to other road users: "I'm in AD (Automated Drive) mode", "I'm about to yield", "I'm resting" and "I'm about to start" [41]. Ford have called out to other self-driving vehicle developers, automakers and technology companies to create an industry standard for communicating driving intent. They are suggesting a similar solution to the AVIP-system with a light bar above the windshield communicating three scenarios: "Yielding", "Active driving mode" and "Start-to-go" [42].

Volvo Cars have also expressed the need for a standard for universal safety of AV communication. With the 360c concept, Volvo Cars envisions a future where AVs will be introduced in a mixed traffic environment where driverless cars and human drivers share the road [43]. To ensure that the communication needs between humans and AVs are met, the Volvo 360c concept uses external sound, colours, visuals and movements to communicate the vehicle's intentions to other road users [43]. In a video made by Volvo Cars, they show that the 360c vehicle is equipped with a LED-strip, fully surrounding the car that is able to communicate acceleration, yielding, turning, lane change as well as letting VRUs know that they have been detected by the vehicle [44]. Volvo Cars also says that they will only communicate vehicle intentions and not instruct others what to do to avoid potential confusion [43].

Mercedes-Benz's autonomous F 015 research vehicle communicates with its surroundings with both visual and acoustic signals using LED displays, laser projections, sounds and spoken instructions [45]. The LED display can for example display the word "STOP" to vehicles behind if the traffic ahead would suddenly come to a stop and the laser projections could indicate needed brake distance or communicate to a pedestrian that it is safe to cross [45], see Figure 2.4.

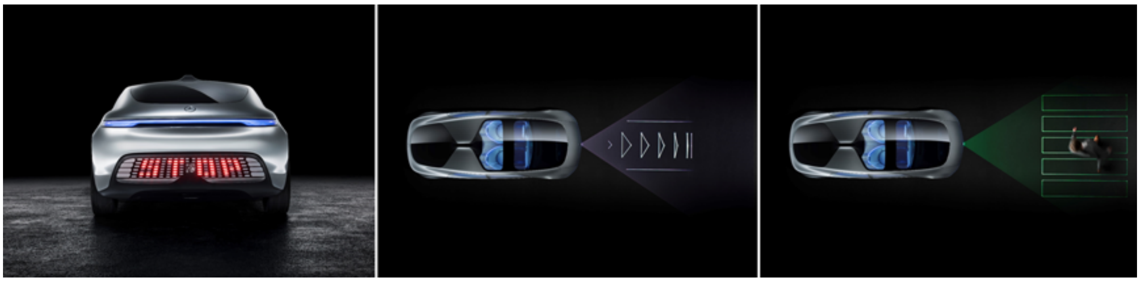


Figure 2.4: Mercedes-Benz F 015. (1) Use of LED display. (2) & (3) Use of laser projections[4]

In a previous thesis project performed at Volvo GTT with the aim of investigating how visual communication aids can support drivers' communication needs, two external light communication concepts were developed, see Figure 2.5. These concepts are meant to improve safety in two different traffic situations that are particularly

[4]Figure from `https://media.daimler.com/` [Accessed 7 March 2019].

dangerous for VRUs; when a truck is turning right and when a truck is approaching a zebra crossing. When the truck is making a turn, it lights up the area where the truck intends to go using projections in order to gain attention from VRUs. This is also combined with audio and visual cues to the driver if a VRU were to enter the needed space. In the zebra crossing situation, the truck also uses projections to facilitate communication between the vehicle and VRUs, similar to the Mercedes-Benz F 015 [1].

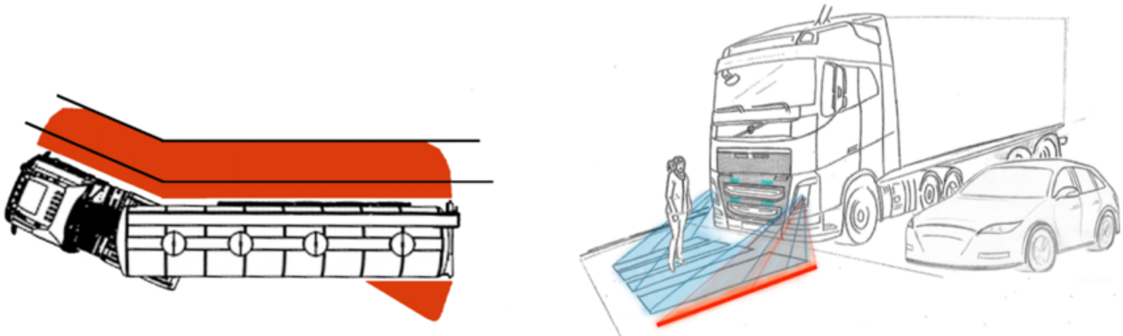


Figure 2.5: Visual communication concepts. (1) Projecting needed area when turning and (2) projecting zebra crossing for VRU [1]

In a patent application by Uber, a light output system for a self-driving vehicle is described. The system includes determining appropriate actions of the self-driving vehicles in certain situations and also how to communicate these actions to other road users using the light output system. As can be seen in Figure 2.6, there are several different alternatives for communicating with pedestrians. Both projections similar to the Mercedes Benz F 015 and illuminated signs text and arrows can be used. A display showing a human making gestures is also an alternative to replace the informal communication otherwise lost with a self-driving vehicle [2].

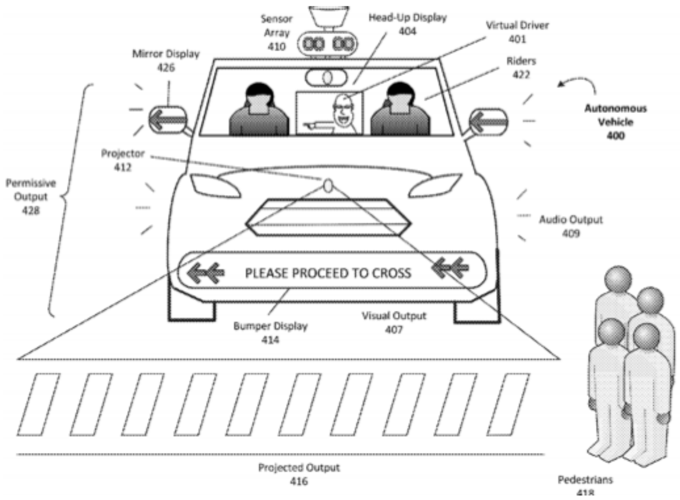


Figure 2.6: Patent application by Uber showing a light output system for a self-driving vehicle [2]

There are many other patent applications utilising projections and illumination of the ground to communicate vehicle intentions to other road users. One shows a projected arrow in front of the vehicle communicating the intended path, see Figure 2.7a [3], while another projects the turn signal on the ground alongside the vehicle to show the intentions to vehicles behind, see Figure 2.7b [4]. In a patent application specifically for HGVs, a system for illuminating needed ground area when making a turn is described, similar to the previous thesis work carried out at Volvo GTT, see Figure 2.7c [5].

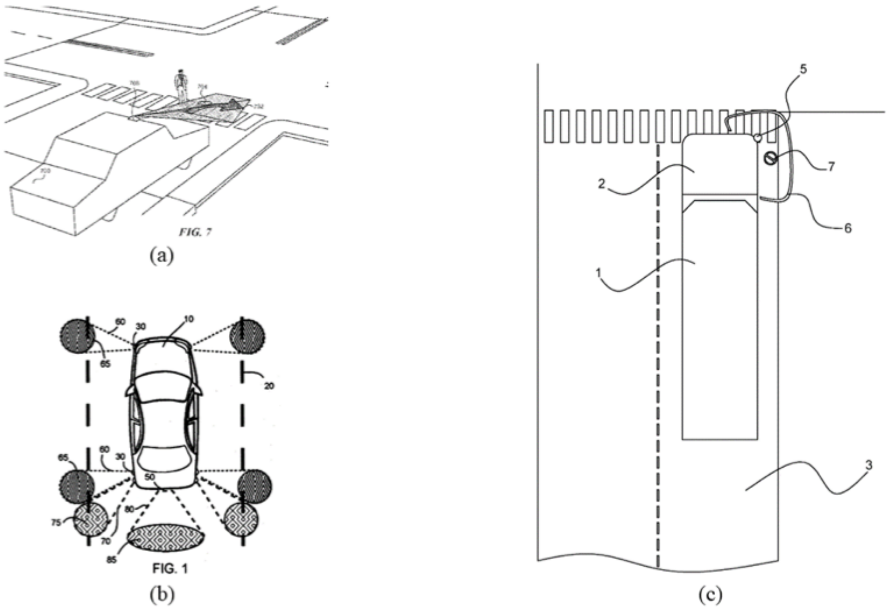


Figure 2.7: Examples of patent applications regarding vehicle intention communication [3, 4, 5]

2.6 Laws and regulation

There are many regulations concerning which lights that are required on a vehicle, how these lights are operated and when they are required to be either on or off. The permitted colours of the light emitted by the lamps are listed in Table 2.1 [46].

Table 2.1: Permitted colors of light emitted by vehicle lamps

Lamp	**Colour**
Main-beam headlamp	White
Dipped-beam headlamp	White
Front fog lamp	White or selective yellow
Reversing lamp	White
Turn signal lamp	Amber
Hazard warning signal	Amber
Stop lamp	Red
Emergency stop signal	Amber or red
Rear-end collision alert signal	Amber
Rear registration plate lamp	White
Front position lamp	White
Rear position lamp	Red
Rear fog lamp	Red
Parking lamp	White in front, red at rear, amber if reciprocally incorporated in the side turn signal lamps or in the side-marker lamps
Side-marker lamp	Amber, the rearmost side-marker lamp can be red if it is grouped or combined or reciprocally incorporated with the rear position lamp, the rear end-outline marker lamp, the rear fog lamp, the stop lamp or is grouped or has part of the light emitting surface in common with the rear retro-reflector
End-outline marker lamp	White in front, read at the rear
Daytime running lamp	White
Rear retro-reflector, non-triangular	Red
Rear retro-reflector, triangular	Red
Front retro-reflector, non-triangular	Identical to incident light
Side retro-reflector, non-triangular	Amber, the rearmost side retro-reflector can be red if it is grouped or has part of the light emitting surface in common with the rear position lamp, the rear end outline marker lamp, the rear fog lamp the stop-lamp, the red rearmost side-marker lamp or the rear retro-reflector non-triangular
Cornering light	White
Conspicuity marking	White to the front; white or yellow to the side; red or yellow to the rear
Adaptive front-lighting systems	White
Exterior courtesy lamp	White
Manoeuvring lamp	White

The turn signal light shall be flashing 90 ± 30 times per minute. If a motor vehicle is equipped to draw a trailer, the control of the turn signal lamps on the vehicle shall also operate the turn signal lamps of the trailer [46].

2.7 Literature summary

Continuous development regarding AVs is ongoing among many different companies. It is not clear how the implementation of driverless vehicles will be done, how the infrastructure will change or how the society will accept the new technology. Probably there will be a time where AVs will share the roads with human drivers, and with that comes new challenges. Human driving behaviour can vary a lot as mentioned in section 2.3.1, and AVs will have to be able to respond to that. Communication such as eye contact, gestures or similar will no longer exist when the driver is removed from the vehicle and it is today unclear how this important communication will be replaced. New ways of sharing information and how AVs should communicate are being researched and some examples are presented in section 2.5. Some of the inventions are limited due to the existing laws and regulations, but as mentioned earlier, it is not clearly known how the implementation of AVs will be. It is not unlikely that changes will be done regarding today's laws and restrictions.

3

Product development methods

In this chapter, different methods that were used in the project will be presented. The purpose of each method will be explained as well as how to implement it. First, some ways of how to collect data are presented followed by tools to use for developing and ranking concepts within product development processes.

3.1 Data collection

There exist two types of data: qualitative and quantitative. Qualitative data is often used when trying to understand underlying reasons, motivations or opinions regarding a case while quantitative data often means numerical data that can easily be compared [47]. In the category of qualitative data, methods as interviews and focus groups can be found. For quantitative data, different types of surveys and systematic observations are often used. The method does not have to be pure qualitative or quantitative, a mix of both also occurs. Below, some of the existing methods that are relevant for this project will be explained.

3.1.1 Interviews

An interview is a meeting with a person of interest where the aim is to gather information regarding their experience, opinion, attitude, motivation and behaviour concerning products and services [48]. Interviews can also be used as a mean to gather information from experts within certain fields. It can be used in different stages in a development process depending on what information that is desired. In the early stages of a project, interviews can be used to get valuable information about customer needs and behaviour but they can also be used as a mean to get feedback and evaluate concepts [48]. Interviews can be structured, meaning that all the questions have been prepared. This gives detailed and exact answers to the questions but does not leave room for questions that the interviewer has not thought about on beforehand [48]. An interview can also be unstructured which is more like a conversation where the interviewee speaks freely about a subject of interest [48]. A semi-structured interview is a mix between the two, meaning that questions have been prepared but there is also room for follow-up questions and discussion [48].

3.1.2 Survey

A survey is a methodology and tool used to collect, handle and analyse information from a large group of individuals in a systematic way. One way of conducting a survey is through questionnaires [49]. A questionnaire can be viewed as a form of structured interview with predetermined questions in a specific order. However, it does not require any personal contact since the questions can be distributed through forms, both physical and digital. A questionnaire can be both qualitative and quantitative, meaning it can serve as a tool for gathering data where the participant either can answer freely or from a fixed set of predetermined alternatives. The standardised nature of a quantitative questionnaire enables researchers to make generalisations based on the result but also limits the respondent to alternatives that may not correlate to their actual preferred answer [50].

3.1.3 SAM (Self-assessment manikin)

SAM is a common tool to measure an individual's emotions and has been used for decades when doing surveys [51]. The tool consists of three different scales which can be seen in Figure 3.1. Each scale has five different illustrations and an interval from 1 to 9 that describes the level of the representing emotion. There are three scales that show pleasure, arousal and dominance. Respectively, the scales go from a happy figure to an unhappy figure, from sleepy to excited and from a small figure to a large figure [52].

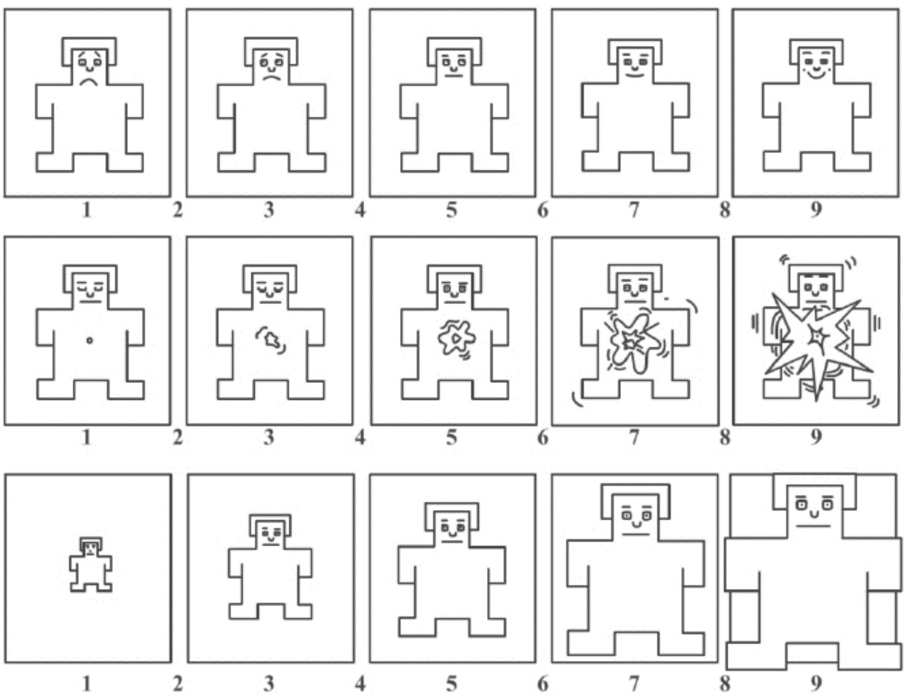


Figure 3.1: The scale of SAM, top: valence, middle: arousal, bottom: dominance

3.2 Concept generation

In this section methods for how to establish customer needs, produce and create ideas and concepts will be presented and explained.

3.2.1 Customer needs and requirements

To be able to meet the customer's expectations with a new product, it is important to have an understanding of what the customers actually want. Sometimes it is easy to find the customer's needs but there are also hidden needs to be found. Not even the customers may know what they need at all times and to find those needs, different tools can be used. Ulrich and Eppinger suggest the following steps to find and establish the customer's needs for a product [53]:

1. Gather raw data from customers
2. Interpret the raw data in terms of customer needs
3. Organise the needs into a hierarchy of primary, secondary and (if necessary) tertiary needs
4. Establish the relative importance of the needs
5. Reflect on the results and the process

3.2.2 Brainstorming

Brainstorming is a method used to generate a large number of ideas. The execution can vary, but in principle it follows the following four ground rules [48].

1. Do not criticise yourself or others – do not think about usability, how realistic the idea is or the cost. Do not be logical and do not express negativity towards other's ideas
2. Aim for wild and crazy ideas – every idea is valuable and everyone should feel safe and secure in expressing wild and crazy ideas
3. Combine and improve each other's idea
4. Aim for quantity, not quality – the chance of getting a few quality ideas increases if there are many quantitative ideas to choose from

A brainstorming session starts with a definition of the topic and question relating to that topic. All ideas are written down on post-it notes, a whiteboard or sketched on paper. After about 15-30 minutes, it is time for a break. It is better to have several short sessions rather than one long to keep the participants focused and creative [48].

3.2.3 Concept combination table

One tool to generate ideas and concepts is the concept combination table. Ulrich and Eppinger describe the tool as a systematic way to find combinations of a potential solution to the problem [53]. The idea with the tool is to list all sub-functions and their possible solutions in rows. The sub-function should be defined in the previous stage. A concept can then take form by drawing a line between the different solutions for each sub-function, see Table 3.1. Sometimes two solutions may not be able to combine and those concepts can be ignored.

Table 3.1: Example of a Concept Combination Table

Sub-Functions	Solutions				
Sub-Function 1	Solution 1.1	Solution 1.2	Solution 1.3	Solution 1.4	Solution 1.5
Sub-Function 2	Solution 2.1	Solution 2.2	Solution 2.3	Solution 2.4	Solution 2.5
Sub-Function 3	Solution 3.1	Solution 3.2	Solution 3.3	Solution 3.4	Solution 3.5
Sub-Function 4	Solution 4.1	Solution 4.2	Solution 4.3	Solution 4.4	Solution 4.5
Sub-Function 5	Solution 5.1	Solution 5.2	Solution 5.3	Solution 5.4	Solution 5.5

3.2.4 Idea rating sheet

The idea rating sheet is a way to evaluate ideas in an early stage to determine which ideas have the best potential. With this method, all ideas are presented in a similar way on a sheet of paper with limited space for text and sketches, see Figure 3.2. Participants are then given the opportunity to vote on what ideas they like and do not like. This democratic process allows for a fair comparison between the ideas and eliminates the risk of favouritism. Each participant is also given the opportunity to comment on the ideas and to write down potential strengths and weaknesses [48].

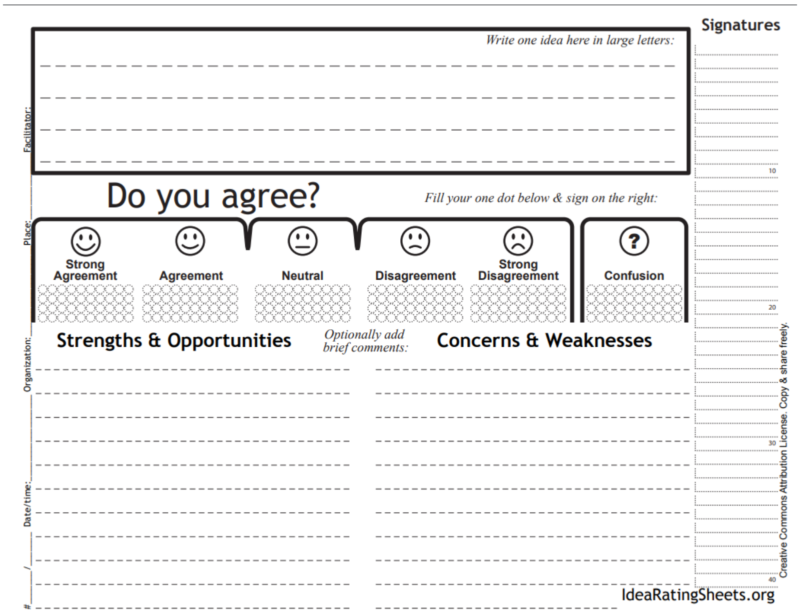


Figure 3.2: Example of an idea rating sheet[5]

3.3 Concept selection

In this section, some methods for screening and scoring concepts will be presented and explained.

3.3.1 Concept screening

Concept screening is one way to narrow down the number of concepts in a fast and systematic way. Ulrich and Eppinger describes the method with six steps where the first step is to create the selection matrix [53]. An example of how a selection matrix can be designed is shown in Table 3.2. In the first column of the matrix, different criteria are listed and in the following columns are the concepts presented.

Table 3.2: Example of a concept screening matrix

Concepts					
Selection Criteria	Concept A (Reference)	Concept B	Concept C	Concept D	Concept E
Criteria 1	0	+	-	+	+
Criteria 2	0	+	-	+	+
Criteria 3	0	0	-	+	+
Criteria 4	0	0	+	+	-
Criteria 5	0	0	0	0	-
Criteria 6	0	-	0	0	0
Criteria 7	0	-	0	+	0
Sum +	0	2	1	5	3
Sum 0	7	3	3	2	2
Sum -	0	2	3	0	2
Total	0	0	-2	5	1
Rank	3	3	4	1	2
Continue?	Revise	Revise	No	Yes	Yes

One of the concepts will be chosen as a reference (in this case concept A) and will automatically get a score of zero. The second step is to compare the other concepts to the reference for each criterion in the first column. The scores that can be given are "better than", "same as" or "worse than" compared to the reference and will be symbolised with "+", "0" or "-" respectively. The next step is to rank the concepts due to the score given to them where high score is considered best. The next step is to investigate if combination between concepts is possible. Maybe there is one concept that is good overall but does not fulfil all criteria in a satisfactory way. If combination of concepts is done, they will be added to the matrix and rated and ranked with the other concepts. Step five is to select one or more concepts for further development. How many concepts that will be developed further depends on the resources available and how they were ranked. The last step is to reflect

[5] Figure from `http://idearatingsheets.org/` [Accessed 26 April 2019].

on the process and the results, does the matrix consider all necessary criteria or is something missing? If yes, add the criteria and do it again [53].

3.3.2 Concept scoring

Concept scoring is used to rank different concepts, but here the various criteria can be weighted differently depending of importance. Ulrich and Eppinger explains the method with six steps [53]. The first step is to prepare a selection matrix and to define a reference concept. If the criteria may seem fuzzy or difficult to rate, they can be broken down into more criteria in a hierarchical way. When all the criteria are added to the matrix, they will be weighted based on importance. The second step is to rate the different concepts by going through one criterion at the time. When rating the concepts, Ulrich and Eppinger suggest that a 1-5 scale is used. The next step is to calculate the score for each concept and then rank them. Step four is to look into differences between the concepts and see if they can be improved by combining some of them. Step five is to choose either on or more concepts that seem promising for further development. The concept/s should be chosen with care and not directly after the first round. It is suggested that the ranking and weighing are looked over in order to achieve a fair result, by for example doing several matrices with different weighing of the criteria. The last step is to reflect on the process and the chosen concept/s. Everyone involved should agree on the chosen concept/s since as soon as the decision is made, it can be difficult to go back.

3.4 Concept prototyping

Prototyping is one way to visualise or test a product during the development phase and are used for [53]:

- Learning – See if the product works and/or meet the customer's needs
- Communication – It is easier to show a physical product than to describe it verbally
- Integration – See if the product is compatible with other subsystems as planned
- Milestones – Provide tangible goals, demonstrate progress and to enforce the schedule

There are analytical and physical prototypes. Analytical prototypes often use parameters that can be changed. Due to this, analytical prototypes are easier to adjust than physical prototypes [53]. However, physical prototypes are better for detecting unrelated issues since all geometries and physical laws have to operate together. Therefore, at least one physical prototype should be done [53].

Ulrich and Eppinger suggest four steps when using prototypes where the first step is to define the purpose of the prototype. One way of defining the purpose is to make a list of the different needs within the four categories that are presented above, from that it can be clarified what is expected from the prototype. The second step is to establish the level of approximation of the prototype. Is it really necessary to make a physical prototype or is an analytical prototype enough? In general, the simplest prototype that fulfils the expected needs is the best one. Step three is to outline an experimental plan. Testing prototypes can be compared to performing experiments, and it is therefore good to have a plan for what variables will exist, what the input should be and what output is expected. The last step is to create a schedule for procurement, construction and testing. The creation and utilisation of the prototype can be seen as a sub-project to the main project, and therefore it is recommended to have a schedule over the prototype process involving creating the prototype, testing and analysing [53].

3.5 VR testing

VR testing is one method for creating environments and layouts to be tested before creating the physical product. By using VR, the desired environment with the right prerequisites can be created in a cost efficient and flexible way [54]. Even if complex programming and advanced CAD skills may be required, a VR environment will still probably be more efficient and require fewer material resources [55]. When doing tests with people, it can be hard to make all the people imagine the exact same scenario or situation. With a VR environment that is created for a specific purpose, all the participants will have the same prerequisites to witness the same experience.

One disadvantages that can arise when doing tests in VR is VR-sickness which is similar to the motions sickness that can emerge when going by car. The phenomenon arises due to a disagreement between the visually perceived movement and the movement experienced by the body [56]. Therefore, it is a good idea to have margins when inviting test persons in case someone needs to discontinue with the test.

4 Method

This chapter will explain how the project was executed. A complete overview of key parts of the project can be seen in Figure 4.1.

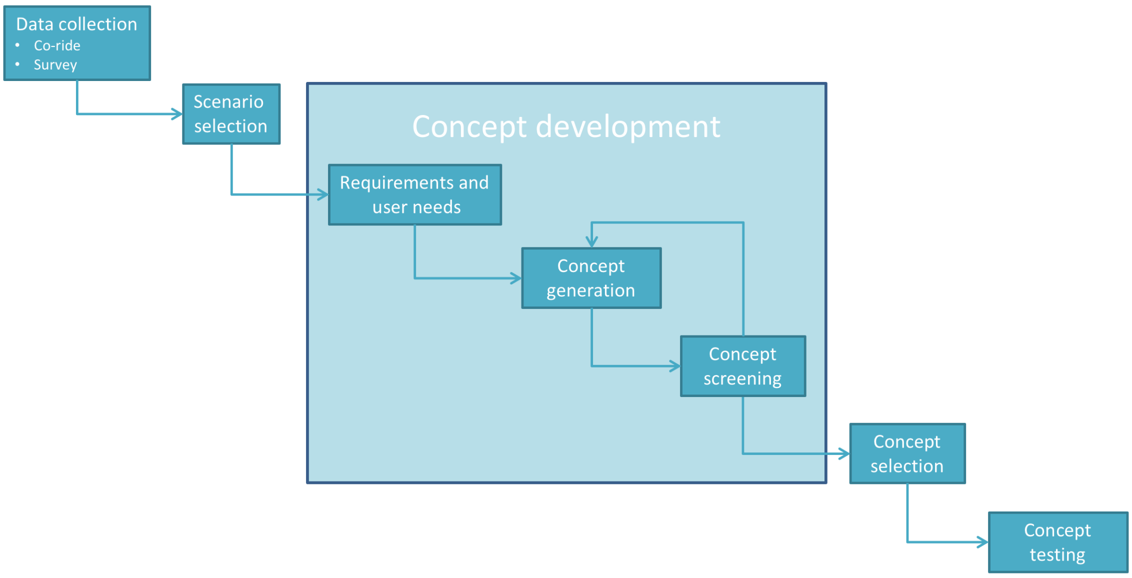


Figure 4.1: Visualisation of method framework

4.1 Data collection

In this section, the course of action for how data were collected is presented as well as how the preparation for the gathering was done together with the actual procedure.

4.1.1 Co-rides

To get a better understanding of the field and to experience how trucks are used in typical work environments, co-rides together with a truck driver was made. To find a truck driver that was willing to bring co-rides during the shift, GLC (Göteborgs Lastbilcentral) was contacted. The co-rides were scheduled in the beginning of the thesis work since the experience was considered valuable and important for the proceeding of the project. The same truck driver was accompanied during two days. Before the co-rides were taking place, some questions were prepared.

The co-ride started by meeting up the driver at 06.00 at the truck company where the routines for planning the route and how to load the truck was observed. The route began at around 06.15 and took about eight hours during which the daily routines and driving behaviour was observed. During the time between destinations, the planned interview with prepared questions was held. The questions can be seen in Appendix A(-D).

4.1.2 Survey

This method was chosen in order to gain insights into how road users respond emotionally to different traffic scenarios and to investigate if any correlation exists regarding how safe road users feel and where accidents often occur. It also aims to convey if VRU's emotions differ when interacting with an HGV compared to a passenger car. Previous studies investigating traffic scenarios often only involve car-to-car, car-to-VRU or truck-to-VRU accidents [57, 58, 59, 60]. However, not many studies concerning potential differences in pedestrian behaviour towards HGVs compared to passenger cars have been made.

The survey covers six different traffic scenarios involving cars, HGVs and VRUs illustrated with animated images. The participants were asked to imagine themselves as the interacting road user in each scenario and then answer the following two questions:

- How peaceful do you feel?
- What is your sense of control?

For each question, the participant was presented with an emotional scale of 1-9 using SAM, see section 3.1.3, and asked to answer accordingly. Ordinarily three scales are used when applying the SAM-scale, but for this survey it was decided to only use the two scales mentioned above. When testing the questions before doing the actual survey, the question "How pleasant do you feel?" was very confusing to the persons testing it and therefore removed.

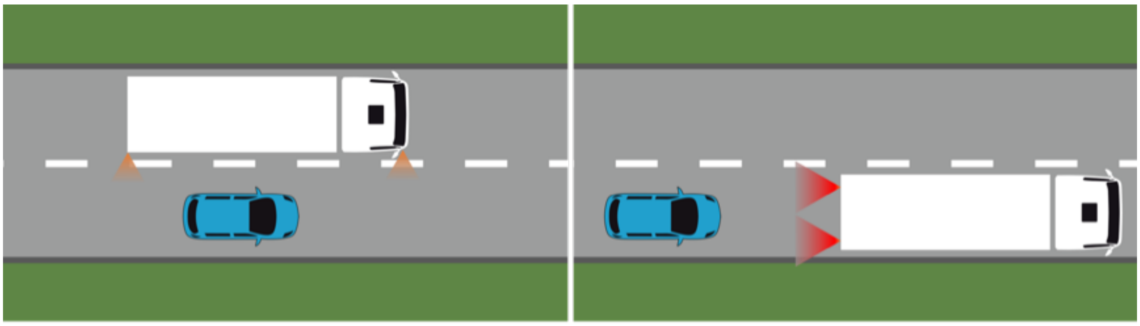
The scenarios were chosen based on identified critical situations involving HGVs in the Volvo Trucks Safety Report 2017 [6]. These scenarios are divided into three categories:

(A) Accidents causing fatalities or severe injuries to heavy goods vehicle occupants

(B) Accidents causing fatalities or severe injuries to car occupants

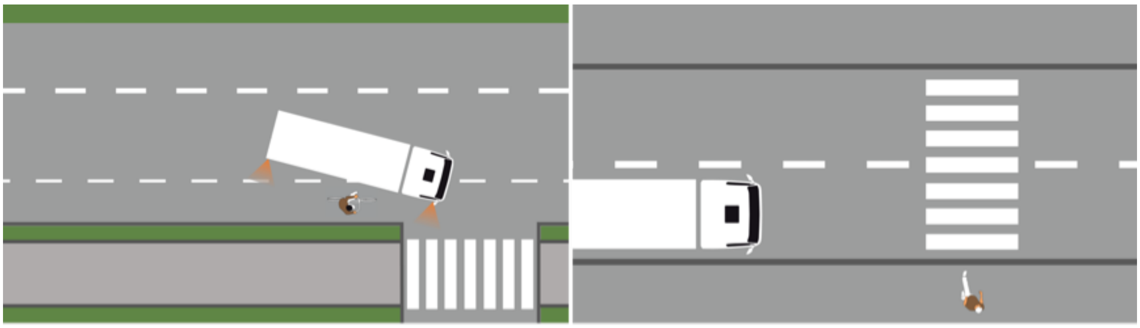
(C) Accidents causing fatalities or severe injuries to VRUs

As type A accidents only involves the HGV driver, these accidents were omitted since no driver is needed in autonomous HGVs. Even if a driver is present, additional external light will not help to prevent this type of accidents since the majority of the accidents were single accidents. In type B and C accidents, Volvo breaks down each category into a number of scenarios where the two most common scenarios from each category were chosen for the survey, see Figure 4.2 and Figure 4.3. In addition, two type C scenarios involving a car instead of an HGV were added to gain insight of possible emotional differences between cars and HGVs, see Figure 4.4.



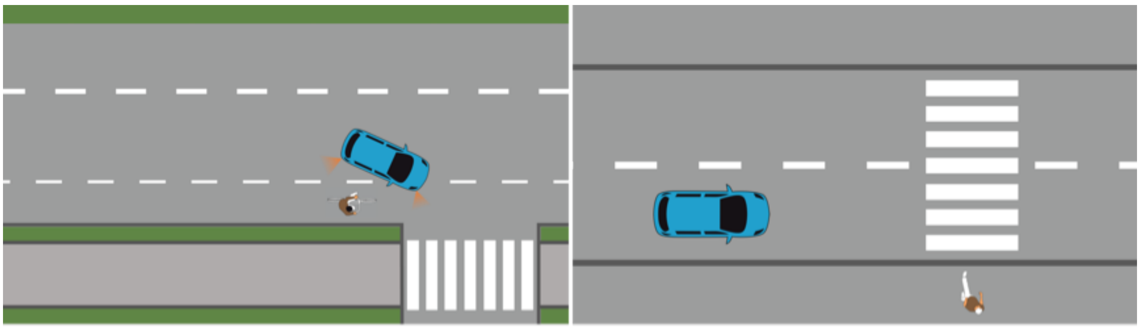
B1 B2

Figure 4.2: Type B scenarios involving HGV and passenger vehicle



C1 C2

Figure 4.3: Type C scenarios involving an HGV and a VRU



C1.1 C2.1

Figure 4.4: Type C scenarios involving a passenger vehicle and a VRU

When collecting the survey, 111 participants had answered the questionnaire. Of the 111 participants, 45,9% (n=51) were males and 54,1% (n=60) were females. When the participants were to fill in their age, 8 of them chose to not answer. The year span of which the participants were born reaches from year 1941 to 2000 and the median age was 25 years old. When the participants were asked if they had a driver's license, 95,5% (n=106) said yes.

The answers for each scenario were compiled into bubble charts to visualise the overall emotion response to each scenario, see Appendix B(-D). The average emotional response for each scenario was also plotted in a bubble chart to get an indication of how scenarios compare to each other, see Figure 4.5. Scenario B1 and C1 are the ones that the participants felt most uncomfortable with while scenario B2 and C2.1 did not trigger a negative emotional response in the same extent. The participants felt neutral to scenario C2 and C1.1.

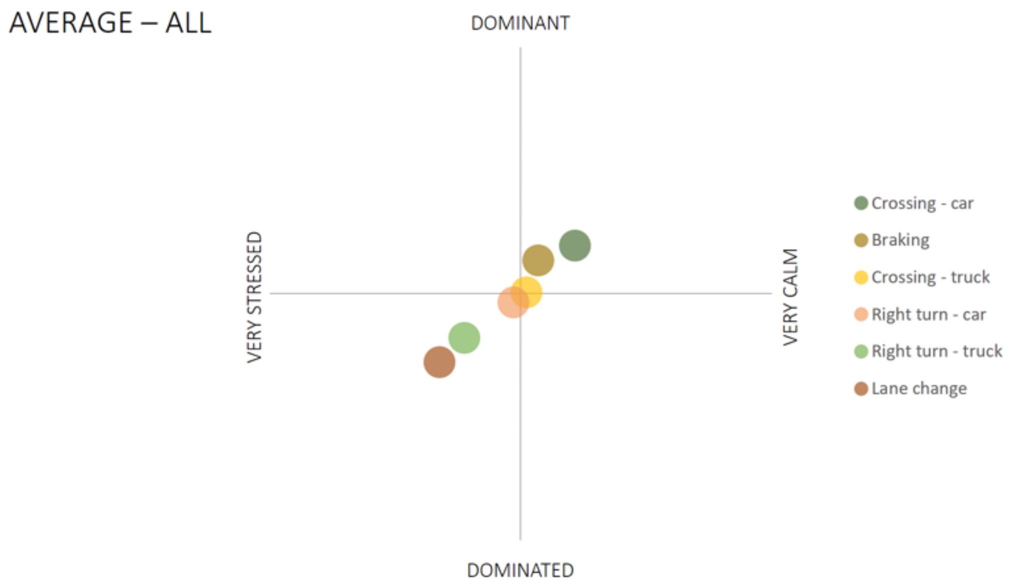


Figure 4.5: Average emotional response to traffic scenario survey

4.2 Scenario selection

Since the participants from the survey felt most uncomfortable with scenario B1 and C1 and these scenarios are also highly represented in accident statistics involving HGVs, they are both natural to continue to investigate. However, since all scenarios from the survey are based on current statistics that only includes non-autonomous vehicles it is uncertain how, or even if, these scenarios are relevant in an autonomous future. To find realistic scenarios involving AVs where there is a risk of incidents or uncertainty, scenario B1 and C1 where analysed based on the assumption that the HGV is fully autonomous. What would happen in these scenarios when the HGV has full knowledge of its surroundings, no blind spots and is programmed to not ever hit anything or anyone?

In scenario B1, when the HGV switches on its turn signal indicating to the passenger car that it wants to change lane it is fully dependent on the car to yield by either slowing down or speeding up. If the driver in the passenger car is inattentive or just does not care of the HGVs intentions to change lane, the HGV could theoretically be stuck in its lane forever. A human driver would probably indicate that it wants to change lane even more by positioning the vehicle closer to the edge of the lane, use gestures or even start to slowly change lane anyway. An autonomous vehicle can also use positioning to indicate intentions but if it were to act with assertive behaviour, additional communication and safety measures could be beneficial.

In scenario C1, the autonomous HGV is fully aware of its surroundings including cyclist and will therefore yield to the cyclist. However, this can be an uncomfortable and uncertain situation for the cyclist so it is reasonable to imagine that the cyclist would also stop for the HGV. If this happens, a scenario of who will go first will evolve where additional light communication could be beneficial. Traditionally, if a traffic situation is uncertain it can be solved with the help of informal communication, such as eye contact, gestures or flashing lights. With a driverless vehicle, several of these options disappear which indicates that a replacement for this type of communication is needed.

From the analysis of scenario B1 and C1, two new groups of scenarios involving autonomous vehicles in mixed traffic situations

1. Situations where the HGV is waiting for someone else to move out of the way so it can start driving

2. Situations where the HGV wants to change lane, but can not because something or someone is blocking its way

Based on these two groups, a new brainstorming session was held where a variety of scenarios were developed. In total, six scenarios of an HGV standing still and wanting to drive were created, see Figure 4.6 and Figure 4.7, together with five scenarios of a moving HGV wanting to merge, see Figure 4.8.

In Figure 4.6, scenario 1.1 shows an HGV wanting to make a right hand turn. The HGV yields for the pedestrian at the cross walk at the same as a cyclist rides up alongside the HGV. Here, confirmation that the HGV has seen the cyclist and will wait for it to pass could be beneficial. In scenario 1.2, an HGV have stopped at a cross walk where a large number of pedestrians are crossing. This could be outside a venue or arena where a sports game or concert have just ended. What drivers often do today is to start and inch forward slowly through the crowd. An AV however could be forced to wait for a long time. If this automated HGV would also slowly move through the crowd, additional visual communication could be helpful. In scenario 1.3, the white HGV have just finished unloading at a construction site and is ready to leave. However, its path is blocked by construction workers. Here, communication that lets the workers know that the truck wants to leave but that they are in its way could help the overall flow of the construction site.

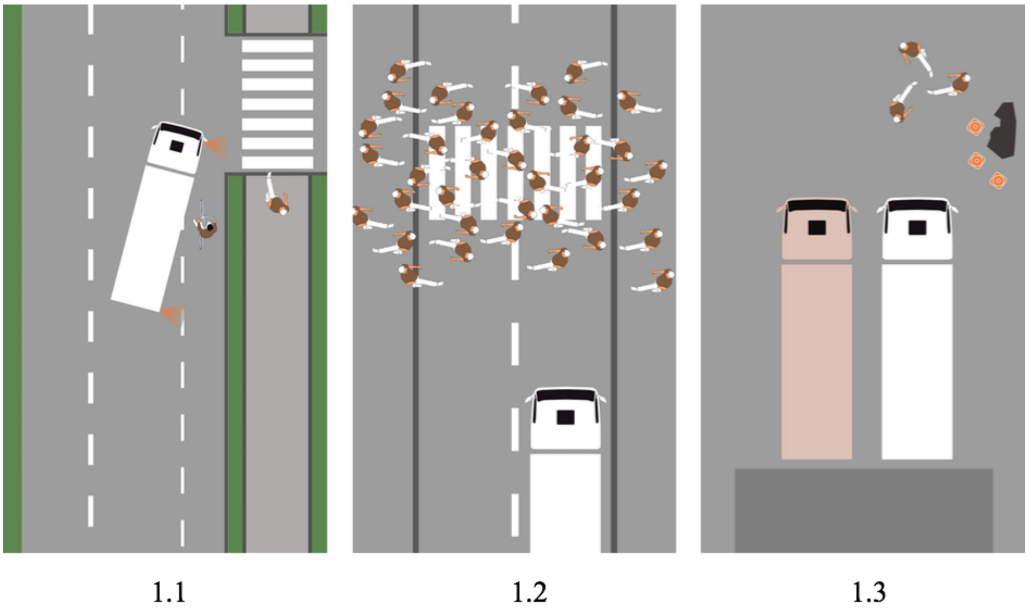


Figure 4.6: Scenarios where a HGV wants to drive but something is in its way

In Figure 4.7, three scenarios of a living street are presented. A living street is an area where vehicles and pedestrians share the space but pedestrians have right of way and the maximum speed is walking pace [61]. Here, three scenarios explore what would happen if pedestrians stand in the way of the HGV. Since the pedestrians have the right on their side, the HGV could theoretically be stationary indefinitely. New ways of communicating the intentions of the HGV could potentially help the pedestrians to understand that the HGV wants to move.

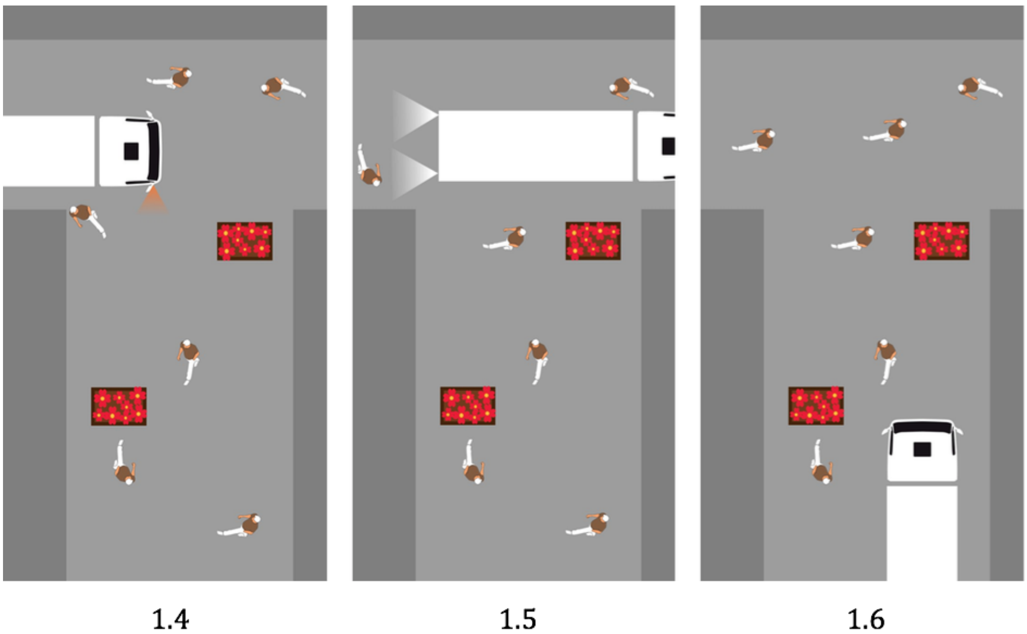


Figure 4.7: Scenarios on a living street where pedestrians are blocking the path of an HGV

In Figure 4.8, five scenarios of an HGV wanting to merge into high density traffic on a highway are presented. All scenarios take place in slow moving traffic or traffic congestion and it is assumed that the HGV needs to act assertive to be able to complete its action. In scenario 2.1, an HGV is driving behind a slow moving vehicle and wants to merge into the left lane where the density of vehicles is high. In scenario 2.2, an HGV approaches road construction at low speed and must change lane to avoid being forced to stop on the highway. Scenario 2.3 shows an HGV driving in the left lane but want to take the exit on the right. The HGV could have come from a merging highway earlier and is therefore forced to make a quick exit. In scenario 2.4, an HGV drives on the on ramp to a highway with high density traffic and needs to merge before the on ramp ends which potentially could force the HGV to stop. Scenario 2.5 shows a situation where two lanes merge into one. The typical principle here is the vehicles to take turns on when to drive. However, in a scenario where the driver of the other vehicles knows that the HGV is automated and programmed to not make any risky moves, the drivers in the other lane could take advantage of the situation and never let the HGV merge.

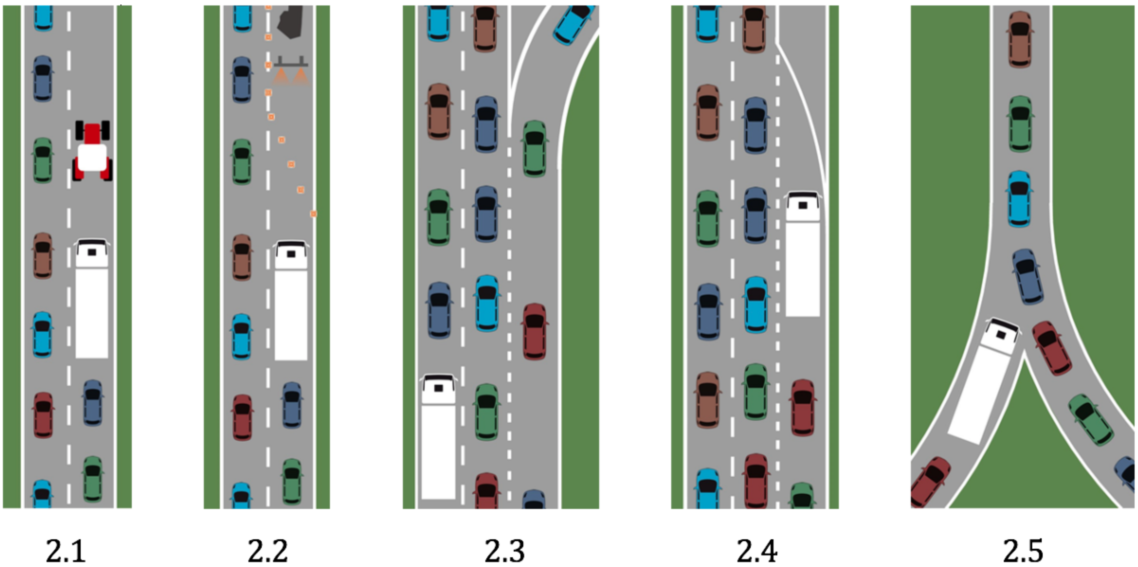


Figure 4.8: Merging scenarios on a highway with slow moving, high density traffic

To be able to choose one relevant scenario to base the concept development on, several criteria were stated to make ranking possible. Based on a discussion with experts at Volvo GTT, the following four criteria were established

- Frequency – how often do this situation occur?
- Consequence – what risks exist in the situation?
- Acceptance – how would a solution help the general acceptance of AVs in the society?
- Legal – what rights does the HGV have in the situation based on traffic regulations today?

The criteria were also weighted (ω) on a scale from 1-10. Here, consequence and frequency have a big importance and were therefore given the weights 9 and 8 respectively. The general acceptance criterion was given a weight of 5 due to the fact that if AVs are to succeed and take over our transportation solutions, acceptance and trust to the technology is needed from the society. The legal criterion was given a weight of 2. The reasoning here is that if solutions are developed that are proven to increase safety, even though they are not following the traffic regulations of today, the regulations can be changed. The entering of AVs to the society will need new regulations anyway which is why such small consideration has been given to the traffic laws and regulations of today.

Each scenario was then given a score of 1-3 for each criterion. For example, if a scenario was believed to happen often it was given a score of 3 for the frequency criterion. If the safety risks were believed to be low, for example if the only consequence is that the HGV has to wait longer, the scenario was given a score of 1 for the consequence criterion. The complete ranking of the scenarios can be seen in Table 4.1.

Table 4.1: Ranking of scenarios based on weighted criteria

	Frequency $\omega = 8$	Consequence $\omega = 9$	Legal $\omega = 2$	Acceptance $\omega = 5$	Total weighted
1.1	2	1	1	2	37
1.2	1	1	1	2	29
1.3	1	1	2	3	36
1.4	2	1	1	2	37
1.5	1	1	1	2	29
1.6	2	1	1	2	37
2.1	1	2	1	1	33
2.2	2	2	2	2	48
2.3	1	2	1	1	33
2.4	**3**	**3**	**2**	**3**	**70**
2.5	1	2	3	3	47

4.2.1 Chosen scenario

With scenario 2.4 scoring the highest, this was the scenario chosen for further analysis and concept development. To be able to analyse the scenario in detail, it was broken down into shorter events. A list including all events was created where all actions performed by both the HGV and the passenger vehicle were listed. To better illustrate the events, a timeline was created visualising the order of actions, see Figure 4.9. With help of the timeline, an exact moment of when an additional communication solution is needed was identified, also marked in Figure 4.9.

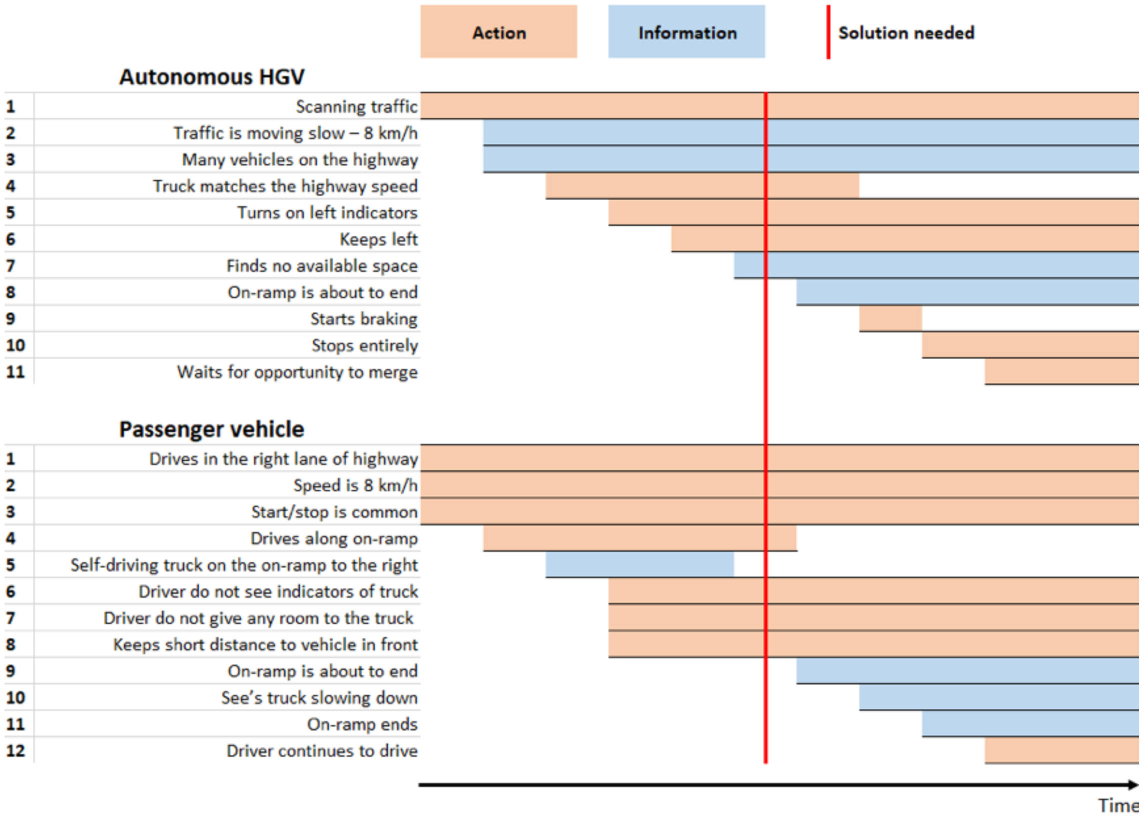


Figure 4.9: Timeline of events taking place when HGV wants to merge but passenger vehicle will not let it

Based on analysis of the scenario and the events visualised in Figure 4.9, three key user needs for the light signal was identified. The developed communication concepts need to communicate the following to other road user

1. Communicate that the HGV will merge
2. Communicate the urgency of the situation
3. Communicate when the HGV will initiate the turn

4.3 Concept development

In this section, the method for the development phase will be presented. The process of how the user needs and requirements were stated to how a single concept could be chosen will be explained.

4.3.1 Requirements and user needs

When the chosen scenario had been broken down into smaller events, the time of when a solution is needed could be identified. It was analysed and discussed what was happening in the situation at the identified time and why it was happening.

From this, several factors could be stated for causing the scenario and needs for how to avoid it could be established. The needs are both from the perspective of the HGV and the other road users. After stating what needs are required in the direct situation it was discussed what requirements that need to be fulfilled for a functioning solution, see Table 4.2. Several categories could be found: Visibility, Intentions, Reliability and Acceptance. Within each category, several requirements was listed. This was done to ease the next step where the user needs and requirements will be used for evaluating different concepts.

Table 4.2: Established user needs

User Needs	
1.	**VISIBILITY**
1.1	From inside other vehicle
1.2	Independent of position along HGV
1.3	Attract attention from affected road users
1.4	Neutral impact on non-affected road users
1.5	Visible in all weathers
1.6	Visible during all times of day
1.7	Comfortable light intensity
2.	**INTENTIONS**
2.1	Easy to interpret
2.2	Independent of language
2.3	Easy to understand situation is critical
2.4	Easily distinguished from other signals
2.5	Encourage safe behaviour of other road users
2.6	Easy to interpret meaning of colours
3.	**RELIABILITY**
3.1	Work in all conditions
3.2	Countdown between signal and action
3.3	Activates only in critical situation
4.	**ACCEPTANCE**
4.1	Help traffic flow
4.2	Show intention of vehicle

4.3.2 Concept generation

From section 4.2.1, three requirements of what the truck has to communicated could be stated:

1. Communicate that the HGV will merge
2. Communicate the urgency of the situation
3. Communicate when the HGV will initiate the turn

A brainstorming session was conducted to create solutions to each one of the communication requirements that were stated above. The brainstorming was divided into three rounds that took 20 minutes each. For every round, one requirement was treated. For each round, the participants should come up with as many solutions as possible to solve that specific question. The solutions were written down on post-it notes and in the end of every round, all the solutions were discussed and explained before the next round started. All post-it notes were put up on the wall to give the participants an overview of the suggested solutions, see Figure 4.10.

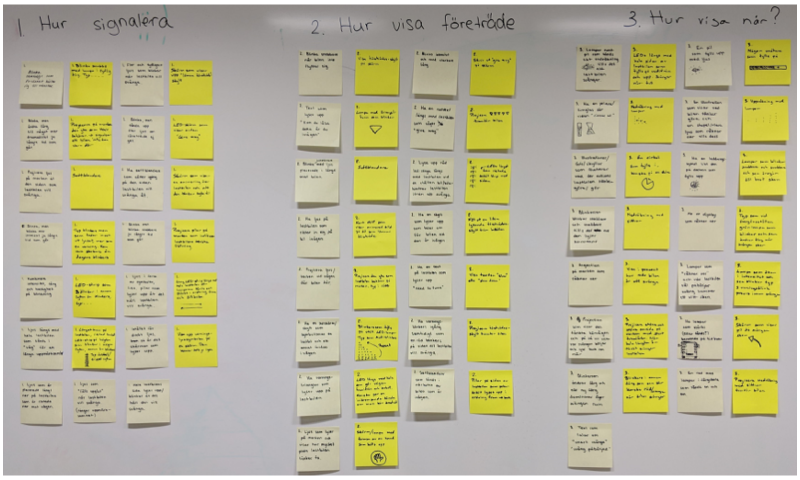


Figure 4.10: All the suggested solutions for each question

Some of the solutions were similar to each other and they could therefore be grouped together and sometimes even merged into one, see Figure 4.11. For every requirement, five groups could be created:

1. “Regular” turn signals
2. Symbols
3. Projections
4. Increased number of lights
5. LED-strips along the vehicle

For requirement 1 and 2, a sixth group called “Others” was created.

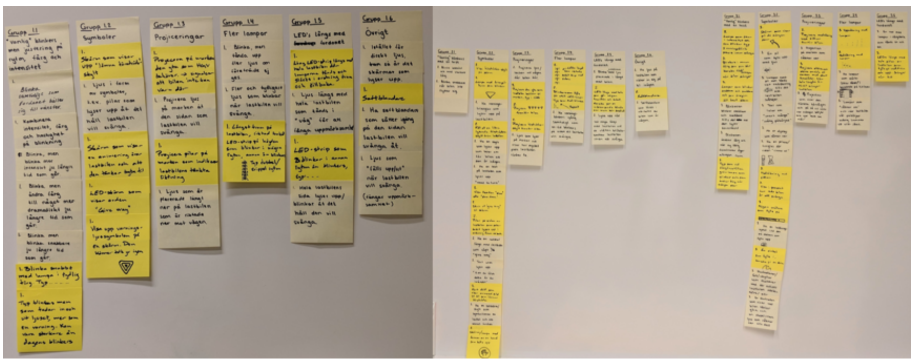


Figure 4.11: Grouped solutions for every question

When the sub solutions had been conducted in different groups, a Concept Combination Table could be created, see Table 4.3. Each row represents possible solutions for each requirement.

Table 4.3: A Concept Combination Table to generate different concepts

		Suggested Solution					
Function	How to signal that the truck wants to turn	Group 1.1 Regular blinkers with new features such as other colors, other intensity and/or other flashing rythm	Group 1.2 Solutions involving symbols or texts that show the truck's intentions.	Group 1.3 Different types of projections	Group 1.4 Add more lightsources on the vehicle	Group 1.5 Add different types of LED-stipes on the vehicle	Group 1.6 Others: Add other types of lightsources for instance siren light or folfable light device
	How to signal that the truck needs precedence	Group 2.1 Regular blinkers with new features such as other colors, other intensity and/or other flashing rythm	Group 2.2 Solutions involving symbols or texts that show the truck's intentions.	Group 2.3 Different types of projections	Group 2.4 Add more lightsources on the vehicle	Group 2.5 Add different types of LED-stipes on the vehicle	Group 2.6 Others: Add other types of lightsources for instance siren light or folfable light device
	How to signal when the truck is about to turn	Group 3.1 Regular blinkers with new features such as other colors, other intensity and/or other flashing rythm	Group 3.2 Solutions involving symbols or texts that show the truck's intentions.	Group 3.3 Different types of projections	Group 3.4 Add more lightsources on the vehicle	Group 3.5 Add different types of LED-stipes on the vehicle	

After creating the Concept Combination Table, a session to come up with concepts was held. By using Idea Generating Sheets, see section 3.2.4, the participants designed eight concepts each where four of them were to be realistic viable concepts, two innovative but still viable and finally two concepts with a feeling of the future. After compiling all the generated concepts, a short presentation of each concept was made. After the presentation, the participants filled in the sheets for the "Strengths & Opportunities" and "Concerns & Weaknesses". When the participants had commented on all the concepts, they were reviewed one by one. Concepts that had a majority of negative comments and no advantages that could make up to it were eliminated. So were also the concepts that directly seemed unrealistic or in other way impossible to go through with. If an eliminated concept had a good comment or maybe some other useful feature, notes were taken in case it could be applicable to another concept in order to improve that one. After reviewing all the concepts and their comments, two new concepts were created by combining some of the positive comments in order to improve these. At the end of the session, eleven concepts were ready for the next stage in the development process.

4.3.3 Concept screening

In the next step, a Concept Screening Matrix was created, see Table 4.4. The concepts were discussed one by one if they fulfilled the needs. If they did, a "Y" was marked for "Yes", if not, an "N" was marked for "No". The "REF", that can be seen in the first column of the concepts stands for reference and represent the turn signals that exist today.

Table 4.4: The Concept Screening Matrix

		Concepts											
User Needs		REF	A	B	C	D	E	F	G	H	I	J	K
1.	**VISIBILITY**												
1.1	From inside other vehicle	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
1.2	Independent of position along HGV	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y
1.3	Attract attention from affected road users	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
1.4	Neutral impact on non-affected road users	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
1.5	Visible in all weathers	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
1.6	Visible during all times of day	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
1.7	Comfortable light intensity	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2.	**INTENTIONS**												
2.1	Easy to interpret	Y	Y	N	Y	Y	Y	N	Y	Y	Y	Y	Y
2.2	Independent of language	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2.3	Easy to understand situation is critical	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
2.4	Easily distinguished from other signals	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2.5	Encourage safe behaviour of other road users	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
2.6	Easy to interpret meaning of colors	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N
3.	**RELIABILITY**												
3.1	Work in all conditions	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3.2	Countdown between signal and action	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
3.3	Activates only in ciritcal situation	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4.	**ACCEPTANCE**												
4.1	Help traffic flow	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4.2	Show intention of vehicle	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
Number of YES		14	17	17	18	18	18	14	18	18	16	17	16
Number of NO		4	1	1	0	0	0	4	0	0	2	1	2

Concepts that got 18 "Yes" (the maximum score), were directly approved for further progress while concepts that got one or more "No" were discussed once more to investigate why. The concepts that were approved for further development were: A, C, D, E, G, H, I and J. The reason why B did not get approved although it had the same score as A and J and even more points than I was because of the need that it did not fulfil. After discussion, it was clarified that the need "Easy to interpret" is of very high importance and since concept B did not fulfil that, it could not be approved.

Next step in the process was to compare the concepts with each other. It was done by using a Concept Selection Matrix. The Concept Selection Matrix was used several times to iterate towards a stable result. One concept at the time was compared with the reference. It was discussed for every user need which concept was better and why. For the first round, a regular turn signal was used as reference, see Table 4.5.

Table 4.5: The first round using the Concept Selection Matrix

Reference = Regular turn signal		Reference	Concept A	Concept C	Concept D	Concept E	Concept G	Concept H	Concept I	Concept J
User Needs		Rating	Rating	Rating	Rating	Rating	Rating	Rating	Rating	Rating
1.	**VISIBILITY**									
1.1	From inside other vehicle		0	+	0	0	+	+	0	0
1.2	Independent of position along HGV		0	+	+	0	+	+	0	0
1.3	Attract attention from affected road users		+	+	+	0	+	+	+	+
1.4	Neutral impact on non-affected road users		0	0	0	0	0	0	0	0
2.	**INTENTIONS**									
2.1	Easy to interpret - wants to turn		0	0	0	0	0	0	0	0
2.2	Easy to understand situation is critical		+	+	+	+	+	+	+	0
2.3	Easy to understand when it's turning		+	+	+	+	0	+	+	+
2.4	Easily distinguished from other signals		0	0	0	0	0	0	-	0
2.5	Encourage others to let truck merge		+	+	+	+	+	+	+	+
2.6	Avoid getting other road users stressed		-	-	-	-	-	-	0	-
2.7	Easy to interpret meaning of colors		0	0	0	0	0	-	-	0
3.	**RELIABILITY**									
3.1	Work in all conditions		0	0	0	0	0	0	0	0
3.2	Countdown between signal and action		+	+	+	+	0	+	0	+
4.	**ACCEPTANCE**									
4.1	Help traffic flow		+	+	+	+	0	+	+	+
4.2	Show intention of vehicle		+	+	+	+	+	+	+	+
TOTAL +			7	9	8	6	6	9	6	6
TOTAL 0			7	5	6	8	8	4	7	8
TOTAL -			1	1	1	1	1	2	2	1
TOTAL OVERALL			**6**	**8**	**7**	**5**	**5**	**7**	**4**	**5**

Since all concept got a high score compared to the reference, all the concepts except the reference were allowed to proceed to the second round with the Concept Selection Matrix. For the second round, concept C was used as the reference, see Table 4.6, since it got the highest score in the first round.

Table 4.6: The second round using the Concept Selection Matrix

Reference = Concept C		Concept A	Concept C	Concept D	Concept E	Concept G	Concept H	Concept I	Concept J
User Needs		Rating	Rating	Rating	Rating	Rating	Rating	Rating	Rating
1.	**VISIBILITY**								
1.1	From inside other vehicle	-		+	+	0	0	-	-
1.2	Independent of position along HGV	-		0	-	0	0	-	-
1.3	Attract attention from affected road users	-		+	0	0	0	-	-
1.4	Neutral impact on non-affected road users	0		0	0	0	0	0	0
2.	**INTENTIONS**								
2.1	Easy to interpret - wants to turn	0		0	0	0	0	0	+
2.2	Easy to understand situation is critical	0		+	-	0	+	+	-
2.3	Easy to understand when it's turning	+		+	-	-	0	-	+
2.4	Easily distinguished from other signals	0		0	0	0	-	-	-
2.5	Encourage others to let truck merge	0		0	0	0	0	+	0
2.6	Avoid getting other road users stressed	+		+	+	0	+	0	+
2.7	Easy to interpret meaning of colors	0		0	0	0	-	-	0
3.	**RELIABILITY**								
3.1	Work in all conditions	0		0	0	0	0	0	0
3.2	Countdown between signal and action	+		+	-	-	+	-	0
4.	**ACCEPTANCE**								
4.1	Help traffic flow	0		0	0	0	0	0	0
4.2	Show intention of vehicle	0		0	-	-	0	-	+
TOTAL +		3		6	2	0	3	2	4
TOTAL 0		9		9	8	12	10	5	6
TOTAL -		3		0	5	3	2	8	5
TOTAL OVERALL		**0**		**6**	**-3**	**-3**	**1**	**-6**	**-1**

In the second round, concept D appeared to be the best when using concept C as a reference. Second best was concept H followed by concept A. Concept I got the lowest score of -6 and was eliminated before the next round. For the third round, concept D chosen as a reference, see Table 4.7.

Table 4.7: The third round using the Concept Selection Matrix

	Reference = Concept D	Concept A	Concept C	Concept D	Concept E	Concept G	Concept H	Concept J
	User Needs	**Rating**	**Rating**	**Rating**	**Rating**	**Rating**	**Rating**	**Rating**
1.	**VISIBILITY**							
1.1	From inside other vehicle	-	-		-	0	0	-
1.2	Independent of position along HGV	-	0		-	+	+	-
1.3	Attract attention from affected road users	-	-		-	-	-	-
1.4	Neutral impact on non-affected road users	0	0		0	0	0	0
2.	**INTENTIONS**							
2.1	Easy to interpret - wants to turn	0	0		0	0	0	+
2.2	Easy to understand situation is critical	-	-		-	0	0	-
2.3	Easy to understand when it's turning	0	-		-	-	-	0
2.4	Easily distinguished from other signals	0	0		0	0	-	0
2.5	Encourage others to let truck merge	-	0		0	0	0	0
2.6	Avoid getting other road users stressed	+	-		+	-	0	0
2.7	Easy to interpret meaning of colors	0	0		0	0	-	0
3.	**RELIABILITY**							
3.1	Work in all conditions	0	0		0	0	0	0
3.2	Countdown between signal and action	0	-		-	-	-	-
4.	**ACCEPTANCE**							
4.1	Help traffic flow	0	0		0	0	0	0
4.2	Show intention of vehicle	-	0		-	-	-	+
	TOTAL +	1	0		1	1	1	2
	TOTAL 0	8	9		7	9	8	8
	TOTAL -	6	6		7	5	6	5
	TOTAL OVERALL	**-5**	**-6**		**-6**	**-4**	**-5**	**-3**

According to the Concept Selection Matrix, concept D appeared to be the best. But to avoid the selection of concept to be too subjective and to investigate if the matrices actually give a reliable result, it was decided to invite other people with experience within the area to evaluation sessions in order to get another view of the matter. Before the evaluation sessions were performed, more detailed sketches were done to illustrate the concepts. To visualise how the signal was executed, animations were designed. To make the evaluation fairer, all concepts were drawn on the same base sketch, see Figure 4.12.

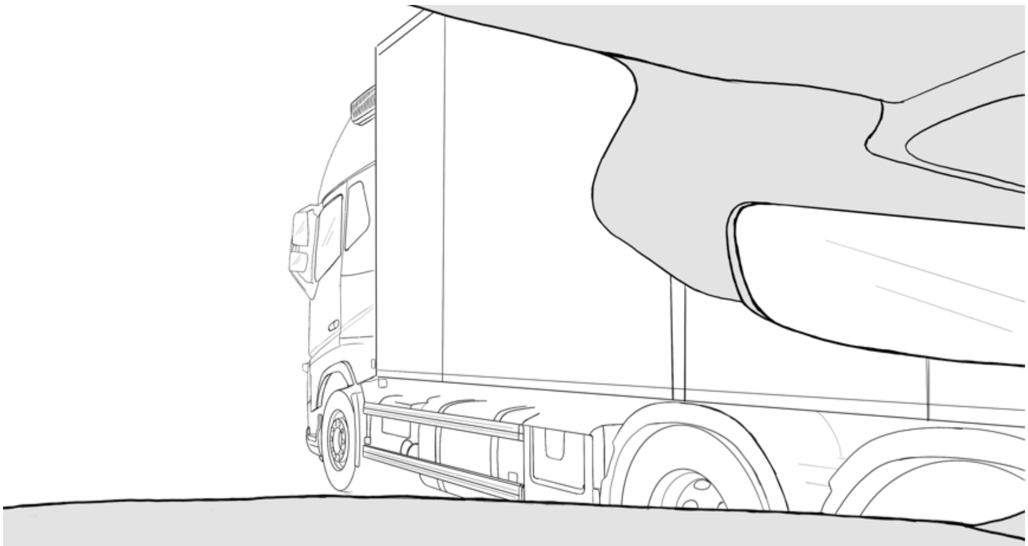


Figure 4.12: The sketch that worked as the base for all the concept animations

The evaluation sessions took approximately 45 minutes each and contained three parts where the first part was a short introduction about the project and the chosen scenario. In the second part, every concept was presented, one by one, in the shape of a GIF and the person participating spoke freely about how he/she interpreted the signal. The last part of the session was to rate each concept for how well the concept indicated that the HGV *has* to change lane and how well the concept communicated *when* the truck is going to change lane. The person could rate the concepts between 1 to 5 where 1 meant very bad and 5 meant very well. A total of five sessions were made with five different persons. All the comments were compiled and analysed to see how the participants had perceived the different concepts. After analysing the comments, some of the concepts could be combined in order to achieve a new final concept.

4.4 Concept presentation

In this section, the potential concepts presented to the experts will be explained and illustrated.

Concept A

The first concept is concept A, see Figure 4.13. This concept is a variant of existing indicator lights but more advanced. Around the already existing indicator lights, several smaller lights are placed in a circle. An alternative to several smaller lights is a LED-strip that are formed as a circle around the ordinary one. To show that the HGV wants to turn, the ordinary lights start to flash at first. To count down to when the turn will take place, the small lights one by one starts to flash together with the regular one. When all the small lights are lit, the HGV will initiate the turn.

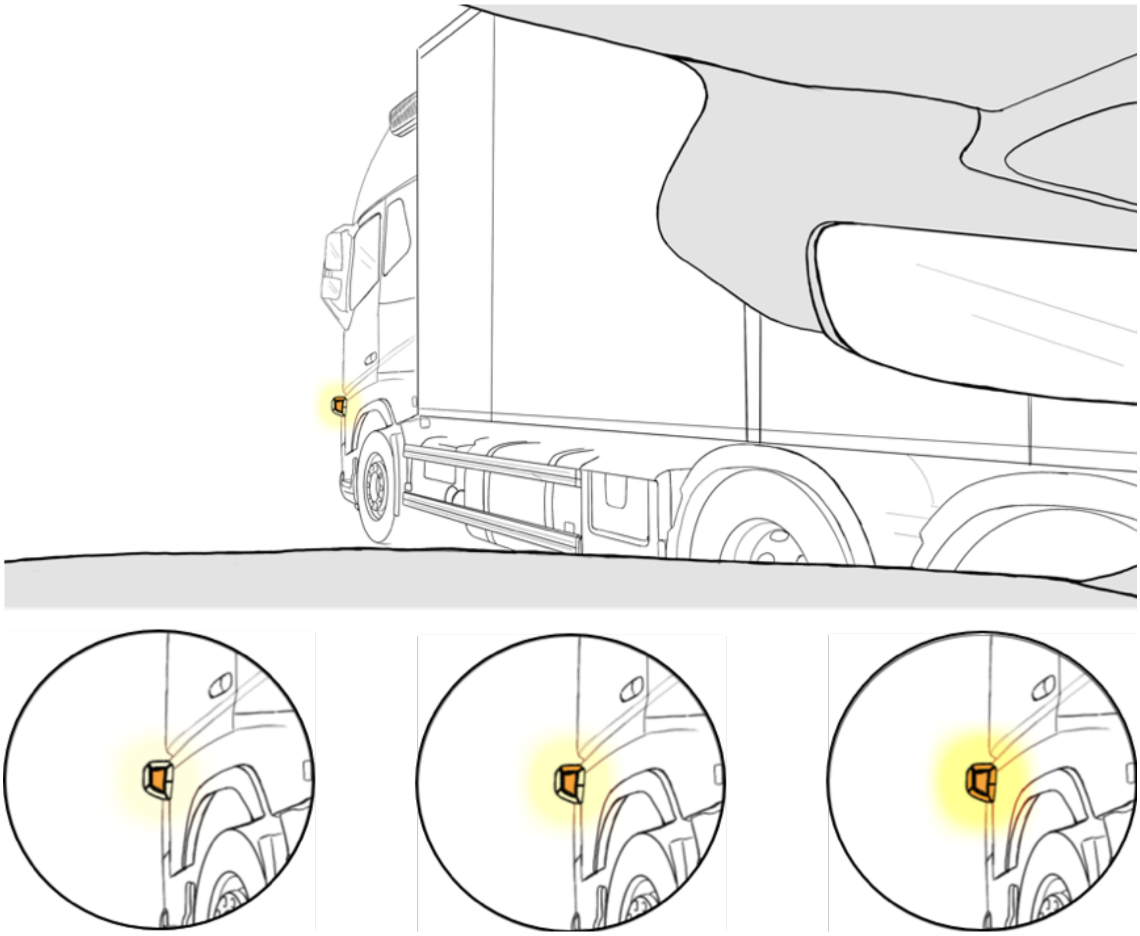


Figure 4.13: Concept A

Concept C

Concept C consists of LED modules that are about 50 cm long, see Figure 4.14. These modules are placed along the entire HGV about 20 cm apart. Each module consists of one big main light and several smaller lights both above and below the main light. When the HGV needs to turn, the main light is flashing in the same fashion as regular turn signals today. If the situations gets more critical, the flash frequency change to indicate urgency. Only the modules closest to the affected vehicle are lit to indicate even more that that vehicle needs to move. To show other road users when the HGV will initiate the turn, the additional smaller lights are lit in sequence as a form of countdown. When all lights are lit, the HGV initiates the turn.

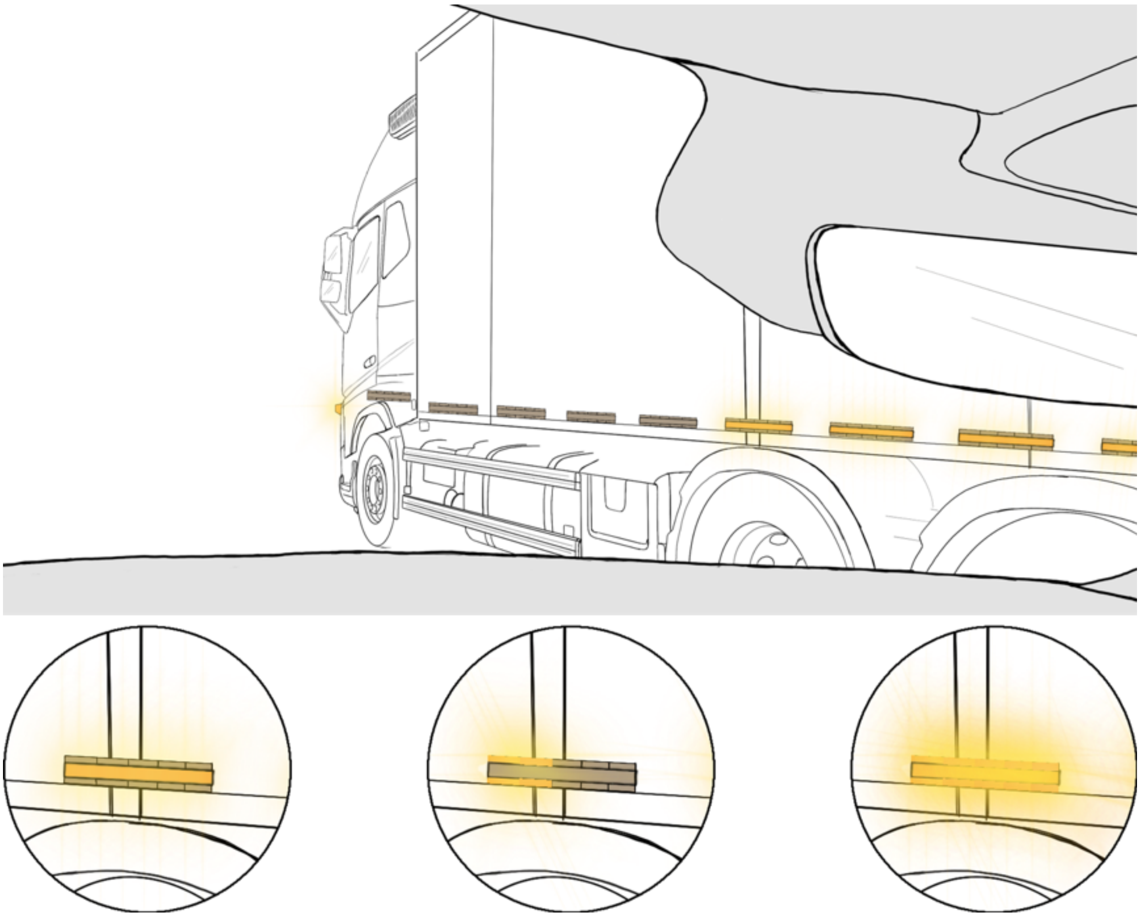


Figure 4.14: Concept C

Concept D

This concept contains an adaptive light source that is mounted in the front of the HGV, see Figure 4.15. The light is pointing backwards and will aim at or close to the driver to get her/his attention. The directing light will work like adaptive headlights that already exist on the market. To show that the situation is getting urgent, the lights will flash in a special rhythm. Around the amber adaptive light source are more and smaller lights placed, these will light up in sequences to tell when the HGV is going to turn.

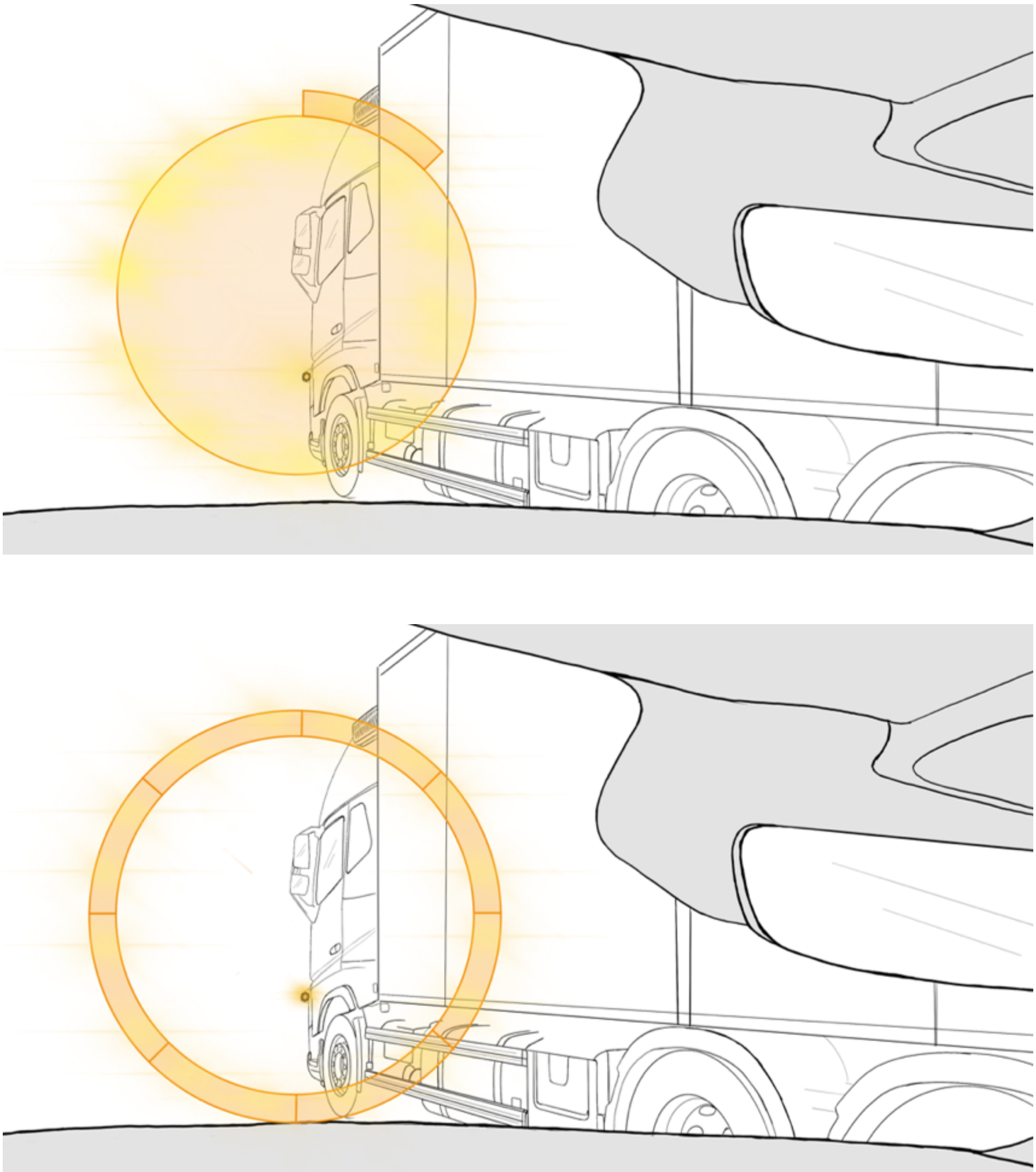


Figure 4.15: Concept D

Concept E

In concept E, several lights are placed on top of each other in an array, see Figure 4.16. The arrays can be placed in the front, in the middle and in the rear of the truck to improve the visibility. There are five lights in each array. When the HGV needs to turn, the light on the bottom of the array start to flash followed by the next light and so on until all the lights are flashing. When all lights in the array are flashing, the HGV is turning.

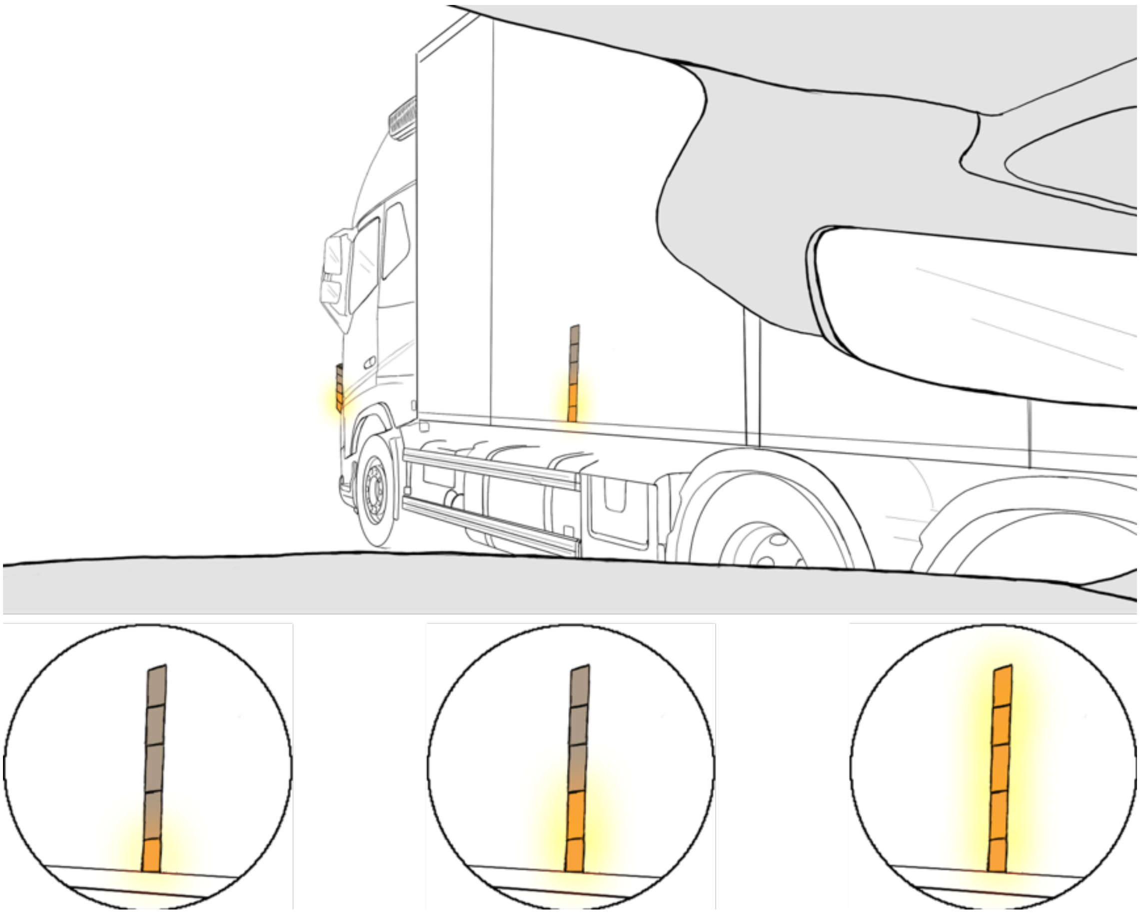


Figure 4.16: Concept E

Concept G

Concept G uses regular turn signals, but it also has a LED-strip mounted along the whole vehicle, see Figure 4.17. To show that the HGV wants to merge the ordinary turning signals start to flash at first. If another vehicle happens to be in the way of the HGV, a light in the length of the driver's view will light up. This to ensure that the attention of the relevant driver is caught and to avoid disturbing other drivers. To visualise the count down to the turn, the turn signal start to flash faster and faster until a solid light takes over and the HGV starts to turn.

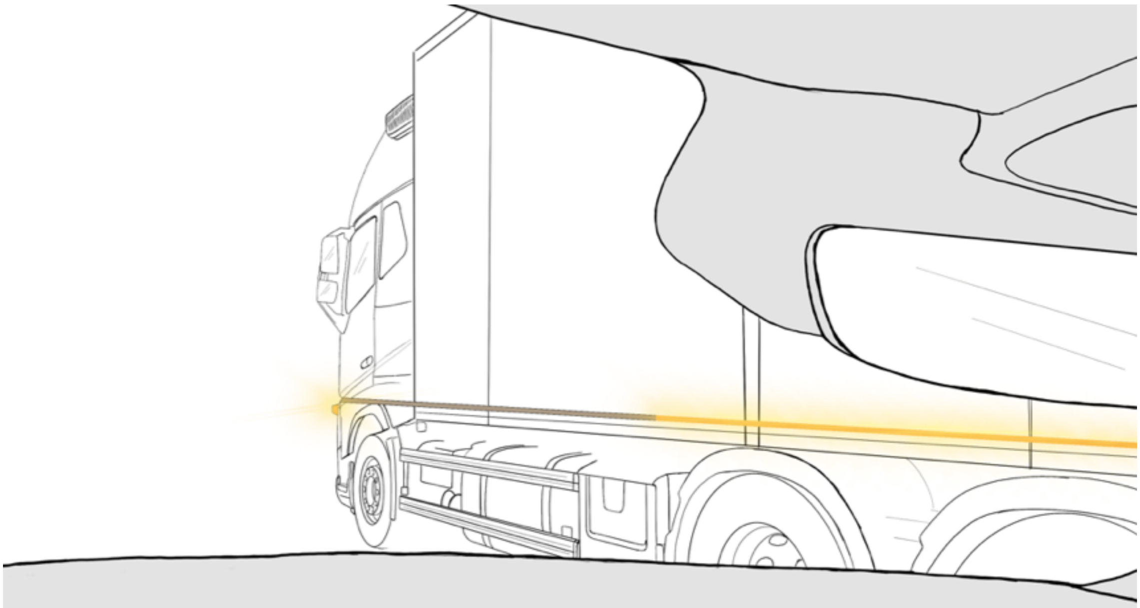


Figure 4.17: Concept G

Concept H (Hb - blue and Hr- red)

This concept has both regular turn signals and LED-strips that goes along the vehicle, see Figure 4.18. The LED-strips contain several sections of lights with space between. The HGV uses the regular turning signals at first, but as soon as the situation starts to get critical, the LEDs along the vehicle also start to flash in the same rhythm as the regular ones. To show when the HGV is turning, one light at a time on each LED-strip change colour, for instance to red or blue. When all the lights in the strip have changed colour, the HGV starts to turn.

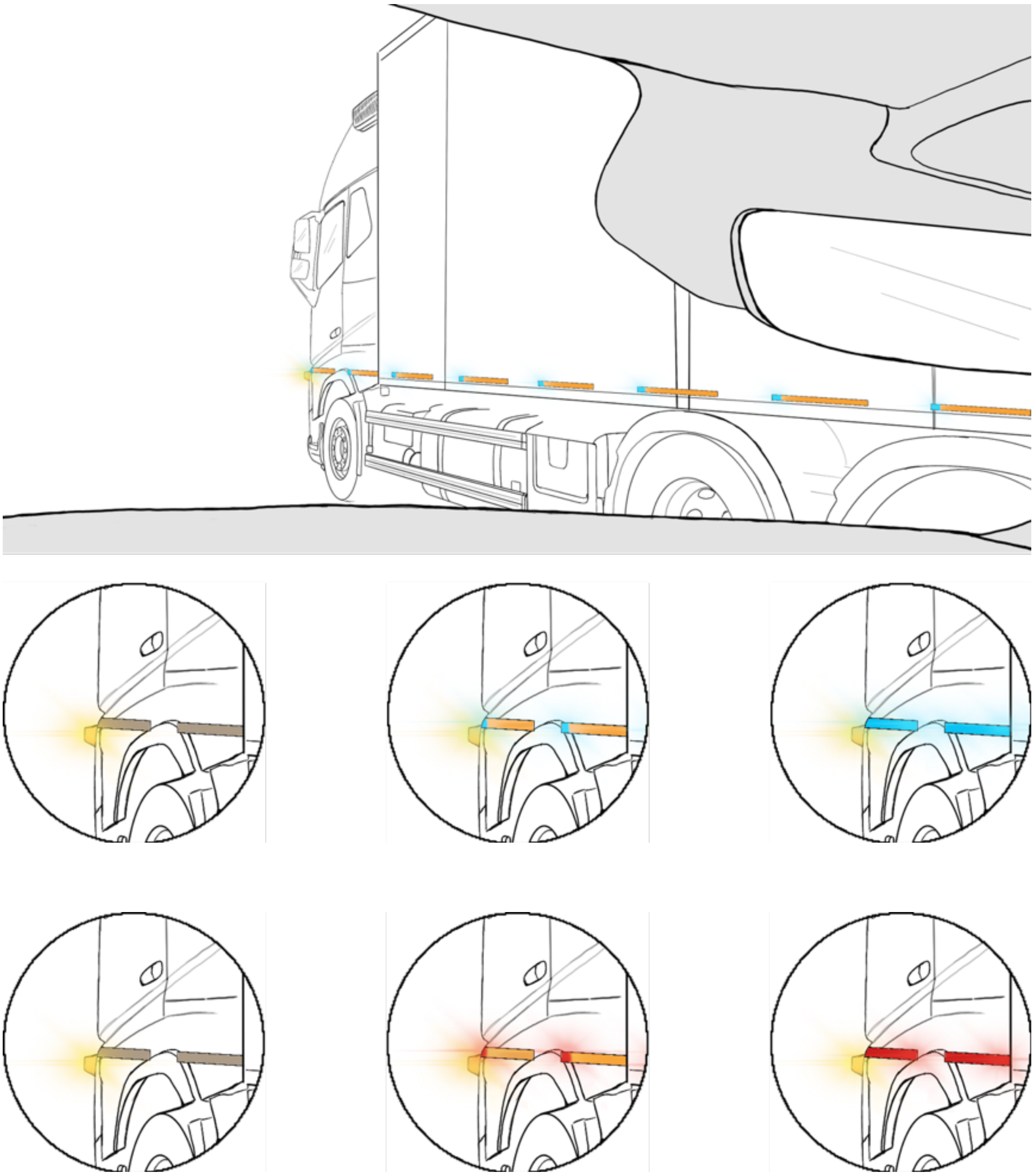


Figure 4.18: Concept H

Concept J

The last concept is concept J where an arrow is mounted at an angle from the side of the HGV so that it is visible from the side and the rear, see Figure 4.19. The arrow is mounted at the front, middle and rear and should be big enough so that road users can see and interpret the meaning of it. The colour is amber, both for the frame and the fill. It starts with the regular turning signal, then only the frame starts to flash in the same rhythm as the regular signal while the arrow slowly fills up with amber light. When the arrow is fully filled, the HGV will turn.

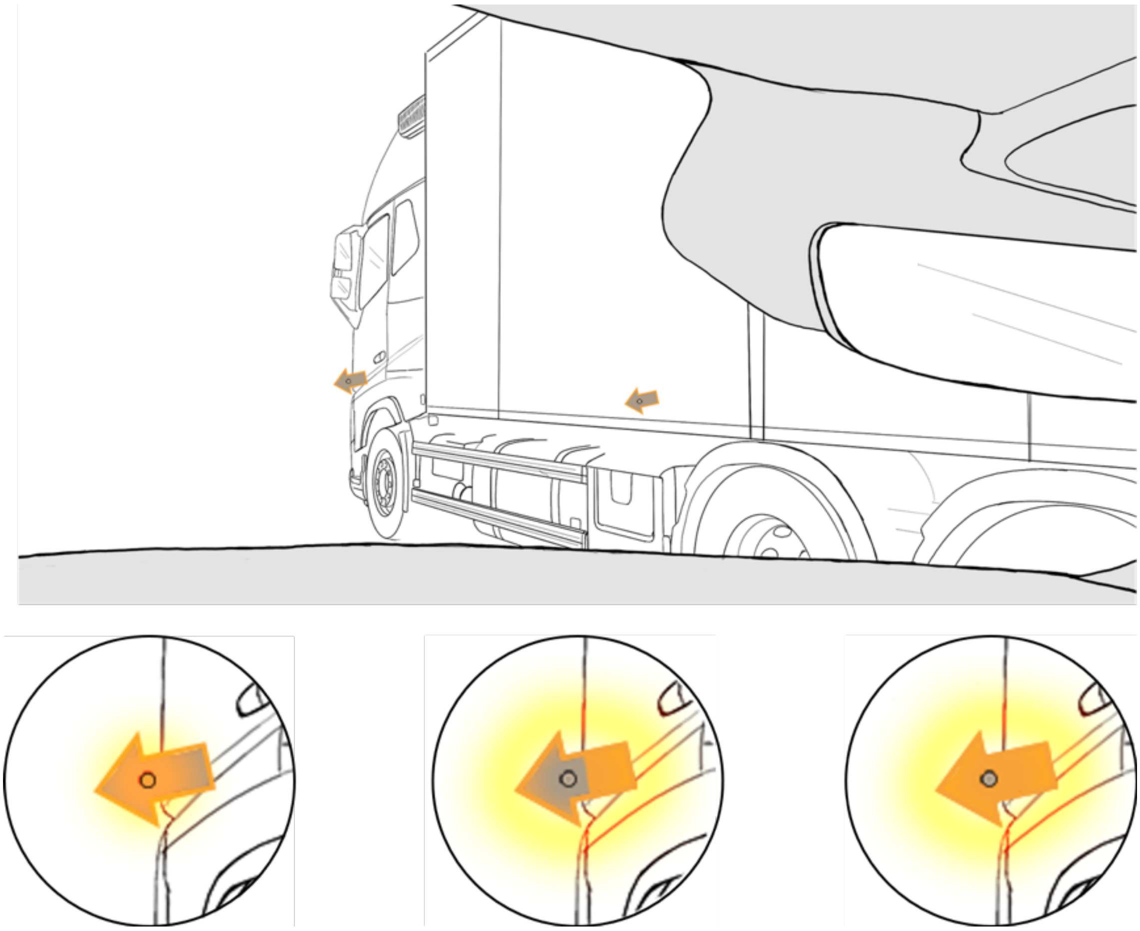


Figure 4.19: Concept J

4.5 Concept selection

Based on the results from the concept selection matrices and the interviews, one new final concept was created and chosen for further development. Although concept D seemed promising based on the matrices, several of the interview subjects raised concerns regarding its potential stressful and aggravating appearance. According to the interviews, the signal would be hard to ignore but it was not fully clear what it meant. Concerns about the implementation of concept D was also raised as projections do not work well in daylight and that it would probably result in additional glare and obstruction of visibility for the other road user.

In general, the interviews concluded that changing the colour of the turn signal is not preferred. In the presented concepts, two versions were made that have another colour than the standard amber colour: one blue and one red. Although the red version seemed to communicate urgency or importance, the intentions of the HGV were not fully understood as red vehicle lights are strongly associated with braking. The blue light was also confusing as the interviewees did not understand its meaning. Someone thought that the blue meant that the HGV was changing state from driver controlled to autonomous drive while another thought it communicated that the HGV was about to start driving forward. The blue colour also seemed to communicate a calm feeling to the interview subjects.

One feature that got positive feedback was the change of flash frequency. Both concept C and G utilises this feature which seemed to communicate urgency and an extra layer of importance to the interviewees. Although neither of these concepts was received without some criticism, the concept of changing flash frequency to communicate vehicle intentions was received well and was therefore chosen for further investigation and development.

To communicate when the HGV planned to initiate the turn, several concepts had some sort of countdown feature. In concept C, E, Hb, Hr and J, the countdown was designed to light up more and more lights along a horizontal or vertical line. In concept A and D, this was communicated by lighting up additional lights in a circle. During the interviews, it became clear that many of the participants understood that this feature was a countdown, but they did not necessarily understand what it was for. These countdown features also requires the attention of the other road user for a long time in order to perceive the dynamic changes in the communication sequence. In concept G, an increase in flash frequency is used instead which seemed sufficient to communicate when the turn is initiated according to several of the interview subjects.

The adaptive feature of concept C and G that only light up in the area close to the affected car got mix feedback in the interviews. Some understood directly that it was meant to indicate that the other road user was driving in a less preferable location while others assumed that something was wrong with the animation. Concerns about that some road users may not understand that the light signal is directed towards them, but rather assume that the other lights are broken, was also raised.

A table of concept rankings and comments from the interview subjects can be seen in Appendix C(-D).

4.6 Concept testing

To test the final concept in the chosen scenario, a virtual environment was created according to Figure 4.20. The two lane road stretches for 3500 meters and include four on-ramps to the highway. HGVs were place at on-ramp B and D and synchronised to the traffic so that it lined up with the test subject when driving along the on-ramp. At on-ramp B, an HGV with regular turn signals was used while two versions of the final concept were tested on on-ramp D. A and C were added as distraction for the test subject so that an HGV would not emerge on every on-ramp.

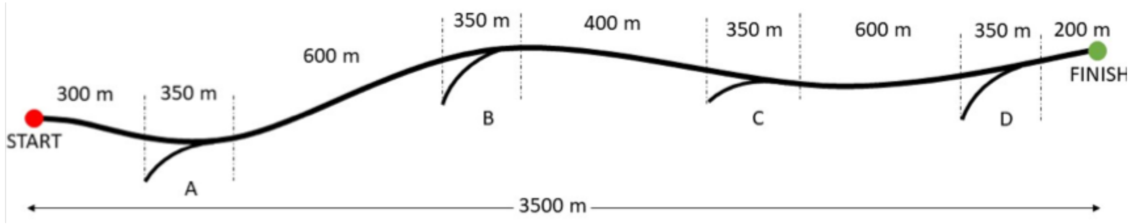


Figure 4.20: Schematic of virtual reality test environment

The on-ramps were designed according to Figure 4.21 based on recommendations from the Swedish Transport Administration [62].

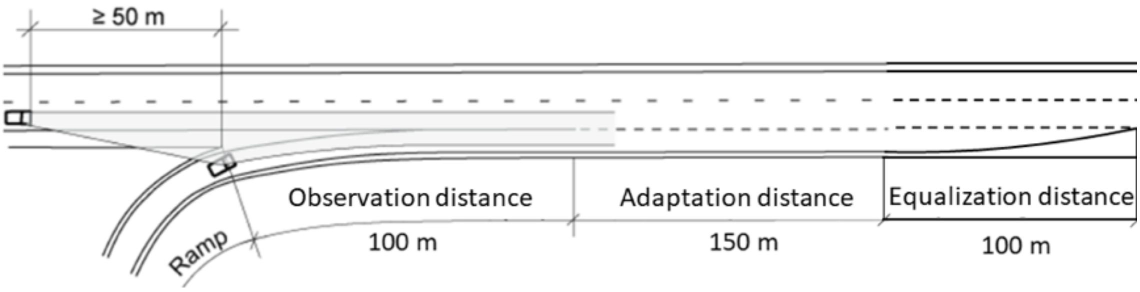


Figure 4.21: On-ramp design for a highway in Sweden with 110 km/h speed limit

To simulate a traffic congestion, other vehicles were added to the simulation in both lanes preventing the test subject from overtaking them, see Figure 4.22. Their speed was limited to 30 km/h which in turn also limited the speed of the test subject. The participants were told to position themselves closely behind the last car in the right lane and drive there for as long as possible without causing any incidents.

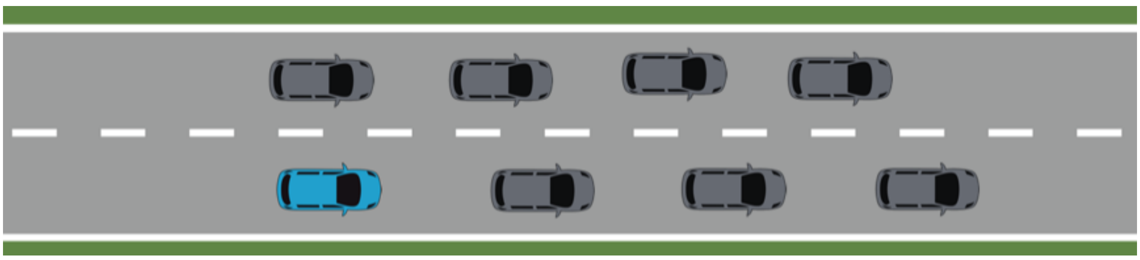


Figure 4.22: Visualisation of traffic congestion. Test subject is driving the blue car

Eleven test subjects were used to evaluate the concepts. The concepts were tested in a randomised order to reduce the learning effects of the results. When the test subject approached on-ramp B and D, the HGV was programmed to line up alongside the test vehicle and switch on its turn signal. It was then up to the test subject to decide whether to let the HGV merge or not, see Figure 4.23 for a snapshot of the testing. After each HGV encounter, the simulation was paused and the test subject was asked questions of how they perceived the situation and the HGV's behaviour. The questionnaire can be seen in Appendix D(-D). After the three scenarios, the proposed concept was explained to the test subject making sure they understood the meaning of the new light signals. The test subject was then asked to drive the new concept scenario one more time which was then followed up by interview questions regarding their subjective thoughts on the concept.

Figure 4.23: Test subject point of view at one of the on-ramps in the virtual environment

To assess the validity of the results, questions about how the test subject perceived the virtual environment, the vehicle, if they would have behaved differently in reality and if they felt any motion sickness was also asked.

5

Results

In this chapter, the answers to the research questions that were stated in section 1.2 will be presented followed by the final concept and the result of the verification test.

5.1 Traffic scenario

To answer the research question of when additional information can be beneficial, several scenarios were identified and one specific scenario was chosen for further research. The choice was based on gathered statistics over traffic accidents, a survey investigating in what traffic situations people feel most uncomfortable and several sessions where different scenarios were evaluated and ranked. The chosen scenario can be seen in Figure 5.1 and illustrates an HGV on an on-ramp that needs to merge on to a highway with slow moving high density traffic. For AVs to work efficiently in mixed traffic environments, they need to be able to act assertive just as human driver do to help the overall traffic flow and avoid critical situations. In the chosen scenario, other road users may take advantage of the HGV being automated or may not understand the importance of the HGV's need to merge. Therefore, the HGV may need to act in assertive ways to avoid being stuck on the on-ramp. To help the acceptance of AVs, additional light communication that informs other road users of the HGVs upcoming action can therefore be beneficial.

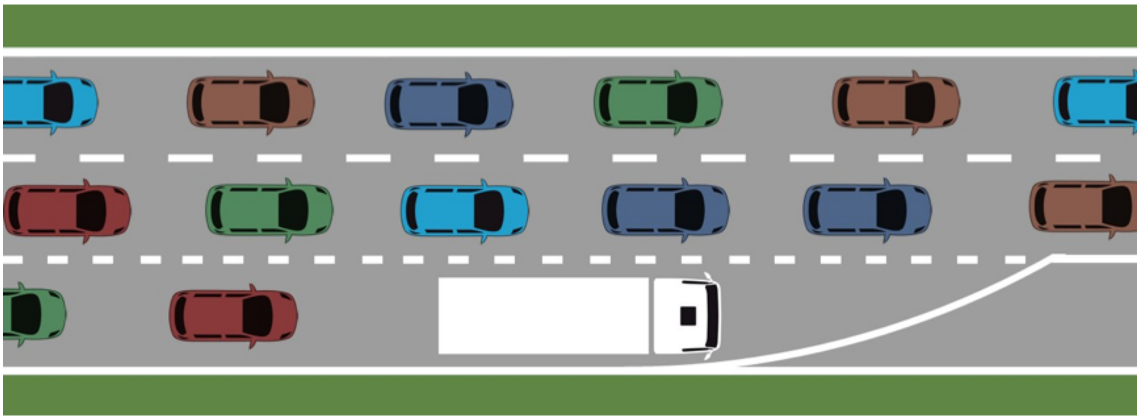


Figure 5.1: The scenario where improved communication is needed

5.2 Information to communicate

From section 4.2.1, a timeline for the chosen scenario was created. The timeline was analysed and broken down into smaller sequences to state what was happening in the situation. From the analysis, three main requirements could be stated:

1. Communicate that the HGV will merge

2. Communicate the urgency of the situation

3. Communicate when the HGV will initiate the turn

The information that needs to be communicated has to indicate urgency from the HGV's perspective but also needs to be assertive to make other road users understand that they should give way. It should also be communicated when the HGV will perform its actions. Even if the communication should give the feeling of urgency, it should not cause too much stress for other road users. It is of importance that the communication does not encourage the other road users to specific actions that can appear risky or dangerous.

5.3 Final concept

The proposed concept, see Figure 5.2 and Figure 5.3, mainly utilises two features that got positive feedback based on the concept evaluation – more light along the vehicle and a modified flash frequency to communicate urgency and turn initiation. It uses the already established amber colour which is heavily associated with turning intentions. Since Volvo Trucks are only responsible for developing and manufacturing the actual truck and not the trailer, the LED-strips along the side are mounted between the first and second vehicle axles. An additional LED-strip is added to the cab which follows the already existing design features. Aside from adding to the aesthetics of the cab, the angled LED-strip also makes it easier for drivers to see the turn signal from vehicles of different heights. By mounting lights only on the cab and on the side between the wheels allows Volvo to implement the solution in their whole range of European trucks, not just the FH.

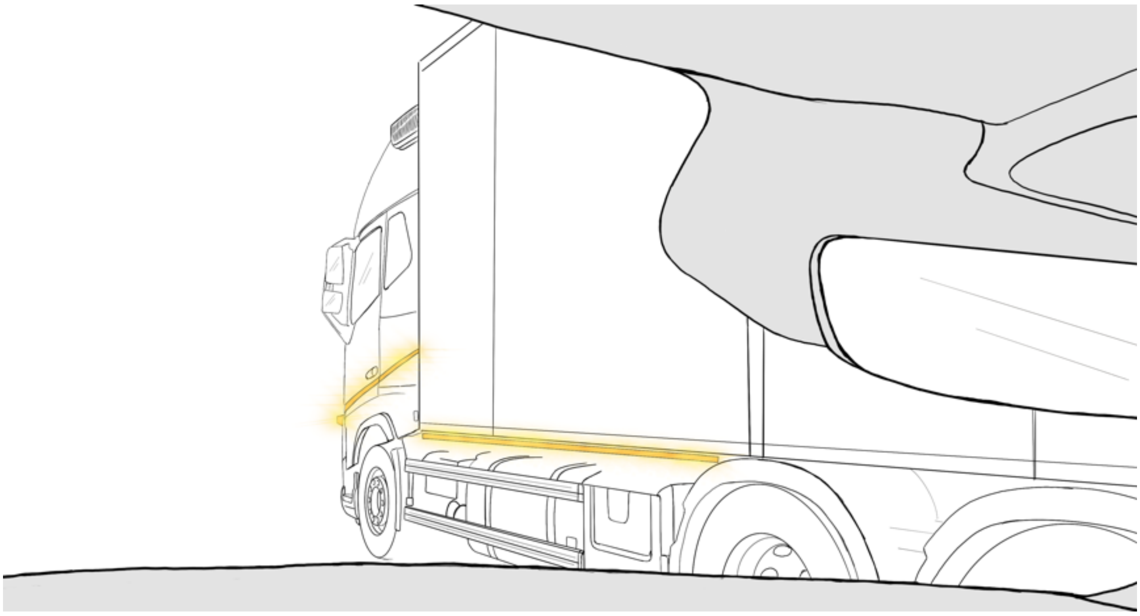


Figure 5.2: Final concept with additional LED-strip along the HGV

Figure 5.3: Visualisation of final concept in the VR-environment

The flash sequence can be divided in three phases, see Figure 5.4. In phase 1, the turn signal works in the same steady fashion as already used by the industry today. This is to be used in most situations where no other vehicle is in the way and where the HGV do not need to act assertive. In situations where it is more urgent for the HGV to turn, such as the chosen scenario, phase 2 and 3 are added to the flash sequence. To communicate urgency to other road users, phase 2 utilises a double flash rhythm which gives the other road user information that the HGV is about to make a safe but assertive manoeuvre. Shortly before the HGV initiates the lane change, phase 3 takes over which is a steady flash in a faster pace. This is used thought out the full manoeuvre until the lane change is completed and the turn signal is switched off.

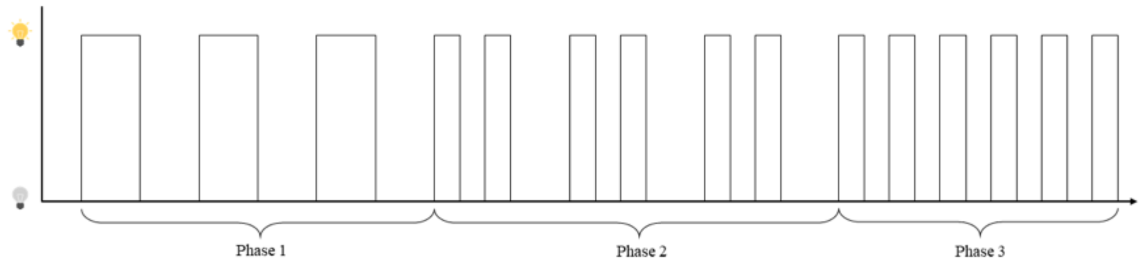


Figure 5.4: Representation of the flash sequence of proposed concept

Aside from communicating intent when turning, the proposed concept is also designed in a way which allows additional light communication to other road users in accordance with examples mentioned in section 2.5. The AVIP-system, the suggestion from Ford and the Volvo 360c concept uses LED-strips to communicate intentions to VRUs and other road users. To be compatibles with these types of ideas, the LED-strip on the cab is designed to cover both the sides and the front. Although no effort have been made in this project to design light communications in the front, Figure 5.5 shows a suggestion of how the proposed concept can be combined with other colours and signals to communicate that the HGV is in an automated drive state for example.

Figure 5.5: Visualisation of how the proposed concept can communicate to the front

5.4 Concept verification

The purpose of the concept testing was to verify that the proposed solution did have intended effects on the test subjects, namely draw their attention to the HGV and make them understand that it is important for the HGV to change lane. The features of the new turn signal concept are to communicate urgency as well as give the other road users information about when the HGV will start to change lane. The test set up can be seen in Table 5.1.

Table 5.1: Test set-up

<table>
<tr><td rowspan="3">Randomised order</td><td>Scenario 1</td><td>Regular turn signal used today</td></tr>
<tr><td>Scenario 2</td><td>Regular turn signal lamps with added
flash sequence of new concept</td></tr>
<tr><td>Scenario 3</td><td>Proposed concept with LED-strips
along the cab and side and new flash sequence</td></tr>
</table>

During the testing, 18% claimed that they felt dizzy and nauseous when they were driving with the VR-headset on. Another 27% said that they felt a bit dizzy but only during brief moments, for example when braking or driving up a hill. 55% of the test subjects did not feel any motion sickness when driving.

When asked if the participants thought that they would act in a similar way when driving in reality, they answered according to Table 5.2 for each scenario.

Table 5.2: Proportion of test subjects that claimed they acted as in reality

Scenario	1	2	3
Proportion (Yes, would act the same in reality)	36%	55%	73%

When instead looking at how the test order affected the participants' answers to if they would act in a similar way in reality, a difference between the first test compared to the two following can be seen according to Table 5.3.

Table 5.3: Effects of test order

Test order	1	2	3
Proportion (Yes, would act the same in reality)	18%	73%	73%

When asked if the participants noticed any differences between the light signals in each scenario, 73% of the participants mentioned that they had noticed the LED-strips on the cab and along the side of the truck and 18% noticed a difference of the flash sequence. 27% claimed that they did not notice any differences at all between the three scenarios.

Out of the in total 33 driving scenarios with the participants, the HGV was allowed to merge in 32 cases, either by slowing down and letting it merge in front of the test vehicle or by changing lane. In one case, the test subject drove very close to the vehicle in front to let the HGV merge behind. When asked why, the participant claimed to be curious about if the HGV would crash and also mentioned that he/she thought that it would have crashed in real life.

When holding the test clinic and asking the same questions to each participant, it became clear that there are many factors that affect a driver's assessment of any given situation. When asked why the participants did or did not let the truck merge, almost all mentioned factors concerning the position and driving behaviour of the HGV as well as not fully being aware of the surroundings. Example of comments influencing the participants' willingness to let the HGV merge are:

- The rear-view mirrors were missing so I did not know if there was someone behind me
- The HGV was driving very aggressively in its lane. It bounced when it was driving along my lane and I got nervous
- It was driving further ahead of me. It felt like I was behind, so based on that, I should let it merge in front of me
- I noticed how the road looked like ahead and saw that the HGV's lane was about to end
- I felt that it needed to get in. That is usually the case on an on-ramp
- It did not slow down and all the other cars were driving close together. It should have adapted its speed
- I expected that the HGV would come and changed lane right away, before it even activated its turn signal
- The peripheral vision in the headset is bad. I did not see anything on the sides so I got scared when I noticed the HGV
- It was driving on the line, far to the left in its lane so I assumed it wanted to merge

After explaining the proposed concept to the participants, they were asked to drive scenario 3 again and were then asked questions of how their experience had been. The participants were in general positive towards the new solution and expressed that they thought that it communicated the HGV's intentions well. Some were concerned that the LED-strips were too big which could be stressful but that it definitely helped to attract attention. A few participants also commented that the concept might come off as aggressive. Concerning the new flash sequences, the intended message was also received well. A majority felt that it communicated a sense of urgency and that it was important for the HGV to change lane. One participant expressed a wish to decrease the flash intervals even more to achieve a more significant difference to the regular turn signal. Another mentioned that the faster the light flashes, the more important it seems while concerns also was raised about the signal being stressful.

The participants were also asked to position how well the new concept communicates the desired information on a scale from 1-10, see Table 5.4.

Table 5.4: Communication ranking

How well does the signal communicate that the HGV HAS to change lane?	7.6 (on average)
How well does the signal communicate WHEN it will begin to change lane?	8.5 (on average)

6
Discussion

In this chapter, the scenario and how it was selected will be discussed followed by what kind of communication is needed and why. After that, a discussion regarding the final concept and how people perceived the signal it communicates will follow. Environmental and ethical aspects as well as recommendations for future research will also be discussed.

6.1 The scenario

In order to find the most critical scenario, statistics analysis, a survey and different evaluating methods were used. The chosen scenario is one of many potential scenarios that may need improved communication for a safer traffic environment in the future as AVs will get more common. Information and accident statistics regarding AVs is very limited since it is not implemented on the roads yet. Therefore, it is difficult to guarantee that the chosen scenario within the project will be of relevance in the future. However, studies indicate that there will be a time when AVs and human drivers will share the roads and new ways to communicate will be necessary. Furthermore, the survey that was sent out also implies that lane changes appear to be a situation in which people seem to be more stressed and lack control.

During the ranking of the different scenarios in section 4.2, different factors had an impact on the outcome. For this project, four different factors were weighted according to importance together with experts from Volvo Trucks. Even if there were no data available regarding the different factors, the different scenarios could be compared relative to each other. However, it can be investigated if there exists other factors that should be taken into account when comparing the different scenarios. Some examples of other potential factors could be the number of places where the situation may occur or how high the probability is for the situation to get critical.

When choosing scenario, it was assumed that the HGV always will take actions to avoid an accident which is why several scenarios could be eliminated as they did not involve risks any longer. However, an HGV that always brakes in time or yields to others to avoid a collision will probably end up in other problematic situations where it is waiting for others to move out of the way. If it becomes a habit for other road users to presume that the HGV will always give way if they are assertive enough, it can lead to hazardous situations where the HGV is force to stop in dangerous locations. If the HGV is forced to stop at the on-ramp, it will block the traffic behind it as well. This can result in long queues which will make other drivers stressed and maybe encourage other drivers to take dangerous decision like trying to pass the HGV without having a clear view. Autonomous HGVs that will cause long queues and dangerous situations will have a harder time being accepted by the society. Therefore, situations like these are in need of improved communication. As stated earlier, there is no accident data involving AVs and no one can predict the future. However, it is likely that long haul HGVs will be automated before vehicles that drives in urban areas which make the scenario with the on-ramp likely to occur. As time proceeds and development of AVs moves forward, it will become clear what critical situations that actually will occur.

6.2 Information to communicate

To get a better understanding of the scenario and the critical situation, a timeline was created, see section 4.2.1. The timeline was then analysed carefully to understand what is going on and why. As a human driver, intentions can be shown by placing the vehicle in a specific position. Take a lane change scenario for example: if a driver intends to change lane, it is sometimes possible to anticipate this action just by observing the position of the vehicle within its lane even if the turn signal has not been switched on yet. However, if the vehicle was to be autonomous, other road users may have the attitude that the HGV can wait since they know that it will always yield to avoid accidents. As mentioned in section 2.3.1, there are several driving styles that relates to dissociative, angry and risky behaviour. These driving styles need to be taking into account when designing light communication for AVs. To change other drivers' mind-set, the HGV needs to show that it is positioned in a critical situation. It must also communicate it has to merge and that the situation is urgent.

Compared to a human driver, an AV will always have the route planned and will therefore also know when actions, like turning or braking, will take place. This gives the AV the possibility to pass on this information to other road users as well. If other road users are aware of the AV's intentions, they can act accordingly. However, the AV should not encourage other road users to specific actions. Instead, the AV should communicate its own intentions and let the other road users decide how to act safe, similar to the AVIP-system [41] and Volvo 360c concept [43] mentioned in section 2.5.

The user needs for the signal were established from the the timeline created in 4.2.1 by analysing what is happening and why. Another way to find user needs is to identify and interview potential users. According to Ulrich and Eppinger, between 10 to 50 interviews would be enough to find the most of the user needs [49]. Due to the limited time frame, it was not possible for the project to identify and then carry on with that many interviews. Hence, there is a possibility that undiscovered needs exist.

6.3 The final concept

The final concept was developed for a certain scenario involving an HGV wanting to merge on a highway with high density traffic. Even if the chosen scenario is very specific, the developed concept has potential to be useful in other similar situations for example ordinary lane changes or other situations involving an HGV intending to turn. Furthermore, the added turn signal lamps can also be used to better communicate other information. For example, the added LED-strips can help to better visualise and communicate hazard warnings. As seen in Figure 5.5, the proposed concept can also be used to communicate other intentions in accordance with for example the AVIP-system [41] and Volvo 360c concept [43] mentioned in section 2.5.

During the concept evaluation sessions, it could be concluded that changing colour of the turn signal would lead to confusion. Colours in traffic are strongly associated with certain actions, for example, red often indicates braking or encourage drivers to stop while amber often implies that a vehicle is about to do a turn. Due to that and the regulations mentioned in section 2.6, it was decided to keep the amber colour of the signal.

Many of the methods used to generate, evaluate and rank the concepts could not prevent subjective thoughts. To decrease the influence of subjectivity, external people were invited to participate in evaluation- and ranking sessions. The people invited were mostly people that had some sort of expertise within the area. To get a more trustworthy result, more people with different backgrounds and experiences could have been invited.

6.4 Verification test

The test phase of the concept gave valuable insights in both the concept and the configuration and development of the user test itself. The goal with the VR-testing was to evaluate if the proposed concept did communicate its intended information and if people understood the information without someone explaining it to them. The test scenario and environment were designed with as much detail as possible within the time frame to make it feel real. When interviewing the test subjects, it became clear that they noticed small differences between the three scenarios not related to the light communication that influenced their decision making. The relative position of the HGV compared to the test vehicle was for example mentioned by several participants as a vital cause of their actions. The two separate on-ramps had different topographies that resulted in a non-consistent behaviour of the HGV and the other vehicles between the scenarios. As seen in table 5.2, the participants had a higher tendency to drive as they would in reality in scenario 2 and 3 compared to scenario 1. In scenario 1, the full length of the on-ramp was for a brief moment visible by the test subject which in several cases resulted in them giving way to the HGV early in the merging process. This is not what was intended with the testing as it does not fully represent the chosen scenario where the ability to give way to the HGV should be closer to the end of the on-ramp. However, there is also a difference in how close to real life the participants claimed to behave between scenario 2 (55%) and 3 (73%) even though these scenarios where identical in environment and HGV driving behaviour. The only thing separating the two was the difference in driving by the test subject and the added LED-strips to the HGV. When asked what the participants would have done differently in reality, almost all answered that they would have let the HGV merge earlier. This indicates that there might be a correlation between the added LED-strips and the participants' willingness to let the truck merge earlier which should be investigated further.

Several participants also mentioned that the lack of rear view mirrors and the limited peripheral vision of the headset contributed to not getting a complete view of the surrounding traffic conditions. As no vehicles were place behind the test subject, a decision to brake and let the HGV merge might have been easier to make in the simulation compared to reality.

Only 18% of the participants mentioned that they noticed the different flash sequences which show that they paid little attention to the turn signal. When asked specifically about the new concept and its different stages after the fourth test drive, the overall feedback was positive and several participants mentioned that they thought it would be helpful in difficult traffic situations. However, the question of why the participants did not notice the change in the three test scenarios still remains. There are of course several potential answers to this question and further investigation is needed to determine the real cause of it. It could be that a turn signal is already well known and once a driver sees it, it is immediately understood and the driver shifts its attention to other surrounding factors while preparing to move out of the way. The light sequence in the test scenarios were several seconds long. Based on observations, the test subject did not spend that much time looking at the lights. To better evaluate the impact of the new flash sequences, it could be a good idea to test them individually.

The added LED-strips was noticed by 73% of the test subjects which all expressed that they were clear and understandable while some also mentioned that they were a bit stressful. When designing the LED-strips in the simulation, little effort was made to test different sizes and light intensities which may have impacted how stressful and aggressive they were perceived. For further development, the effects of different sizes and intensities should be investigated. Another reason why the LED-strips may come off as stressful could be that the turn signal of the HGV was the only light signal present in the simulation. No other vehicle had functioning position lights which may have depicted the LED-strips as disproportionately strong.

6.5 Environment and ethics

There are several arguments that encourage the development of AVs. Some examples are the increased safety, more efficient fuel consumption and lowered costs. Increased safety can be achieved since an AV will probably be better at avoiding accidents than human drivers. Reducing the risks of accident also open up to other opportunities like the possibility to choose lighter and more climate friendly materials when producing the vehicles [63]. AVs also allow platooning since they can be connected which will lead to a more efficient fuel consumption due to aerodynamics [64]. It is also known that a driving style that includes a lot of acceleration and/or braking is less fuel efficient. The purposes with the developed concept is to increases the chances of safe and smooth lane change with minimal adaption to other road users. If this is successful, it will also help to reduce fuel consumption.

Even if AVs seem to be positive in many ways, there are some that are not completely convinced. AVs will allow kids, old and disabled people to transport themselves, which may lead to an increased number of trips that would not have been done otherwise [65]. With that in mind, could it also be possible that the number of transports with HGVs will increase too? An autonomous HGV will remove the costs for a driver, it will also allow the HGV to drive around the clock since resting and other breaks will be unnecessary.

6.6 Future recommendations

This project has mainly been an exploratory work where the need for additional intelligent light communication for AVs has been investigated. In addition to identify critical scenarios, several concepts have been evaluated and tested. For continued research within the subject, it is recommended to further explore scenarios where new light communication can be helpful and where the proposed concept can be utilised. It is also important to investigate legislation and regulations further as the proposed concept do not fully comply with today's regulations. It is believed that changes in the regulations of today could be necessary to better suit a society with AVs which is why little consideration of this subject has been made.

The proposed concept needs to be tested more, preferable in focused user studies where the effects of the individual phases are investigated. The conducted VR-test gave some initial insight and comments supporting the need for better light communication when AVs change lane in mixed traffic environments. However, better understanding of how people intuitively interpret the light sequences and what actions that entails is needed. As mentioned in section 5.3, the proposed solution is prepared for additional communication in line with concepts and solutions mentions in section 2.5. It is recommended to explore this area even more and consider opportunities of communicating information to for example VRUs in front of the HGV.

Further development of the proposed concept considering decision making, exact light intensities and flash frequency are also recommended. In current state, an actual algorithm of how and when the three phases should be initiated is not in place. Investigations of how decisions shall be taken regarding when a situation goes from normal to critical also needs to be made. For implementation of the solution on current and future vehicles made by Volvo Trucks, investigating light technologies is recommended to choose suitable lamps and LED-arrays. Development of attachment components, electronics and sensor equipment is also needed.

7 Conclusions

There were three questions about how AVs can communicate information to other road users in order to safely function in mixed traffic situations that needed to be answered in this project:

1. When should the information be communicated?
2. What type of information should be communicated?
3. How should the information be communicated?

For the question of *when* information is needed, it could be stated that situations which can result in total stops for the HGV are of high relevance, for instance in situations where other road users take for granted that the HGV will stop and yield for them.

When discussing *what* type of information that should be communicated, it was specified that the communication should indicate urgency and that the situation is critical for the HGV. Communication that encourage other road users to certain actions should be avoided, instead the intentions of the HGV should be shared. For how the communication should be shared, a concept was developed. It was clarified that bigger light sources and a change of flash frequency for the lights could modulate urgency and the critical level for the situation.

It is also stated that the final concept will need further development both from a user experience perspective and technical perspective, including algorithm development, options for assembly and manufacturing. The sessions held during the concept development phase showed that a change of the flash sequence communicated urgency and/or criticality while changing colour seemed confusing. Even if people noticed the turn signal during the VR-test, it could also be stated that people seemed to give a lot more attention to how the HGV was positioned. Further testing of the proposed solution is needed, preferably in more isolated tests, where each phase is evaluated separately.

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Appendix A(-D)
Co-drive interview questions

Hur länge har du kört lastbil? / For how long have you been a truck driver?

Hur länge har du jobbat på GLC? / How long have you been working at GLC?

Hur ser en typisk arbetsdag ut? / Describe a typical work day!

Kör man samma lastbil varje dag eller byter man? / Do you drive the same truck every day?

Om olika lastbilar, vilka lastbilar föredrar du och varför? / If different trucks, which one do you prefer, and why?

Vilka områden kör du, är det landsvägar, motorvägar eller stadsmiljö? / In what areas do you drive? Rural roads, high ways, urban environment?

Har du någon gång varit med om en olycka eller nära en olycka? Vad hände? / Have you even been involved, or close to involved, in an accident? What happened?

Vilke situationer i trafiken tycker du är jobbiga/svåra? / What driving situations do you think are more challenging?

Vilka trafikanter behöver du oftast se upp för och varför? / What type of road user are most important to look out for? Why?

Hur skiljer det sig att köra lastbil och personbil? / What differs driving a truck from a car?

Upplever du några skillnader mellan hur andra uppfattar lastbilar kontra personbilar? / Do you see any differences between how others perceive trucks compared to cars?

Brukar du söka ögonkontakt med andra trafikanter? / Do you seek eye contact with other road users?

Hur kommunicerar du med andra i trafiken? I vilka situationer? / How do you communicate with other road users? In what situations?

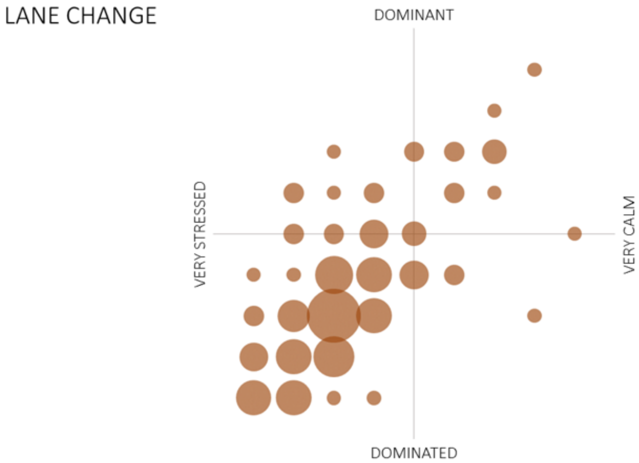
Upplever du att det kan uppstå missförstånd med kommunikationen? / Do you feel that communication misunderstandings can occur?

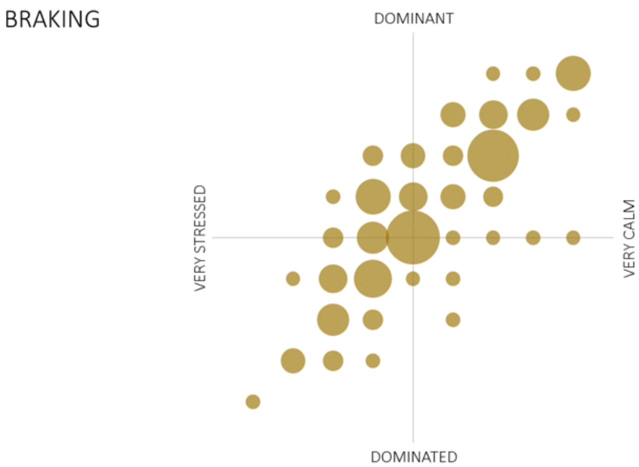
Använder du några assistantfunktioner? Varför? Vilka? / Do you use any assistance systems? Why? Which?

Känner du att du saknar några funktioner med lastbilen? / Do the truck lack any functions that you would like to have?

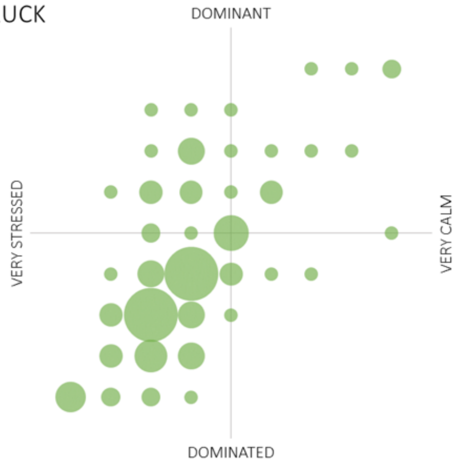
Hur tycker du sikten är i lastbilen? / What do you think about the visibility from the cab?

Appendix B(-D)
Survey results

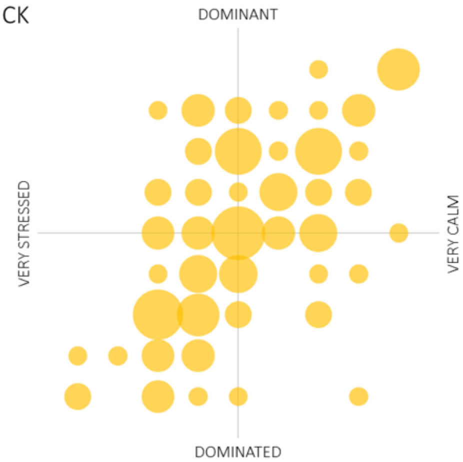




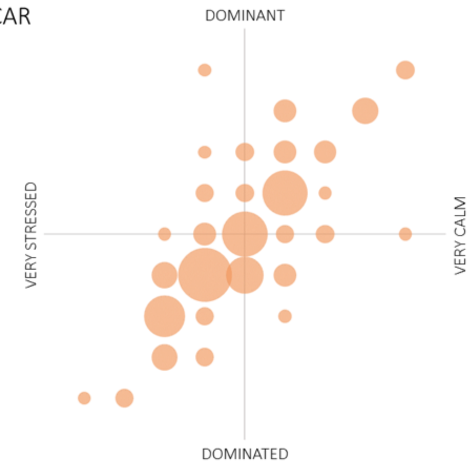
RIGHT TURN - TRUCK

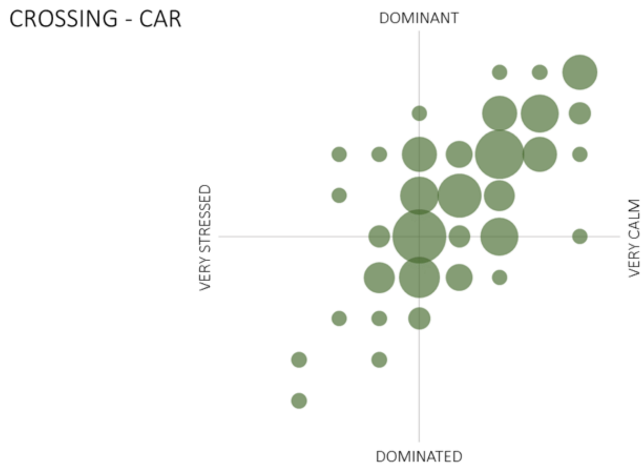


CROSSING - TRUCK



RIGHT TURN - CAR




CROSSING - CAR
DOMINANT
VERY STRESSED
VERY CALM
DOMINATED

Appendix C(-D)
Concept evaluation feedback

Question / Concept	A					C					D					E				
Q1. How well does it communicate that the truck WILL merge? (1-5)	3	5	1	2	3	4	5	4	4	4	3	5	1	3	5	3	3	2	3	3
Q2. How well does it communicate WHEN the truck will merge? (1-5)	1	5	3	2	3	2	5	3	4	3	4	5	2	4	4,5	3,5	4,5	2	2	4
Total Q1	14					21					17					14				
Total Q2	14					17					19,5					16				
TOTAL OVERALL	28					38					36,5					30				
Comments	- Hard to see the chane in stages - Clear that it want to change lane but not that its critical - Several did not see difference compared to current solution - Not sure what the countdown is for - May be good idea to increase frequency to indicate urgency - Would have been better if bigger					- As a driver you understand that you're in a bad position - Prefer normal frequency, this can be percieved as annoying - It has identified that I'm driving in the rear - Can identify different stages but they are hard do interpret - Frequency change is good. Even if countdown fails, double flash will be good - Is countdown distance or seconds? Would be worried if its seconds - Puts lots of pressure on driver - Hard to distinguish the countdown - Change from single to double blink is clear - Lights not flashing might be broken - Not totally clear what countdown is for - Very visible and clear - Goes from a little to more. Interpret it as first show intention, then follow through on it					- Projection do not work well in daylight - Additional reflections - Would dislike this very much - Would block my view - Creates more danger than it helps - Feels scary - Understand that it's ponted at me but not what it wants - Feels more like I'm doing something wrong - Countdown feels more lika a loading sequence - Probably hard do develop, different angels and speed - Very clear, you don't miss it. - Dramatic, threatning					- Would be better if it was static before it starts over. So static when turning - Clear that something is gonna happen, but not whats gonna happen - More of a buffering or processing than a countdown. - What happens if one bulb goes out? - Might be confusing first time. Not second - More unclear. Feels more like a level of something - Mostly feels like something thats filled up - Better if horizontal - Not as clear as the circle - Not optimal for aerodynamics - Calm and nice signal. Not aggressive - Hard to say how clear it is when looking straight ahead				

Question / Concept	G					Hb					Hr					J				
Q1. How well does it communicate that the truck WILL merge? (1-5)	5	3	5	4	4,5	3	1,5	2	2	3	4	3	3	2	5	3	5	2	5	4
Q2. How well does it communicate WHEN the truck will merge? (1-5)	5	3	3	5	4,5	1	5	3	3	3	4	5	3	4	5	3	5	2	2	4
Total Q1	21,5					11,5					17					19				
Total Q2	20,5					15					21					16				
TOTAL OVERALL	42					26,5					38					35				
Comments	- Connecting to emergency lights, something is happening - Crystal clear when going over to static light - Very easy to understand - Problem for epeleptic people - Static do not always indicate wanting to move - Turning is connected to dynamic lights - Confusing in the end - Not really clear when it ends - Not as clear as in C that I'm the problem - Indicates that the side of the vehicle is important - Indicates more urgency than the double flash - Feels much more urgent, but not in a dangerous - Working with frequency feels like a good idea. Especially if the intensity can change as well. - Turning lights higher up on the truck feels like a good idea - If the gradual transiton between slow and fast is designed in a good way, indicating WHEN turn could be very good					- Think the truck becomes more autonomous with the blue light - Could be moving towards a state - Unclear what blue means - Something is gonna happen. Not sure what. - Blue is some kind of calm state - Feels less ugrent since not flashing - Blue feels calm - Would be better if flasing - Blue could mean the truck is going to start driving - Don't know what the blue means - Causes more confusion					- The more red, the closer to "now I'm going" - Something critical is coming. - Would not be supprised if its turning when fully red. - Could also be stopping - Feels more important than the blue - Not all clear that it has to do with turning - Would be more clear if they flash - There's some sort of danger along the car - Communicates danger more than "I'm turning" - Connects it to some sort of emergency - Like that its along the full side - Better to work with frequency than color.					- This was tricky - Moving to fast between stages - I dig this one. Feels much clearer - Could fill up twice fast first, and then once slow when turning - Hard to get through business - Aerodynamic issues - Does not feel urgent - Would percieve it as some after market gimmic - Feel like some sort of toy - Crystal clear that it wants to turn - Too small area thats filled - Might be better to fill it vertically - Could also be a signal to the car driver to change lane - Encourages the car driver to get out of the way				

Appendix D(-D) Concept test interview questions

Before testing

Hur länge har du haft körkort? Vad har du för körkort? / For how long have you had a driver's license? What kind of license?

Hur ofta kör du bil/annat fordon? / How often do you drive?

Ålder? / Age?

After VR-playtime

Hur upplevde du simuleringen? / What did you think of the simulation?

Kändes den verklig? / Did it feel real?

Hur kändes bilen och dess kontroller? / How did the vehicle feel and behave?

Kände du av något illamående? / Did you feel any motion sickness?

Questions after each scenario

Varför släppte du in/inte in lastbilen? / Why did/didn't you let the the truck merge?

Hade du väntat lika länge med att släppa in lastbilen i verkligheten? / Would you have waited this long to let the truck merge in the real world?

Hur benägen tycker du att du var att släppa in lastbilen? (1-10) / How inclined to let the truck merge did you feel? (1-10)

Hur kritiskt upplevde du det i stunden att det var för lastbilen att byta fil? (1-10) / How important did you feel it was for the truck to change lane? (1-10)

På vilka sätt visade lastbilen sina intentioner? Hur säker är du på det? (1-10) / In what ways did the truck show its intentions? How sure are you of that? (1-10)

Hur bra tyckte du lastbilen informerade om NÄR den tänker börja filbytet? (1-10) / How well did you feel the truck communicated concerning WHEN it would initiate the turn? (1-10)

After testing

Upplevde du någon skillnad i hur lastbilen betedde sig mellan testen? / Did you perceive any difference between the three tests regarding the behaviour of the truck?

Märkte du av någon skillnad i hur bilarna blinkar? / Did you notice any difference between how the truck uses its turn signal?

Vilket av beteendena tycker du är bäst? Varför?/ Which behaviour do think is best?

Skulle du vilja ändra någonting med simuleringen, miljön eller koncepten? / Would you like to change anything regarding the simulation, environment or concepts?

Har du någon kommentar eller något du vill tillägga? / Do you have any comments or something to add?

Fourth test

Hur upplevde du ljussignalen? / How did you perceive the turn signal?

Hur kritiskt upplevde du det i stunden att det var för lastbilen att byta fil? (1-10) / How important did you feel it was for the truck to change lane? (1-10)

Hur bra tyckte du lastbilen informerade om NÄR den tänker börja filbytet? (1-10) / How well did you feel the truck communicated concerning WHEN it would initiate the turn? (1-10)