CHALMERS
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Cockpit Layouts for Different Transport Segments

Master's thesis in Product Development

Julius Sylvén & Kristín Lóa Viðarsdóttir

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

MASTER´S THESIS 2016

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Development of future truck interior increasing visibility

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Cover: Illustration of future cockpit layout for long-haul and city distribution

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ABSTRACT

In order for Volvo Group Trucks Technology to keep their competitive edge on the global truck market, new technologies need to be implemented in a clever way. New technologies might enable trucks to operate in a safer manner, which is incentive enough to conduct research on how and what to be introduced in future trucks. The thesis covers the development of future cockpit layouts for two different transport segments; long-haul and city distribution. The focus is on improving the vision of the truck surroundings as well as the position of the visual in-vehicle information in order to increase safety and comfort for the driver. The study identifies the differences between the two market segments that need to be taken into consideration when developing the cockpit layouts since the trucks are used for different applications.

The development process consisted of background research, requirement specification, idea and concept generation, concept screening and final concept development with evaluation. Engineering methods were used in each phase of the development process. To gather all necessary background information; literature study, benchmarking, observations and interviews with 10 experts in different areas were conducted.

Two different final concepts were developed, one for each transport segment. These concepts were illustrated with CAD modelling and tested against various ergonomics requirements. A questionnaire was administered to evaluate the final concepts.

The final concept for the city distribution truck had numerous changes compared to the cockpit layout of the current cab. In order to increase the direct vision all six mirrors were removed, the instrument panel and side windows were lowered and the windscreen was extended downwards. The mirror views are shown in displays instead, via Camera Monitor System technology, providing better indirect vision. The visual in-vehicle information is placed close to the drivers' central field of view without any obstructions from the steering wheel.

The final concept for the long-haul truck resulted in a completely different layout. The direct vision was improved by reclining the windscreen, providing partly transparent A-pillars and doors as well as removing all mirrors. The new position of the mirror views results in better indirect vision that is closer to the driver's line of sight. The visual in-vehicle information is also presented in a new way with Head Up Display technology and Touch technology.

The outcome of the thesis is two feasible concepts suitable to implement in the future Volvo trucks for two different transport segments. Both concepts were found to increase the vision of the surroundings, provide feasible placement for visual in-vehicle information and be well adapted for their respective transport segments.

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Julius Sylvén and Kristín Lóa Viðarsdóttir, Gothenburg, June 2016

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ABBREVIATIONS

CMS = Camera Monitor System

CRT = Cathode Ray Tube

DID = Driver Information Display

ECU = Electronic Control Unit

FCW = Forward Collision Warnings

FE = Medium Duty truck. FL being the smallest (Forward control Low entry)

FPM = Flat Panel Monitors

FH = Forward control High entry

GTT = Group Trucks Technology

HD = High Definition

HMI = Human Machine Interface

HUD = Head Up Technology

HVAC = Heat Ventilation Air Conditioning

IC = Instrument Cluster

IP = Instrument Panel

LCD = Liquid Crystals Display

LCS = Lane Changing Support

LED = Light Emitting Diodes

OLED = Organic LED

SID = Secondary Information Display

TFT = Thin Film Transistor

1 INTRODUCTION

This document forms the report of the master thesis performed at the Cab Division at Volvo Group Trucks Technology (GTT) in Gothenburg, Sweden. The thesis is of an exploratory nature, where the task provided by Volvo was to investigate possible future cockpit layouts for two different transport segments. The thesis work is part of the Product Development master's program at Chalmers University of Technology. The project was executed during the spring of 2016.

One of the many challenges that the employees at Volvo Trucks are facing daily, is how to keep the competitive edge on the market that they possess today. Part of the challenge is to keep up with the rapid evolution of technology solutions. The truck industry has longer development loops compared to the car industry. That is part of the reason why trucks in general do not have as many driver supporting features as cars. This statement gives rise to the question as to whether the current truck layouts are indeed best adapted for significantly different types of transport or if they in fact are a result from a traditional industry. The possibilities with new technologies should facilitate making things in a different way.

1.1 BACKGROUND

For any company selling trucks today, the global competition is significant. There are many players on the market so in order to be successful in selling trucks a company has to offer something that the competitors do not. This is something Volvo Trucks understands very well and the company is therefore among the top leading truck manufacturers in the world. Needless to say, this requires major investments in continuous improvements.

To be able to meet the market needs, Volvo has divided the market into different transport segments based on different operational requirements. The three main transport segments are city distribution, long-haul, and construction (Volvo GTT, 2013).

One of the many important aspects of a truck is the cab where the truck drivers spend most of their working hours. Therefore, in order to have efficient and satisfied truck drivers, the cab layout needs to be well designed from an ergonomic perspective and according to the needs within the main transport segments. Often there is a lack of truck drivers and in order to attract the best drivers, a visually appealing driver environment and ease of use are important aspects. When driving a truck, having adequate vision of what is happening in the vehicle's surroundings and getting continuous visual feedback of the vehicle status are of utmost importance. Improving the vision for the driver or the way visual information is presented to the driver could mean an improvement in traffic safety and comfort for the driver. These improvements fit well with Volvo's core values: safety, environmental care, and quality (Volvo Trucks, 2011a).

1.2 PURPOSE

The purpose of this master thesis is to suggest and evaluate cockpit layouts for visual information for two different transport segments, long-haul and city distribution. The visual information includes both vision of the surroundings and visual in-vehicle information presented to the driver. This is done in order to improve cost, safety and comfort.

If the cockpit layout for all visual information is better adapted to future and functional needs, the truck drivers are going to be more satisfied, which in turn will give Volvo Trucks an increased competitive edge.

1.3 OBJECTIVE

The objective is to deliver CAD models of new cockpit layouts regarding the positions of visual information according to needs in two transport segments: city distribution and long-haul.

1.3.1 RESEARCH QUESTIONS

The research questions are as follows:

- How should visual information be positioned to increase safety and comfort for the driver?
- What are the differences between the two transport segments that need to be considered when developing new cockpit layouts?
- What measures in the development of new cockpit layouts can be taken in order to keep cost to a minimum?

1.4 LIMITATIONS

Since trucks consist of many parts clear limitations have to be set for the project. The thesis is limited to focus on concepts that support the driver in driving situations. This concerns the interior surrounding the driver seat, the indirect vision devices such as mirrors, and window openings which provide direct vision. This means most of the exterior and the areas used by passengers and for living in the truck are excluded from the project scope. The different truck markets around the globe have different user needs. In this study only the Swedish market will be taken into consideration. The authors, however, are of the opinion that the study is generally representative for other European markets where vehicles drive on the right hand side of the road.

1.4.1 TRANSPORT SEGMENTS

As mentioned in the background section, the three main transport segments are long-haul, city distribution, and construction. This thesis project is limited to include the first two transport segments. The construction segment was excluded since that requires off-road driving which is completely different from on-road driving. However, construction trucks are also used in distribution as well as in long-haul driving. Three different truck models are used for the city distribution today. These are Volvo FL, Volvo FE, and Volvo FM. However, the Volvo FE model will be the one used to represent the city distribution. The truck model used for the long-haul segment is the Volvo FH.

1.4.2 VISUAL INFORMATION

In this project both vision of the surroundings and visual in-vehicle information are in focus. The vision of the surroundings covers both direct vision and indirect vision. The direct vision is what is seen through the windscreen and the side windows. Indirect vision, on the other hand, is what is seen via indirect vision devices (Blomdahl, 2015). Mirrors and cameras are alternative solutions that provide indirect vision. Camera Monitoring Systems are promising for replacing mirrors. Focus is directed at where in the cabin the camera image should be placed. The placement of the cameras as well as what type of lenses the cameras should have, are excluded from the thesis scope and also the technology behind the image processing from the cameras. Hybrid systems, using both cameras and mirrors in parallel are not included in the project. The driving conditions can vary when driving, depending on what time of day and the weather conditions. The thesis focuses on one type of driving condition, which is driving in daylight with good weather conditions and no precipitation.

The visual in-vehicle information is split into three categories:

- **Primary information** (speedometer, fuel level, warning signals, fault messages)
- **Secondary information** (navigation, phone, audio system)
- **Warning systems** (Lane Changing Support (LCS), Collision Support Warnings (CSW))

The visual in-vehicle information was not specifically designed in order to fit the concepts of the layouts.

1.4.3 CAB COMPONENTS IN SCOPE

In order to provide vision of the surroundings and visual in-vehicle information the following solution areas are included in the scope of the thesis among all of the many components inside the cab, see figure 1. These components might be affected when visual information and vision are provided as a result of this thesis.

- Steering wheel
- A-pillars (between windscreen and side windows)
- Instrument panel
- Windscreen
- Side windows
- Doors (coverage of sheet metal and interior panels)

- Indirect vision devices (mirrors and camera system)
- Instrument Cluster (IC) (providing primary information)
- Secondary Information Display (SID) (providing secondary information)
- Active warning system

FIGURE 1: ILLUSTRATION OF THE COMPONENTS IN THE CURRENT VOLVO FH INCLUDED IN THE SCOPE

2 METHODS

This chapter defines the methods used in the thesis. The project process is illustrated in the first section giving a general overview of the project. Then the following sections describe each method in general as well as how it was implemented in the project.

2.1 PROJECT OVERVIEW

An illustration of the project process and the methods used in each phase can be seen in figure 2. The project consists of five phases. First, all necessary information is gathered with background research and all requirements needed were identified. When the requirement list had been compiled, ideas and concepts were generated. Next, the amount of concepts was reduced, resulting in two final concepts which were evaluated in the last phase. The methods for each phase are described in following section.

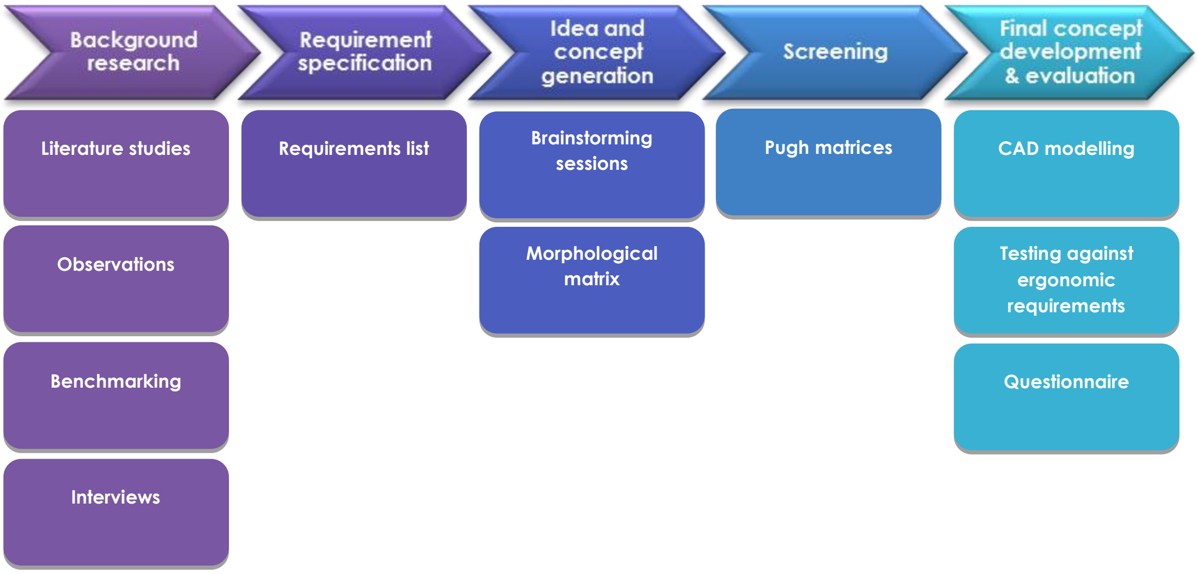

FIGURE 2: THE PROJECT PROCESS AND METHODS USED

2.2 LITERATURE STUDIES

Literature studies are a productive technique to gather external information. Literature that has been published contains for example; magazines, reports and journals. In order to gather information from literature that has been published, an internet search is an effective way (Ulrich & Eppinger, 2012).

Literature studies are conducted to get necessary information for the project. In order to gather necessary background information, existing information inside Volvo Trucks was reviewed. The background information supplied by Volvo consists of previous master theses, PhD theses, books, articles, presentations and reports. The internal information was divided into areas of interest; direct vision, indirect vision, visual in-vehicle information, aspects of city driving, and aspects of long-haul driving. External literature, such as books, reports and articles, was used to get information about relevant theories of ergonomics, methodology and existing solutions.

2.3 BENCHMARKING

In order to get the new product successfully on the market, it is important to understand the products of the competitors. Benchmarking is used to gain an understanding of existing products which can also provide valuable ideas for the new product and the development process (Ulrich & Eppinger, 2012). Information about available solution alternatives was studied and benchmarked to achieve knowledge about trends and new ideas to use as input. Five vehicle segments were benchmarked; future trucks, passenger cars, sports cars, vans and pickup trucks. The benchmarking was conducted using an internet search.

2.4 OBSERVATIONS

Observations are a qualitative method for collecting information. Researchers use all of their senses to explore the current field and may use multiple methods for gathering data such as writing field notes and taking pictures (Cohen & Crabtree, 2006)

Observations of the trucks were performed by the authors at Volvo GTT, in order to fill in any gaps of information and to achieve an understanding of the current cab layouts. The Volvo FE truck model and the Volvo FH truck model were both observed for the city driving and long-haul driving respectively. The observations were performed both during driving and when the trucks were standing still.

2.5 INTERVIEWS

Interviews are one of the most used techniques for gathering qualitative data. They can provide valuable knowledge about views and experiences of the participants. There are three different ways of conducting an interview. It can either be conducted as a structured, semi structured or unstructured interview. Structured interviews are administered questionnaires where all questions have been decided on beforehand, leaving no room for follow-up questions. Semi-structured interviews have several predetermined questions for the areas to be explored but also give the interviewees possibility to explain and reflect on more details. Unstructured interviews, on the other hand, are performed without having any pre-defined questions and the interview has little organisation. When using interview as a method, it is important to tape record and transcribe the interview afterwards in order to have a permanent record of what was said (British Dental Journal, 2008).

Ten interviews were conducted in order to attain necessary and more specific information not found in the literature. Experts inside Volvo, responsible for each of the main competences involved in the cockpit environment and its development, were interviewed individually either face-to-face or via audio conference. Each interview lasted for one hour and different questions were asked depending on the interviewee´s field of expertise. The experts possess valuable information since they have become internal specialists in their respective fields. This is also the case for some key development functions that possess important information for the project. All interviews were recorded and transcribed with permission from the interviewees.

2.6 REQUIREMENTS LIST

When developing a product, it is important to set requirements in order to know what the solution has to fulfil before developing one. Necessary requirements should be set before entering the concept phase where the concept solutions are evaluated against the requirements. The key is to set requirements that are easy to understand, measurable and verifiable in order for the different development functions to agree on what needs to be developed (Volvo GTT, 2015).

A requirements list was compiled with a description of the requirements. The list included value and justification for each requirement as well as indication for the requirements based on regulations.

2.7 BRAINSTORMING

Brainstorming is an internal type of search that uses personal knowledge to create ideas. It is often the most creative part of the development process and can be performed individually or in a group of people. It is important during brainstorming that no critique is allowed and all ideas are welcome (Ulrich & Eppinger, 2012).

To generate ideas for new cockpit layouts, two brainstorming sessions were conducted. The first session was performed by the authors and the second session with seven internal Volvo experts representing different competences and four other master thesis students at Volvo. During the brainstorming sessions, unconventional thinking was encouraged and no critique of ideas was allowed.

2.8 MORPHOLOGICAL MATRIX

Morphological matrix is a simple and powerful combinatorial method. The principle with the Morphological matrix is to generate concepts by combining sub-solutions alternatives. A Morphological matrix covers all possible solutions for the given sub-solutions and from this new combinations can be discovered that have not been considered before. Only sub-solutions that match together should be combined (George, 2012).

In order to generate more concepts, a Morphological matrix was used. Three morphological matrices were created, one matrix for each focus area. Sub-solution alternatives for direct vision, indirect vision and visual in-vehicle information were then combined differently into many total solution concepts. Finally the matrices were merged into one big matrix, creating full solution concepts covering all focus areas.

2.9 PUGH MATRICES

The Pugh matrix is a comprehensive and effective way to narrow the number of concepts quickly. All the relevant requirements are listed in rows, while the concepts are listed in columns. With one given concept as a reference, plus one (+1) or minus one (-1) signs are given for each requirement and concept depending on whether the concept fulfils the requirement better or worse compared to the reference concept. Zeros (0) are given to those concepts that fulfil the requirements equally effective as the reference concept (Ulrich & Eppinger, 2012).

The Pugh matrix was used for screening the concepts gathered previously in the idea and concept generation phase. Two Pugh matrices were created, one for each segment. The requirements gathered in the requirement specification phase were rephrased and listed in the rows of the Pugh matrices. All the concepts were then placed in the columns and the current layout for each transport segment used as a reference concept. Since all requirements were not of equal importance, a weighting factor was added on each requirement. The weighting factors varied between the two Pugh matrices due to the different needs of the two transport segments.

2.10 CAD MODELLING

The surface modelling in Catia V5 was used to illustrate the final concepts and facilitate final evaluation. Catia V5 was used to make the models since it is one of the software programs used within Volvo. This makes it possible for Volvo to modify and use the models later. It is also a more cost efficient way to illustrate concepts rather than building prototypes.

2.11 TESTING AGAINST ERGONOMIC REQUIREMENTS

The CAD models of the final concepts for both segments were tested against ergonomic requirements. This was done by positioning a manikin, which is a computer model of the human body, in the driver's seat. The manikin that was used was the average male (M50) which has stature of 180.3 centimetres and weighs 90.6 kilograms, illustrated in figure 3. This manikin was used to test two different ergonomic requirements. The first one to be implemented was a knee clearance model. This is a combination of knee positions of many drivers put together as two surfaces in a CAD model (Martina, 2011a). This model was placed together with the manikin in the concept in order to test if the layouts provide the driver with the minimum space needed for the knees while driving. Also,

FIGURE 3: MANIKIN USED IN TESTING
(Volvo GTT, 2016)

detection cone model was implemented in the same fashion as for the knee clearance. The detection cone is placed in front of the manikin´s eyes to represent the user's field of vision (Martina, 2011b). This is done for testing visual signals that need to catch the driver's attention, located in the instrument cluster, are within this 30 degree cone representing the user's field of vision.

2.12 QUESTIONNAIRE

For collecting information from individuals, a questionnaire, which is a predefined list of questions, can be conducted. The questionnaire can consist of two types of questions, closed-ended and open-ended questions. In the closed-ended questions the participants can select between different predetermined responses. The open-ended questions require more effort from the participants since they need to answer the questions in their own words (Research connection, 2013).

A questionnaire was conducted in order to evaluate the final concepts. The questionnaire was sent to experts inside Volvo, involved previously in the thesis work. The questions required both grading on a scale and an open-ended answer.

3 THEORY

This chapter describes the theory that, first, is needed in order to fully understand the scope of the project, and, second, adds new knowledge to this field of research. First both transport segments included in the scope are described and compared. The second section describes the different components of the current cabs. Next, all visual information and cognitive ergonomics are explained. The last section presents promising new technology for future trucks.

3.1 TRANSPORT SEGMENTS

As mentioned in the background section, there are three main transport segments defined by Volvo; long-haul, city distribution and construction (Volvo GTT, 2013). These transport segments are illustrated in figure 4. The thesis will focus on the city distribution and the long-haul since these are two transport segments with vastly different needs and uses. Both the long-haul trucks and the city distribution trucks are on-road driving while construction trucks are off-road driving which is completely different and therefore this segment is not included. Another important aspect is that both long-haul trucks and city distribution trucks are possible to use in construction (Volvo AB, 2013).

FIGURE 4: THE MAIN TRANSPORT SEGMENTS – LONG-HAUL, CITY DISTRIBUTION, AND CONSTRUCTION
(Volvo GTT, 2016)

3.1.1 LONG-HAUL TRANSPORTS

The long-haulage means driving long routes with few stops. While parked at truck stops, the driver sleeps in the back of the cab. During driving there is not much happening since most of the driving takes place on highways and motorways. On average there is more than 250 kilometres between delivery points. Examples of typical goods handled by long-haulage are consumer goods, transporting containers, timber haulage, petroleum, agriculture, and packages (Volvo GTT, 2013). Despite the long-haulage being a monotonous driving experience it is very important that the driver plans the route ahead to avoid traffic jams and unnecessary stops. The truck drivers for this type of transport segment drive on average 600 kilometres per day. They work 10.5 hours per day and sleep around 4 to 6 nights per week in the truck (Larsson & Lindström, 2014). The truck model that is predominantly used for the long-haul transports is the Volvo FH, see figure 5.

Volvo FH model

Volvo FH is a truck that is most suitable for driving long distances which puts up different requirements compared to trucks for city driving. The truck is fuel efficient, can maintain high average speeds, thanks to powerful engines, and can also support construction work (Volvo Trucks, 2011b).

FIGURE 5: THE VOLVO FH TRUCK
(Volvo GTT, 2016)

Four cab alternatives exist for the Volvo FH model; day cab, sleeper cab, large sleeper cab (Globetrotter) and extra-large sleeper cab (Globetrotter XL). The day cabs have storage compartments behind the seats and the sleeper cabs have a bed for overnight accommodation for one person. The large sleeper cabs (Globetrotter) have higher roofs than both the day and the sleeper cabs. The higher roof makes it possible for a person to stand in the truck and facilitate equipping the cab with a bunk bed. The extra-large sleeper cabs, (Globetrotter XL) provide even more height for more storage and more comfortable living accommodation for one or two persons (Volvo Trucks, 2011d).

3.1.2 CITY DISTRIBUTION TRANSPORTS

Examples of typical goods handled by city distribution are packages and post, waste and recycling materials and consumer goods. Characteristics of city distribution driving are low average speeds, frequent vehicle stops, frequent entering and exiting the vehicle and a high activity to adapt to the surrounding traffic environment. The distance between collection and delivery is around five kilometres on average, mainly in urban areas with good roads (Volvo GTT, 2013). The typical distribution drivers work in 9 hour shifts and drive around 250 km per day. They do not plan the route themselves but need to be able to re-plan the route in case of traffic jams (Larsson & Lindström, 2014). Three different Volvo truck models are used in the city distribution segment today. These are called Volvo FL, Volvo FE and Volvo FM. However, the Volvo FE model is the only one being considered in this project, see figure 6.

Volvo FE model

The Volvo FE is a truck model that meets the demands of city and regional distribution. Four different cab alternatives exist for the Volvo FE model; day cab, comfort cab, sleeper cab and low entry cab. All the cabs have the same height and width but vary in length. The day cabs are the most compact one, the comfort cabs have extra space for either a bed or a storage compartment, the sleeper cabs always have a bed and the low entry cabs have a

FIGURE 6: THE VOLVO FE TRUCK
(Volvo GTT, 2016)

lower instep, flat floor to facilitate passing through the cab and space for three persons (Volvo Trucks, 2011c).

3.1.3 DIFFERENCES BETWEEN TRANSPORT SEGMENTS

In order to develop new cockpit layouts for both transport segments it is important to consider the difference between long-haul and city distribution. Since the Volvo FE and the Volvo FH trucks are used in different applications the user and customer needs diverse. In order to illustrate the main differences between segments word clouds were used, see figure 7.

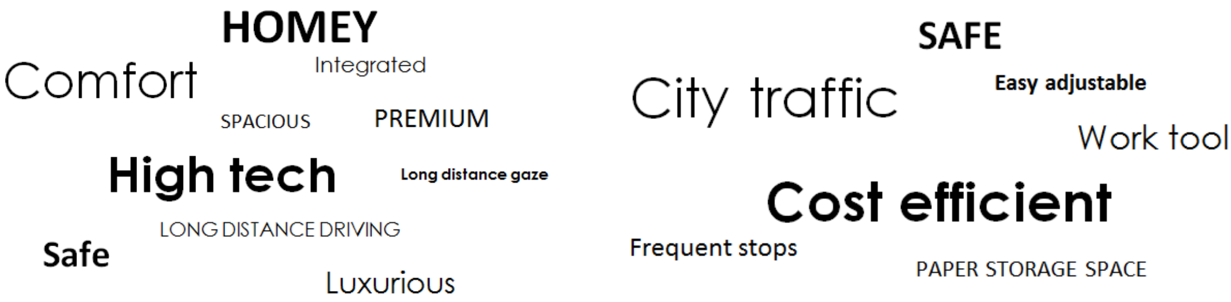

FIGURE 7: WORD CLOUDS – LONG-HAUL (LEFT) AND CITY DISTRIBUTION (RIGHT)

3.2 THE TRUCK CAB

The cab of the truck consists of different physical components which are necessary to know about in order to fully understand the essence of this thesis. As mentioned in the last section, the thesis considers two different truck models adapted for different transport segments. Consequently, this result in two different adapted cab layouts, see figure 8. However, the basic component definitions are still the same regardless of cab and transport segment. The following sections describe the main components and their respective functions.

FIGURE 8: INTERIOR OF DIFFERENT CABS – VOLVO FH (LEFT) AND VOLVO FE (RIGHT)
(Volvo GTT, 2016)

3.2.1 A-PILLARS

The A-pillars are located between the windscreen and the side windows on both sides of the cab, see figure 1 in section 1.4.3. Many electrical cables are placed inside the A-pillars. They also support the roof and provide the structure as an essential part for providing collision safety. However, the A-pillars are also known to obstruct vision in both cars and trucks, since the A-pillars create blind spots for the direct vision provided by the windows. The blind spots which the A-pillars create, require the drivers to move their head and body in certain driving conditions in order to see what is hidden behind the A-pillars.

In both Volvo FE and Volvo FH it is possible to see between the A-pillars and the rear-view mirrors since there is a gap between. However, it depends on the size and location of the driver, how much can be seen of the gap between the A-pillars and the rear-view mirrors.

3.2.2 INSTRUMENT CLUSTER

The instrument cluster is the collection of gauges and indicators usually placed behind the steering device in road vehicles, see figure 1 in section 1.4.3. Information placed in the instrument cluster is viewed through the steering wheel. In the current Volvo FH truck, the speedometer is located in the centre of the instrument cluster with information inside such as gear indicator and cruise control. A four inch display is located on each side of the speedometer, within the instrument cluster. One of the displays is an additional Secondary Information Display (SID) and the other one is a Driver Information Display (DID) including status indicators, driver support functions as well as the possibility to show up to three favourite indicators (Volvo Trucks, 2011f).

Next to the instrument cluster is a Secondary Information Display (SID) that is located beside the steering wheel towards the centre of the truck. This display shows different features, some of which are exterior vision, phone connectivity via Bluetooth, driver time feedback and GPS navigation (Volvo Trucks, 2011f).

3.2.3 INSTRUMENT PANEL

The instrument panel is a module which stretches between the A-pillars, see figure 1 in section 1.4.3. Because of the large nature of the instrument panel, due to the many functions included, it constitutes a big part of the interior's visual appearance. The instrument panel also acts as a cover for packaging several hidden functions provided by electronics, climate system and structural parts.

The instrument panel area facing the driver holds a multitude of controls and switches. These are visible and reachable according to where the instrument panel surface is positioned and where the actual driver has chosen to adjust seat and steering wheel.

3.2.4 STEERING WHEEL

Today the instrument cluster is viewed through the steering wheel and sometimes the steering wheel can be in the way and block the visual in-vehicle information inside the cluster. This can either be due to the fact that information gets blocked during turning when steering wheel spokes get in the way or that a driver of a certain size wants to keep the steering wheel in a position where part of the instrument cluster gets hidden.

The steering wheel also hosts a multitude of controls. Stalks are mounted on the steering column and several switches are normally provided on the steering wheel spokes as well as in the steering wheel centre. The good thing about these controls is that they follow the steering wheel adjustments and therefore can stay at hand for any steering wheel position. The switches provided on spokes and steering wheel centre can be seen in figure 9.

Due to this influence on reachability and visibility, the steering wheel becomes an important component to consider in order to improve driver ergonomics. The steering wheel for both the Volvo FH and Volvo FE trucks comes in two different diameters depending on the specification of the truck. For the Volvo FH the diameter is either 450 millimetres or 500 millimetres while in Volvo FE it is either 460 millimetres or 500 millimetres. Both the steering wheel for Volvo FH and for Volvo FE can be adjusted by the driver in order to create preferred positions. The steering wheel can be adjusted both telescopically and regarding angle. In the case of Volvo FH there is also an additional adjustment so that the steering wheel angle can be adjusted independently of position (Volvo Trucks, 2011e).

FIGURE 9: THE VOLVO FH STEERING WHEEL
(Volvo GTT, 2016)

3.3 VISUAL INFORMATION

Everything that the truck driver sees from the truck seat is considered as visual information and included in the scope of the thesis. This means the visual in-vehicle information and the vision of the surroundings, which can be split into direct and indirect vision.

3.3.1 DIRECT VISION

The direct vision is what the driver can see through the windscreen and the side windows when sitting in the driver´s seat, see figure 10. This means the driver has direct vision both forward and sideways.

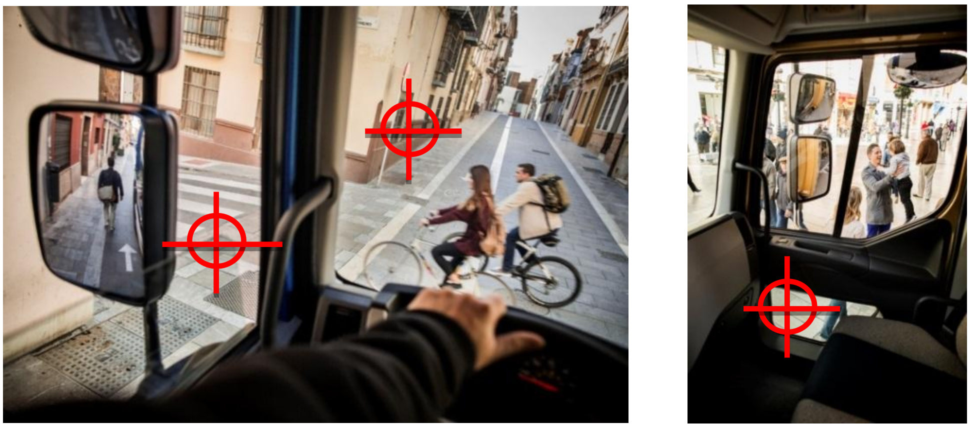

Figure 10: Illustration of what is considered to be direct vision
(Volvo GTT, 2016)

The forward vision through the windscreen is limited to the size of the windscreen and the sideways vision is also limited to the sizes of the side windows. On the current trucks the direct vision is partly blocked by six different types of mirrors and two A-pillars. An illustration of the direct vision can be seen in figure 11. The figure shows a top view of a truck which has been coloured green and the dark grey areas represent the direct vision seen through the windows. The A area in the figure is the direct vision seen through the windscreen and the B area is the direct vision seen through the side windows. The C area can be seen between the A-pillars and the rear-view mirrors.

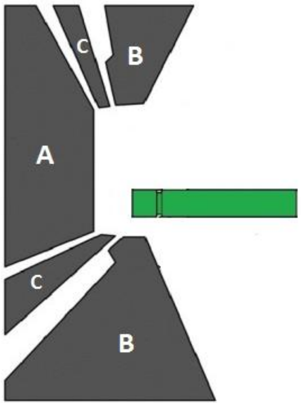

Figure 11: Top view of a truck - grey area represents the direct vision
(Volvo GTT, 2016)

The differences between the transport segments regarding direct vision are first of all the height differences. The Volvo FH is higher above the ground compared to the Volvo FE and, therefore, the driver is able to see further away. On the other hand the direct close-up vision in front of the cab is less in the Volvo FH compared to the Volvo FE due to the height. Another difference of direct vision between transport segments is that the Volvo FE has an extra side window on the passenger door, adding more direct vision to the side. This gives the Volvo FE driver an extra opportunity to detect pedestrians or bicycles. Sufficient direct vision to the side is essential, especially in city traffic, see requirements 2.9 and 2.10 in appendix J.

3.3.2 Indirect vision

Due to the obstructions of direct vision that cannot be avoided, additional vision needs to be provided by indirect vision, see figure 12. The indirect vision includes the views provided by all the mirrors and camera systems.

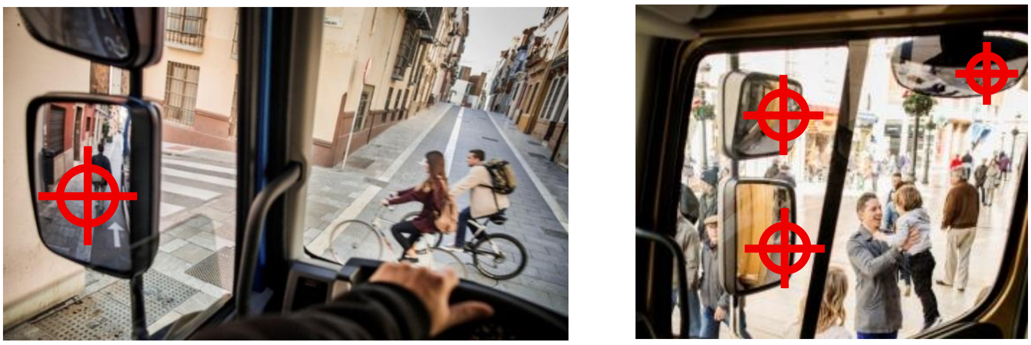

Figure 12: Illustration of what is considered to be indirect vision
(Volvo GTT, 2016)

Existing trucks have four different types of mirrors providing indirect vision, see figure 13 (Fagerström & Gårdlund, 2012). The four mirror types are:

- **Class II:** Main rear-view mirrors for vision far behind the truck.
- **Class IV:** Wide angle rear-view mirrors to cover blind spots closer to the truck including what is required in case of a folded vehicle combination of truck and trailer.
- **Class V:** Close-up kerb view mirror to show what is beside the truck on the passenger side.
- **Class VI:** Close-up front mirror to show what is directly in front of the cab.

Figure 13: Different mirror types on Volvo FH Truck
(Fagerström & Gårdlund, 2012)

An illustration of the indirect vision can be seen in figure 14. The figure shows a top view of a truck which has been coloured green and the grey areas represent the indirect vision provided by the mirrors. The grey areas are marked with class number of the mirrors depending on which mirror is covering the area with indirect vision.

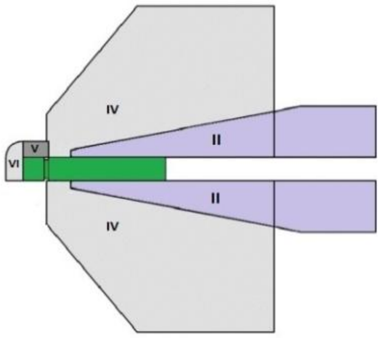

Figure 14: Top view of the truck - gray area represents indirect vision
(Volvo GTT, 2016)

There are some differences between the mirror placements between the two segments. In the Volvo FH truck the main rear-view mirrors are above the wide angle rear-view mirrors but in the Volvo FE truck the opposite applies: the main rear-view mirror is below the wide angle mirror. The reason for this is partly a matter of preference, but some logical reasoning can also apply. City distribution drivers are used to looking more downwards to see around the truck; hence it can be beneficial that their central field of view is lower compared to the long-haul drivers who are used to looking further away from the truck which means they can benefit from providing views at a higher location. Another difference is that the close-up front mirror is placed in the middle, in front of the windscreen in the Volvo FE truck but in the Volvo FH it is placed more to the right of the windscreen. This can also be derived from the fact that the close-up mirror is used more frequently when driving in city distribution transports than during long time-periods of long-haul transport. A closer mirror location is easier to overview and can also cover a larger field of view compared to its size.

Today only one camera view, the reverse view is implemented in the Volvo FH truck and is presented in the SID. The reverse view shows the area behind the truck when needed. There are possibilities for installing additional camera views in the Volvo FE trucks depending on application.

Visual in-vehicle information

The third part of the visual information is the visual in-vehicle information. This covers all the types of information or data given by the truck to the driver while driving. As mentioned in the limitations section, this information is divided into primary information, secondary information, and active warning systems depending on how important the information is for the truck driver when driving.

Primary information

The primary category of information is the most important information for safe driving and most frequently used. The types of information included in this category are the speedometer, fuel level, warning signals and fault messages. Many of them are also directly dictated by regulation and complementary standards regarding what needs to be provided and how it should be provided.

Secondary information

The secondary information covers information less critical for the driver to see during driving compared to the primary information. Navigation systems, transport order management system, phones, audio system and climate system are examples of functions that are part of the secondary information category.

Active warning systems

The warning systems category covers the information that additional driver support systems can provide to make driving safer. In dangerous situations the warning systems inform or even alert the drivers to secure that they are aware of the immediate danger. Examples of systems in the current Volvo trucks that use visual alerts to reduce risk of collisions are Lane Change Support (LCS) and Forward Collision Warning (FCW). The LCS warns the truck driver if there is another vehicle hidden in the blind spot on the passenger side when the indicators are activated to change lanes. The LCS warning is in the form of a flashing icon located on the passenger side A-pillar. The FCW projects an LED warning on the windscreen just in front of the driver when there is a risk that an object in front has not been noticed and, thus, there is the risk for a collision to occur.

3.4 COGNITIVE ERGONOMICS

The mental process of managing information is called cognition. The mental processes concerned with cognitive ergonomics are sensory intake, perception, long term and short term memory, attention, decision making, and response execution (Adams & Berlin, 2015). It is commonly described that humans have five senses; visual, auditory, haptic, olfactory, and taste. When the body receives stimuli, these senses transfer information about the surroundings and the internal body state, sending them as a nerve signal to the brain for processing (Adams & Berlin, 2015). This section describes the necessary information about vision as well as principles when designing a work place.

3.4.1 VISION

Vision is the most used of all the human senses and around 80% of all information taken in is visual. Humans also have a tendency to trust the visual information more than other types of information input. The sense of vision continuously searches for patterns and structures that humans perceive as important (Simonsen, 2014). The field of vision is the part of the environment that the eye perceives when both the head and eyes are not moved. In order to view details the information need to be in the central field of vision. For clear vision the angle of view is limited to 2 degrees from the centre point of where the eye is directed (Adams & Berlin, 2015). As the degree from the central field of view increases, the more difficult it becomes for the eye to detect changes in the environment. However, the field of vision can be extended to about 170 degrees horizontally where it is possible to detect movements but not detailed information. Detailed information must, therefore, be located in central field of view (Adams & Berlin, 2015).

Since movements are easily detected by the human eye, they can be used to attract attention. Other factors that can influence the vision are contrast and colour of the information, depth perception and glare. Around the age of 40, the vision tends to get worse and it becomes more difficult to detect weak stimuli and low contrast and to see small symbols. Therefore, these aspects are very important when designing a work environment (Adams & Berlin, 2015).

The movements of the eye are most efficient within 15° from the central field of view and beyond that the visual acuity decreases fast. The peripheral information can be noticed most precisely within 30° vertically and within 35° horizontally, see figure 15 (Tretten, 2011). This means that primary information should be placed within the 15° from the central field of view in order to see details, since primary information is found to be the most critical information needed during driving. Secondary information should, on the other hand, be placed within 30° vertically and 35° horizontally. Secondary information is not as critical during driving as primary information and, therefore, possible to place further away from the central field

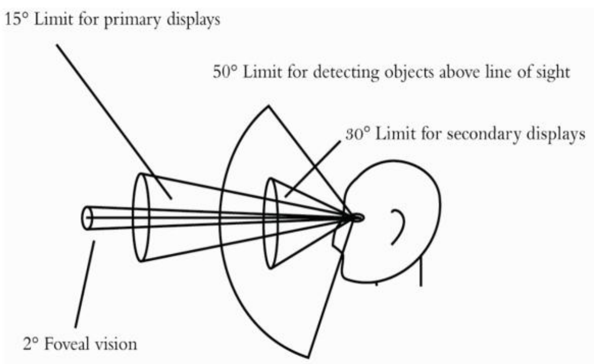

FIGURE 15: FIELDS OF VISION FOR LOCATION OF INFORMATION
(Tretten, 2011)

of view. No information should be positioned above 50° from the line of sight and below 70° from the line of sight since information placed beyond these limits will not be detected (Tretten, 2011).

3.4.2 Design Principles

When designing a workplace, it is very important to think about the human mental abilities. By reducing the mental workload, the impact of fatigue can be reduced. In order to support the human cognitive capabilities, specific design principles need to be taken into consideration (Adams & Berlin, 2015).

In order to support attention, two principles are important. Firstly, to minimize the time and effort it takes to find the information. This means placing the information in the same place, group related information together and place the most frequently used information where it is easily viewable. Secondly, to visually link similar information together by using the same colours, shapes and patterns (Adams & Berlin, 2015).

To support perception, first of all the displays need to be easy to read by using large text, high contrast, good illumination, and the angle of view needs to be correct. Secondly, it is important to put emphasis on unexpected warning signals to make sure they are correctly interpreted by the human. This can be accomplished by placing the signals centrally on a display, increasing the size, using colour change or flashing (Adams & Berlin, 2015).

To reduce memory loading, it is important to minimize the amount of information that needs to be kept in the short term memory. The short term memory can hold up to 7±2 chunks of information at time. The amount of simultaneous sensory stimuli should therefore not exceed that number in order to avoid information overload (Adams & Berlin, 2015).

3.5 New Technology Likely to be Implemented

In this section, focus is given to providing an insight into new technology that is considered likely to be implemented and needed by customers in their future trucks. First, the Camera Monitor System technology is described for replacing mirrors. Then Head Up Display technology as well as different display technologies are described in detail. Parts of the information presented in the following sections are derived from interviews as described in more detail in section 4.3.

3.5.1 Camera Monitor System

Previously, only the close-up kerb view mirror (Class V) and the close-up front mirror (Class VI) were allowed by regulation to be replaced with a Camera Monitor System (CMS). However, these regulations are changed, according to experts in this field, which means that from 2016 it is allowed to replace both the main rear-view mirrors (Class II) and the wide angle mirrors (Class IV) by CMS. Originally the motive behind introducing CMS was to simply replace mirrors with cameras and monitors. However, only replacing the current views with CMS is currently not justifiable in terms of both development and product cost. The only way the introduction of CMS is going to be defendable from a cost perspective is if the technology enables other significant benefits. Benefits such as larger fields of view, reduced or eliminated blind spots. Other benefits would be if the fields of view sets are easier for drivers to understand, in comparison with the rather complex mirror systems that are viewed in several different places, and if CMS can be combined with other technologies such as radar and warning systems. In addition to this, there are also significant reductions in air resistance that can be achieved from replacing large mirror housings with much smaller camera housings. In the case of vehicles that go at higher speeds or cover long distances of transport this improvement corresponds to significant reductions in fuel consumption (Danielsson & Höcke, 2013).

There have been studies and clinics investigating the placement of the Class II and Class IV display views, which all seem to point towards placing them on the A-pillars. Since the A-pillars will most likely be in the same place in the future, it is intuitive to place monitors on them since the images are placed close to where the mirrors are today. Also, the placement would not necessarily mean a reduction in direct visibility, depending on the monitor size. The background research showed that the camera monitor views should be placed as intuitively as possible, such as placing the rear right view on the right hand side with respect to the driver and vice versa for the rear left view.

There are some major safety aspects that need to be considered in order for CMS to be implemented in trucks. Primarily the processing speed of the camera image to the monitor needs to be very close to that of the mirrors today. If there is lag in the image projection, the use of CMS could have devastating consequences. Secondly, the CMS needs to be failsafe which means never fail and to always provide as good visibility as the current mirrors do. If it, for some reason, does fail, there should not be an increased risk for the driver. According to experts in CMS technology, if CMS can evolve to provide zero blind spots for the truck driver then that might push regulations and even make them compulsory in addition to being allowed, since policy makers will always go for the safest solution.

It is also necessary to remember that camera monitors could create disturbing reflections and distraction when driving at night. It is hard to make a display surface completely black. In fact it will shine more than the surroundings when driving in darkness, unless very advanced technology is used. If this is not handled, it can create additional distraction as the brighter surface takes away focus from other things that need to be noticed. There is also a risk that an illuminated display can create disturbing reflections in surrounding window surfaces when driving in darkness. A glossy display surface can also create disturbing reflections of incoming light when driving at daytime.

3.5.2 HEAD UP DISPLAY

The Head Up Display (HUD) technology was first introduced on the market in 1960, initially in military aircraft and later in commercial aircraft and in automobiles. However, the technology did not experience any commercial breakthrough at this time. During the last few years this technology has showed up again and the HUDs are available in many passenger cars (Tretten, 2011).

According to experts in HUD technology, the HUD is considered as one of the safest Human Machine Interfaces (HMI) on the market since the driver can see necessary information and keep the eyes on the road at the same time. Even when the information is in the focus area of the eyes, it is still possible to detect what is happening in the surroundings. Here, there will still be a need to follow rules for overlaying information where added information is not allowed to completely block what can be seen behind.

According to a HUD expert, there are two types of images provided; virtual image and real image. The real image is the one that can be seen without any reflection, for example something printed on a piece of paper. If a mirror were to be placed in front of the paper and the print seen through the mirror instead of seeing the real print on the paper, it is the so called virtual image that is projected onto the mirror.

There are three ways to project the image in front of the driver, in the field of view; direct projection, virtual projection on the windscreen, and a combiner based Head Up Display. The direct projection is based on a real image while the other two options are based on virtual images. This is stated by two experts in HUD technology.

With direct projection, the image is projected on the windscreen. When using direct projection, a very thin film is glued in front of the windscreen and a laser projector used to project the real image. There are some limitations with direct projection. One example of such a limitation is the transparency of the film on which the image is projected. This means part of the light from the projected picture might escape the cab and become visible from outside of the cab. According to legislation it is not allowed to show truck information outside of the cab which complicates the use of direct projection.

The second method is a virtual projection on the windscreen. With this method the image is generated in one part and the light reflected onto the windscreen. This method has been used in the car industry by BMW and Audi for example. The limitations with this method are in terms of price, the technology cost, and the size of the image. However, if more than one laser source is combined it is possible to use the full windscreen as a projection area. When the windscreen is the optical reflection element it is much more expensive compared to a regular windscreen because of the increased complexity in the manufacturing process.

The third option is to use a combiner based HUD. A combiner, which is a piece of glass or plastic, is placed between the driver and the windscreen and used as an obstacle projection element for the HUD. This method is believed to be the most feasible in terms of cost and gives the best possibilities to tune the image in a different way. One alternative for the placement of the combiner is to mount it onto the upper shelf so the image will be above the ordinary field of view. However it is much more difficult for humans to look up without moving the head compared to looking down. Therefore, the most promising alternative is to place it on top of the instrument panel so the image will be roughly 5° to 15° below the driver line of sight. The picture size in this method depends on the combiner size. With a bigger combiner a bigger picture can be achieved but at the same time it requires more packaging space.

There are three key obstacles that need to be solved in order to facilitate implementation of HUD technology in trucks. The first obstacle is the light source. It is very difficult to find a light source that can generate the amount of light power needed to generate an image that will not be washed out in for example sun light. Compared to cars the HUD in trucks will need to cover a three times bigger area, due to the fact that the eye box with alternative driver eye locations is bigger, which means a higher level of intensity in the light sources is needed in trucks. The second obstacle is the visibility that is blocked by the packaging around the combiner to hold it in place. The third obstacle is where to fit the packaging of the HUD inside the cab. The lasers and mirrors need space and the available space inside the instrument panel is very limited in the trucks of today.

According to HUD experts, using laser as a light source is not on the market yet but forms a very promising solution for projecting an image. It can project a full High Definition (HD) image, movie or statics. By combining three lasers; red, green and blue, any colour can be generated. However, there are some safety aspects that need to be taken into consideration when using very powerful laser. In case of an accident it could blind someone and therefore it is important to develop a good safety system for the light source. The cost of the laser source has been decreasing enormously the last years and in the future it will most likely be a very inexpensive solution. For example, light sources have reduced significantly in cost over 3 years from around 2.5 thousand dollars for a laser to around 200 dollars.

3.5.3 DISPLAY TECHNOLOGY

There are many types of displays on the market today and the technology is changing rapidly. A few years ago, an old technology called Cathode Ray Tube (CRT) was the most used technology for producing television screens. The television sets, however, were heavy and massive and it was expensive to change the screen if it broke. Today, this technology has mostly been replaced by Flat Panel Monitors (FPM). FPMs come in different sizes and are made up of two plates of glass with substance between them which is activated in different ways, depending on the monitor type. Many types of Flat Panel Monitors exist today and the most common will be described briefly in the following sections.

Liquid Crystals Display (LCD) is one of the most advanced technologies available. LCD is a flat panel monitor that is lightweight, does not use much electricity and is ideal for showing images in bright light conditions. There are two types of technologies available for LCD, active matrix of Thin Film Transistor (TFT) and Passive Matrix Technology. The TFT technology is more reliable and has both faster response time and better image quality. The general drawback with the LCD independent of technology is the fact that it is relatively expensive; the monitor resolution is not always constant; and the image quality changes between different angles of view (Tech Advisor, 2014).

Another type of flat monitor is the so called Light Emitting Diodes (LED) display. When comparing LED displays to both CRT and LCD displays, the LED display has some advantages over the others. The LED can produce higher contrast images and it is more environmentally friendly when it comes to disposal. It also uses less electrical power and it is found to be more durable than both CRT and LCD monitors. The design of the LED is very thin and it is possible to have slightly curved displays. Another advantage of LED is that it does not generate much heat, which is a very important factor when it comes to placing monitors in the instrument panel of a truck. The truck can be running constantly for weeks and consequently the displays are turned on for a long period of time. Therefore, it is vital to get the heat generated from the screen out of the instrument panel. The drawback of the LED monitors is that it can be more expensive compared to LCD, especially if having the curved design (Tech Advisor, 2014).

Organic LED (OLED) is a technology that can create ultra-thin, flexible and transparent displays which opens up for new possibilities. For example, the transparent display can be placed in the windscreen of the truck and a curved display can be embedded on a non-flat surface. When comparing OLED to LCD displays it is clear that OLED has many advantages. The OLED display has better image quality, greater colour range, a higher level of brightness, faster refresh rates, higher contrast and a wider viewing angle. It also uses less electrical power compared to LCD displays, is more durable and can operate in a bigger temperature range. However it is still more expensive producing an OLED compared to an LCD, but this could change in the future since the OLED is simpler in design. OLED displays are already used in many electronic devices such as mobile phones, digital cameras, laptops, tablets and televisions (Oled Info, 2016).

Touch displays are a special type of display that has a grid of light beams or fine wires on the screen. The user can interact with the touch display with a touch of a finger instead of using a mouse or a keyboard. This makes it much quicker for the user to interact with the device compared to a regular display. Different types of touch screen technologies exist on the market today. A significant benefit with touch displays is that it forms a configurable surface with software interaction instead of physical buttons. Therefore, more functions can be integrated and it is much easier to change the area of the functions in the touch display compared to physical buttons.

When implementing touch screens in trucks, there are some design requirements that need to be taken into consideration. First of all, the positioning of the touch display: it needs to be within comfortable reach for the driver as well as within the recommended field of vision during driving. Another aspect that should be taken into consideration is whether the touch display causes visual manual distraction, which is when the visual attention is distracted during a task. For trucks this could mean that the visual attention is on the display and not on the road while driving. Therefore, an important design aspect should be to not include too many interaction steps in the touch display and to have the interaction as simple and quick as possible. By keeping it simple, the visual attention does not need to be on the display for a long period of time; a quick glance is enough.

However, it is not known to what extent visual manual distraction from touch displays affects the driving safety. This is something that can be investigated in another study. This is also relevant for how any remaining illumination from touch display surfaces might distract driving when driving at night. As mentioned above for camera displays, most displays shine and do not turn completely black. This means touch displays might need additional requirements regarding this compared to traditional switch controls, even though the latter indeed also have backlight symbols.

The third design requirement to consider is that touch displays require precision when touching the area. It is therefore important to keep the icons big enough and also to consider that there can be vibrations when driving a truck. This is an important aspect when considering the size of the touch screen; it should be big enough to fit all the icons without having many screens and menus to swipe between. There might also be a need to provide support surfaces that the hand can rest against to cope with the vibration levels.

4 BACKGROUND RESEARCH

For the authors to deliver proper layout concepts for the future, it was considered appropriate to attain a solid knowledge base. By conducting observations, benchmarking and interviews, that knowledge base was created, as described in the following sections.

4.1 OBSERVATIONS

In the beginning of the project, observations of the current cabs were conducted. Both the Volvo FE and the Volvo FH cabs were observed during driving on public roads, both highway and city traffic as well as at stand still. Attention was paid to all the three areas of interest in this project; direct vision, indirect vision, and visual in-vehicle information.

It has to be remembered that the findings have emerged from studying the Volvo FH and Volvo FE models. Most of the issues are also commonly occurring among other trucks within the market. Many are natural consequences from the need to place the cab on top of the engine (a solution corresponding to valid length legislations) and chosen technologies that follow the laws of physics (as in the case of how mirrors are located to cover regulated fields of view). Others can be seen as industry standards. If there are no clear reasons behind them, they should be questioned in order to come up with alternative approaches.

Neither one of the authors had previously been engaged in actual truck driving. Therefore, the observations were made with an open mind set. When observing the current situation for the direct vision, the key findings turned out to be the limitations in visibility from the driver's seat in certain traffic scenarios. Naturally, the focus was on identifying the problems and issues with the current layout, but also pinpointing the benefits of it to not lose those in future layouts.

FIGURE 16: DIFFERENCE IN SPACE BETWEEN A-PILLARS & MIRRORS–VOLVO FE (LEFT) AND VOLVO FH (RIGHT)

To start with, there are issues with blind spots (blocked fields of vision) around the truck in certain traffic conditions. Figure 16 illustrates two pictures focusing on the difference in visibility obstruction caused by the mirror housings. The gap between the A-pillars and the mirror housings for the Volvo FH is bigger than that of the Volvo FE. This practically means a larger direct vision blind spot in the Volvo FE than in the Volvo FH.

For the Volvo FH, the height of the cab above ground means the driver can overlook the traffic far ahead and thereby plan the driving. When driving on smaller roads, going through roundabouts and changing lanes, the major issue with a high-positioned cab like the Volvo FH is the limited view of what is really close to the truck; both in front and on the sides. Generally, the biggest visibility issues are the blind spots around the truck which is also a problem with both the Volvo FH and the Volvo FE truck. In the Volvo FE, an extra window in the passenger door helps increase visibility of adjacent objects in city traffic, see figure 17.

FIGURE 17: ILLUSTRATION OF THE EXTRA WINDOW IN THE VOLVO FE TRUCK

Another problem with both the Volvo FH and the Volvo FE truck is that the instrument cluster is reflected in the side window in the area where the mirror is reflected. Consequently, the driver sees a reflection of the instrument cluster when looking at the left rear-view mirror, especially a problem when there is low ambient light coming from the outside. Another issue concerning visibility is that the close-up front mirror is obstructing the view straight ahead for the passenger because of its placement. The close-up front mirror is also blocked for the driver when the sun visor is pulled down, which forms a similar problem for both the Volvo FH and the Volvo FE trucks. Furthermore, the Volvo FE truck has an extra window in the passenger door in order to increase visibility of close objects in city traffic. This solution only works if the passenger seat is not occupied, otherwise the passenger legs will cover the extra window.

Furthermore, the steering wheel can block parts of the instrument cluster if adjusted to provide best comfort for specific driver sizes both for the Volvo FH and Volvo FE. Here, a more advanced steering wheel adjustment, like in the Volvo FH with individual neck-tilt, clearly reduces this problem. Finally, the layout of the instrument panel is non-symmetric in two different ways. The general asymmetry in relation to the centre line of the cab gives a nice addition to the driver focused atmosphere of the cab – even though it might not be optimized to cost. Secondly, the instrument panel is also fairly asymmetric with respect to the centre line of the driver. The main and useful control area is mainly located on the internal side of the steering wheel, the side towards the cab centre.

A benefit with the current Volvo FH cab as identified by the authors is that the close-up front mirror is placed in the windshield area that is swept by the windshield wipers. Being able to monitor the close-up front view despite weather conditions is a clear benefit. Something that is important to consider during the coming shift in technology is to position the front close-up view so that it neither gets obstructed by the internal sun-visor nor obstructs vision for any truck occupant. It is also placed in the top right corner further out of sight compared to the Volvo FE, where it is placed in the middle and thereby closer to the line of sight. A reason for this could be that Volvo FH users are seldom driving slowly in city traffic where there are more objects like pedestrians, bicycles and road obstacles close to the front of the truck. Another benefit with the Volvo FH is that there is more space between the A-pillars and the mirror housings. This gives the driver a good possibility to see between them, thus reducing the size of the blind spot. This is not the case for Volvo FE, where the mirror housings are mounted closer to the A-pillars so that the blocked area seems larger.

Another issue with the current layout for the Volvo FE truck is the absence of a secondary display in the centre which means there is no possibility to provide an integrated navigation system from factory. This would instead need to be added on top of the instrument panel where it might give other functional drawbacks. There are also fewer controls in the steering wheel meaning the driver needs to reach for the instrument panel to find corresponding controls. The steering wheel is not shaped in the same way as that of the Volvo FH truck. It has fewer spokes placed in a different way which limits the different ways in which to grip the steering wheel.

4.2 BENCHMARKING

To create a deeper understanding for trends within different fields of use, a benchmarking was conducted.

The benchmarking is divided into five different segments with different user needs that are somehow connected to the topic of this thesis, see figure 18. The future trucks seemed logical to collect information about since that is very much the topic of this study. Passenger cars are part of the benchmarking because the car industry is usually ahead of the truck industry when it comes to integrating new technology in the vehicle. The reason for this is the vast difference in model updates and manufacturing volume. Sports cars are made for performance; they are made to be driven faster than most vehicles on the road and the price tag is of less importance. The idea was to understand how these factors shape the layout of a cockpit for such an application.

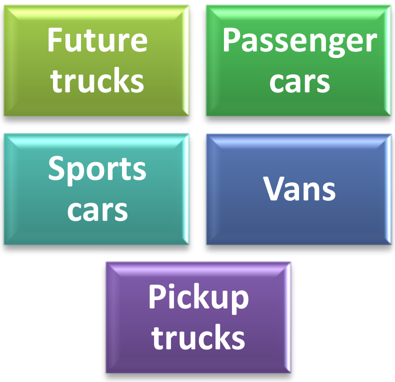

FIGURE 18: THE FIVE VEHICLE SEGMENTS INCLUDED IN THE BENCHMARKING

The authors have found that vans could be considered to be to the automotive segment what distribution trucks are to the truck segment; the driver making stops repeatedly during the workday, entering and exiting the vehicle and using the vehicle as a work tool. Since the FE truck is considered in this thesis, the idea was to see how the work environment and user needs have shaped the cockpit layout in vans. The motivation for including pickup trucks is similar to that of the vans; pickup trucks share many traits to long-haul trucks in the truck segment, pulling heavy and obstructive loads with limited visibility.

In addition to these five market segments, other more radical vehicles were considered such as buses, aircrafts, motor boats and excavators. However, the customer needs of these vehicle applications turned out to be too far away from those posed by the truck customers. Consequently, these vehicle segments were not included in this report.

4.2.1 FUTURE TRUCKS

A benchmark was conducted for future truck concepts. The two most completed cockpit layouts found were the future truck of Mercedes Benz and the Freightliner Inspiration truck, see figure 19. Both of the concepts are using CMS where displays are attached to the A-pillars. However the Freightliner still keeps the wide angle rear-view mirrors with a camera placed in the corner. When comparing the two concepts it can be seen that they look very similar, both layouts are using a large touch display or a PC tablet for secondary information and a fully digital gauge cluster.

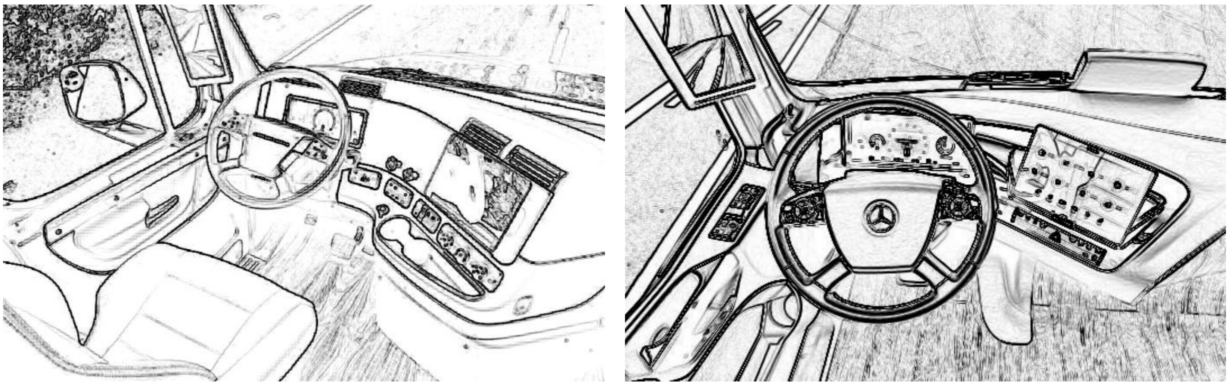

FIGURE 19: FREIGHTLINER CONCEPT (LEFT) AND THE MERCEDES CONCEPT (RIGHT)

4.2.2 CARS

For multiple reasons, the level of technology in trucks is lagging compared to cars. One reason for this is the difference in sales volumes and development cycle time. Another reason is the difference in use; trucks are tools and cars are in many cases a part of the owner's personality. However, because of this difference in technology it is natural, if not a must, to include benchmarking of cars and to reflect on what the trends are. In the following, a number of different brands and models to search for different or somehow special implementations of technology connected to visual information are presented.

In a Peugeot 208 and Peugeot 308 a smaller steering wheel is used and the instrument cluster is placed high, see figure 20. This secures that the instrument cluster can be viewed above the steering wheel, instead of through it, and that it is close to the central field of vision. The reduced size of the steering wheel also makes it easier to handle and increase comfort while driving.

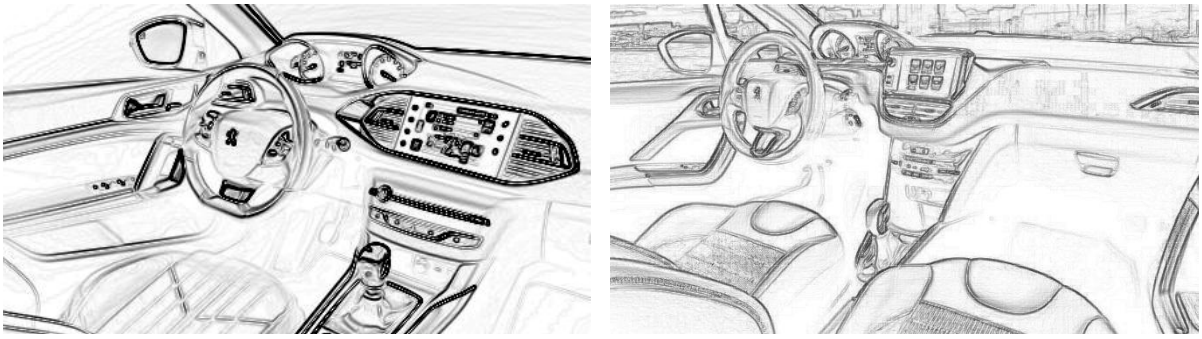

FIGURE 20: THE PEUGEOT 208 (LEFT) AND THE LARGER MODEL PEUGEOT 308 (RIGHT)

In Tesla Model S, a 17 inch touch display is used as the main interface for control and information, see figure 21. The touch screen is directed towards the driver and controls some of the following aspects; climate control, media, camera, navigation and phone. The Tesla Model 3 has taken the idea of few controls, as in the Model S, to the next level by only having one big touch screen in the centre.

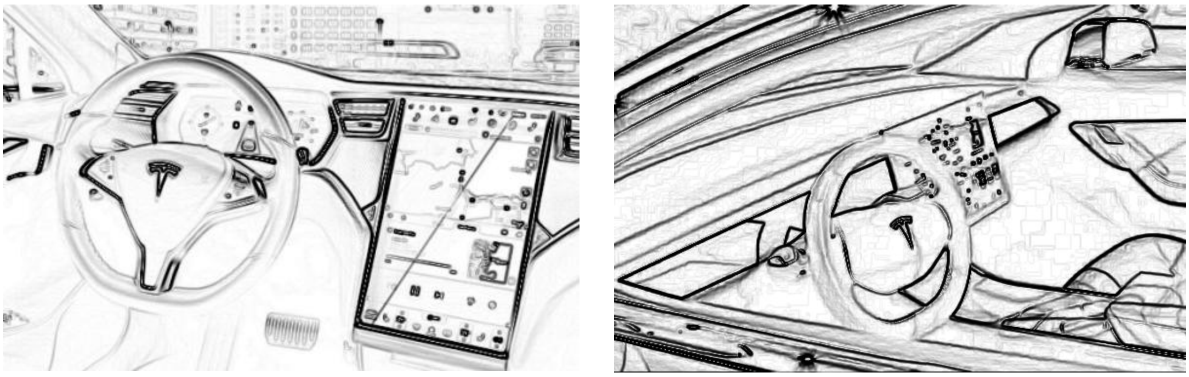

FIGURE 21: THE TESLA MODEL S (LEFT) AND THE TESLA MODEL 3 (RIGHT)

When looking at the 2015 Honda Civic model, the information is split into several different displays which are viewed both trough and above the steering wheel, see figure 22. However, this concept has been removed in the 2016 model.

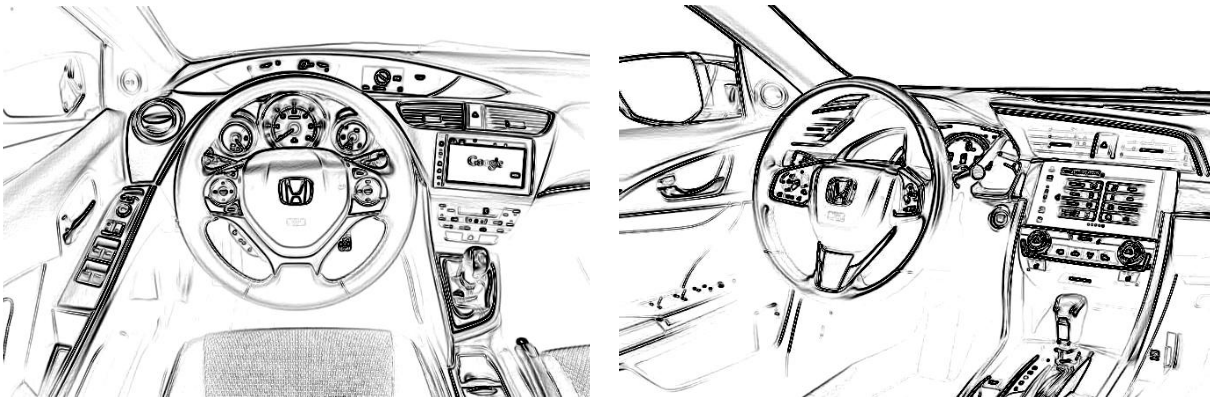

FIGURE 22: HONDA CIVIC 2015 MODEL (LEFT) AND HONDA CIVIC 2016 MODEL (RIGHT)

The BMW i3 has a diverse instrument panel layout, see figure 23. The arrangement of the displayed information is different compared to other car models. In this concept the information is split into two displays placed at approximately the same height, one behind the steering wheel and one in the centre. The instrument panel is clean and uncluttered, although some physical button controls remain in the centre. Because of the nature of the i3's powertrain, there is no transmission placed as in most regular combustion powered cars. This means the floor is flat between the driver and the passenger front seats.

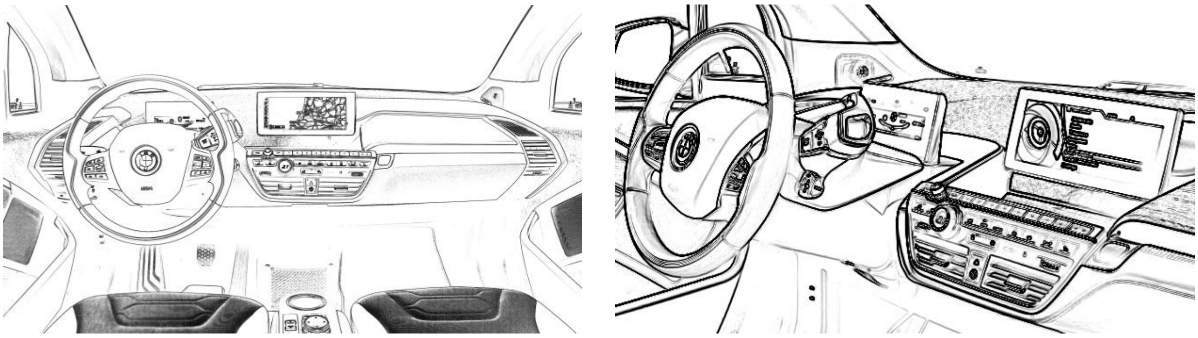

FIGURE 23: THE BMW I3 INTERIOR

The interior of the Mercedes Benz E-class, has several large displays for showing information, see figure 24. There are two 12.3 inch displays which both are high definition and can be personally adapted. One of the displays is for the gauge cluster while the other is for the command system. The steering wheel is also equipped with touch sensitive touch controls to control the infotainment system by swiping with the finger. This is to secure that the driver keep the hands on the steering wheel.

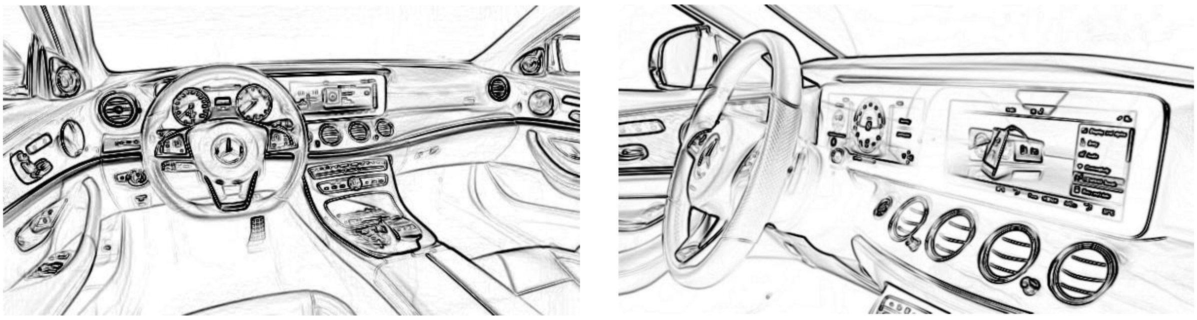

FIGURE 24: MERCEDES BENZ E-CLASS INTERIOR

Another cockpit layout that differs from others is the layout of the Toyota Verso, see figure 25. Here, the instrument cluster has been moved above the steering wheel and is placed more to the centre of the instrument panel.

FIGURE 25: TOYOTA VERSO

The conclusion of the car benchmarking is that there is variety of different solutions for the new car models on the market today. However, some interesting trends have been identified. It can be noted that big central displays or touch displays are becoming standard equipment in cars; having all or many of the controls integrated. At the same time there are very few physical buttons on the instrument panel. Often the instrument cluster is also in the form of a digital display.

4.2.3 SPORTS CARS

The authors have found that sports cars have high demands on performance and function. Because of their extreme nature, the technology used has to be top notch and the latest on the market. Another factor that categorizes sports cars is that final customer price is not a high priority and therefore the manufacturers can put effort into creating the optimum environment for the driver. Below are some of the current and future models of high end sports cars listed in order to try and find a common denominator of the cockpit layout.

The layout of the Toyota FT-1 is clearly aimed for the driver with all information displays in front of the driver, see figure 26. With a Head Up Display and the information projected close to the line of sight, there is no need for the driver to take the eyes off the road. In the cockpit of the Ferrari 458 Italia it is easy to find traits from the F1 racing. The arrangement of visual information is simple and easy to overview. No information is placed so that the driver has to take the eyes off the road in order to receive it. The R8 is Audi's line model of the sports car segment. When making the R8, the arrangement of visual information has been designed with the active driver in mind. Visual information is presented on a big screen behind the steering wheel. No information is placed in the centre stack. This makes the car very focused on spirited driving, and an excellent means of transportation on the highway.

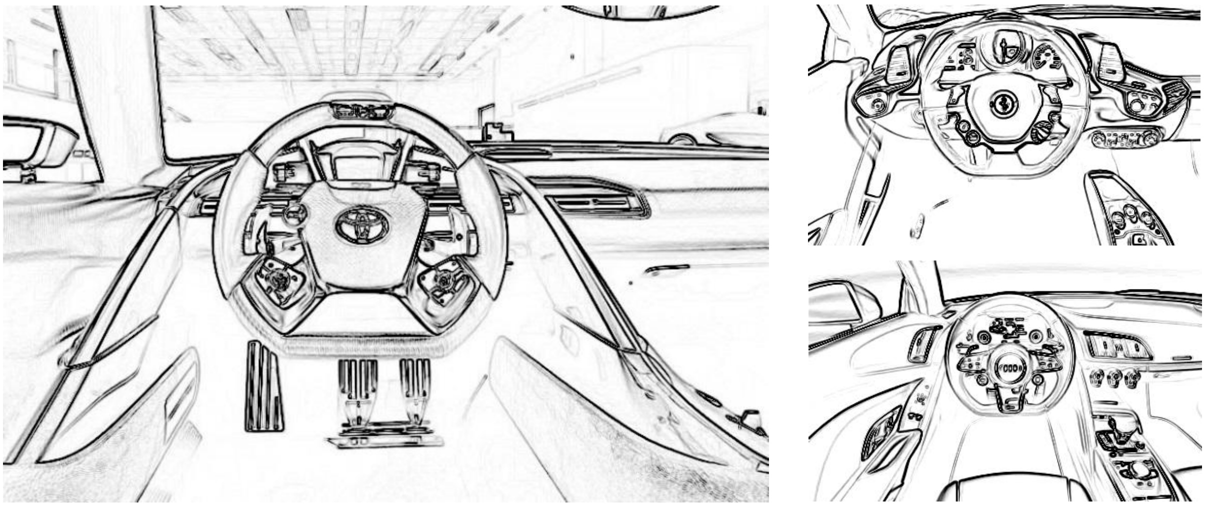

Figure 26: Toyota FT-1 concept (left), Ferrari 458 Italia (top-right) and Audi R8 (low-right)

As illustrated in figure 27, the Lamborghini Huracán has a small display of engine data placed high in the centre stack. Other than that, the visual information is presented in front of the driver to enhance focus on the active driving. Another extreme model from Lamborghini is the Veneno. Large displays behind the steering wheel show only the most vital information for race applications; vehicle and engine speed. All the visual information is easy for the driver to process because of its placement being so close to the line of sight. Also in the Asterion concept car, the visual in-vehicle information is placed in a very functional way. There is a display mounted in the lower centre stack console. However, this display shows information not vital for the driver whilst driving. The vital information is placed directly behind the steering wheel.

Figure 27: Lamborghini Huracán (left), Lamborghini Veneno (top-right), Asterion (low-right)

To summarize the sports car segment, trends can be found with just a small selection of the car models presented above. The first trend, as described in the short descriptions of each car model, is that the information often is placed in the line of sight for the driver to not feel the need to remove the eyes from the road more than necessary. The logic explanation to this is that these types of vehicles are designed to be driven very fast, often with traits from pure race car driving. In the case of racing, the focus is clearly put on performance and not so much things like entertainment for the driver, since the driving experience itself is supposed to represent the means of entertainment. In short, it seems the faster the vehicle is designed to be driven, the more the necessary information needs to be placed in, or close to, the line of sight.

4.2.4 VANS

What vans have in common with distribution type trucks is that they are a working tool rather than a personal vehicle. Especially similar is the use of vans to the use of distribution trucks. Looking at the layout of different vans was therefore found to be of great use. The different van layouts compared were Renault Master, Volkswagen Transporter and Ford Transit, see figure 28. As can be seen in the figure, all the layouts are very symmetric, which could be for cost efficient reasons. Another interesting observation to make is the amount of storage space for things such as papers, pens, work books and cups on the instrument panel in all the three layouts.

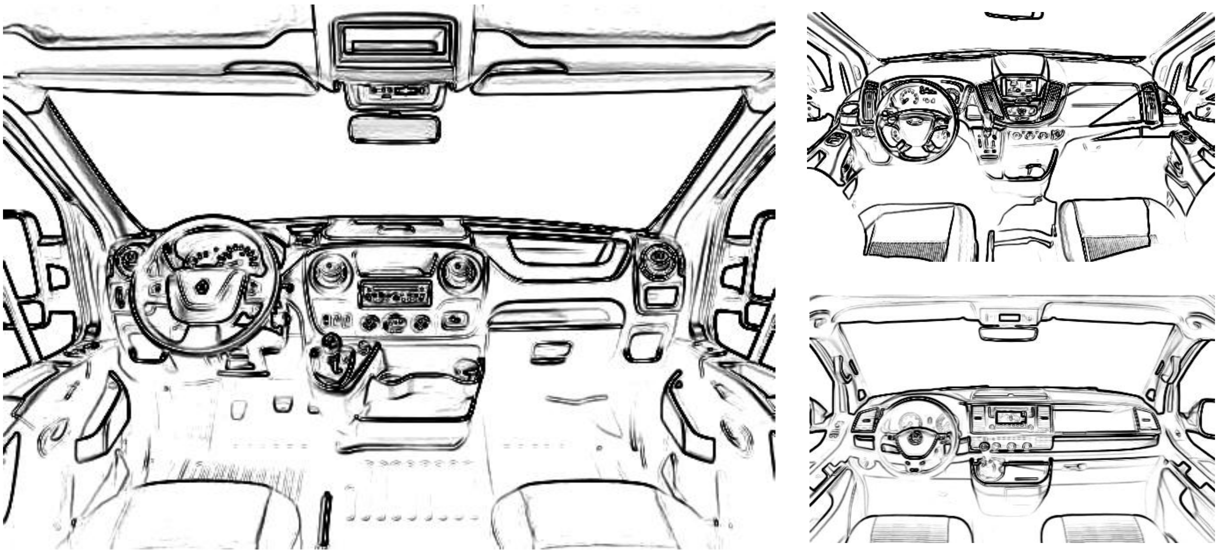

FIGURE 28: RENAULT MASTER (LEFT), FORD TRANSIT (TOP-RIGHT) AND VOLKSWAGEN TRANSPORTER (LOW-RIGHT)

4.2.5 PICKUP TRUCKS

Pickup trucks, similarly to long-haul trucks, are used in a combination of comfort and practicality. Most of the pickup trucks offer a high level of relief while being used to pull heavy and obstructive trailers. Having these similar traits to the long-haul truck segment, it appeared to be interesting to see what trends exist for pickup trucks in the automotive industry.

Illustrated in figure 29 are three pickup trucks made for the American market; the GMC Sierra, Ford F350 and the Dodge Ram 1500. All of these have commonalities which form the basis of the following trends. A rather big SID placed in the high centre stack is common for all pickup trucks studied in this thesis. The layout of the instrument panel also seems to be very symmetric. Symmetry could be a sign of cost efficiency, but could also be a cultural trait, like having big cup holders in the centre.

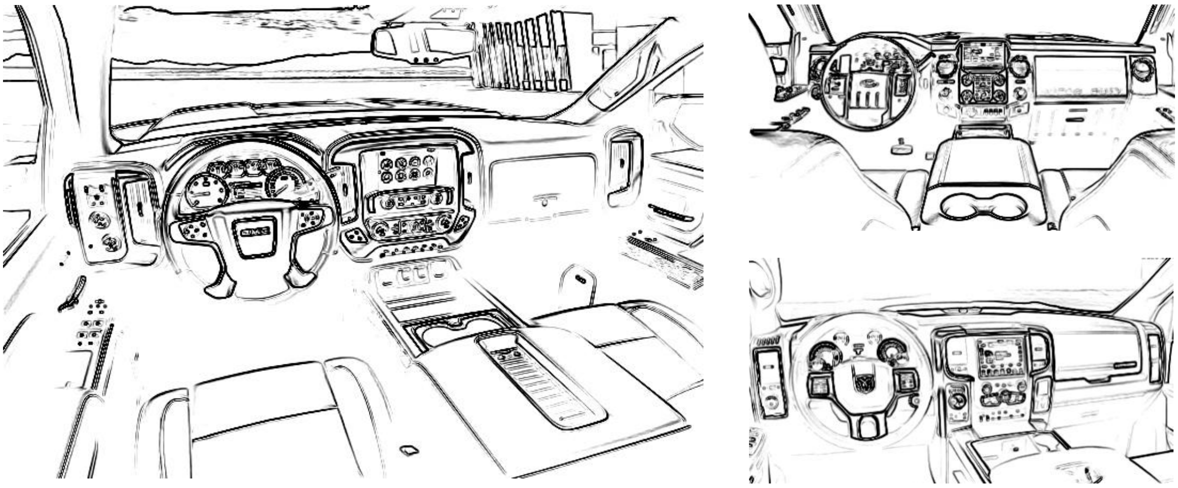

FIGURE 29: GMC SIERRA (LEFT), FORD F350 (TOP-RIGHT) AND DODGE RAM 1500 (LOW-RIGHT)

Below, in figure 30 is a side by side comparison of the 2015 Toyota Tundra and the 2015 Toyota Hilux. The Tundra is made for the American market and the Hilux for European and the Australian market. The comparison is made to see what could be regarded as cultural market differences, in order not to draw any conclusions of trends based on the wrong reasons. On a holistic and general level, the European version is shaped more in a sweeping motion, being less symmetric, whereas the American version looks more symmetric and square like.

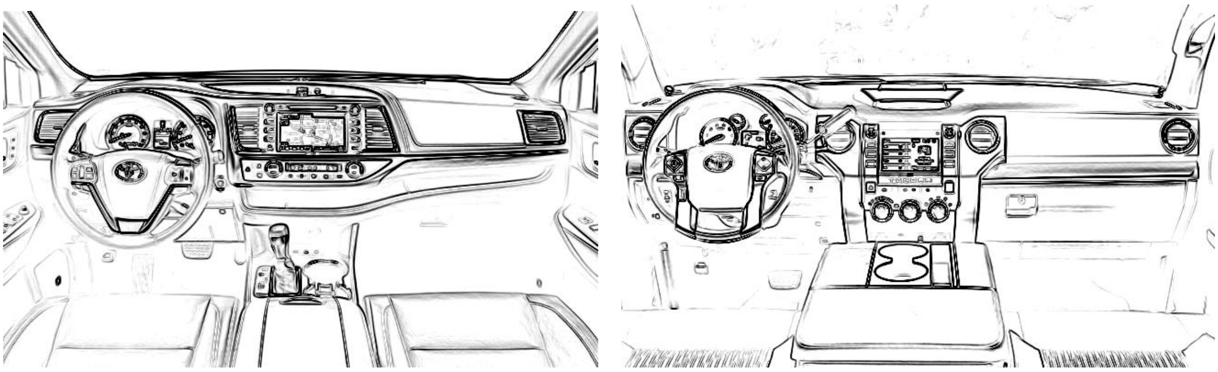

FIGURE 30: TOYOTA HILUX (LEFT) AND TOYOTA TUNDRA (RIGHT)

Figure 31 illustrates three vehicles from the pickup segment being sold outside of the United States. The reason for including these vehicles is to portray an unbiased image of the layout for pickup trucks, in order not to draw any conclusions based on market specific trends, but rather the segment specific trends. Just as for the American trucks, these three all have a big SID in the centre as a common denominator. The instrument panels are made in a more sweeping fashion. However, there are some traits of symmetry of the layouts, although not as obvious as in the American trucks.

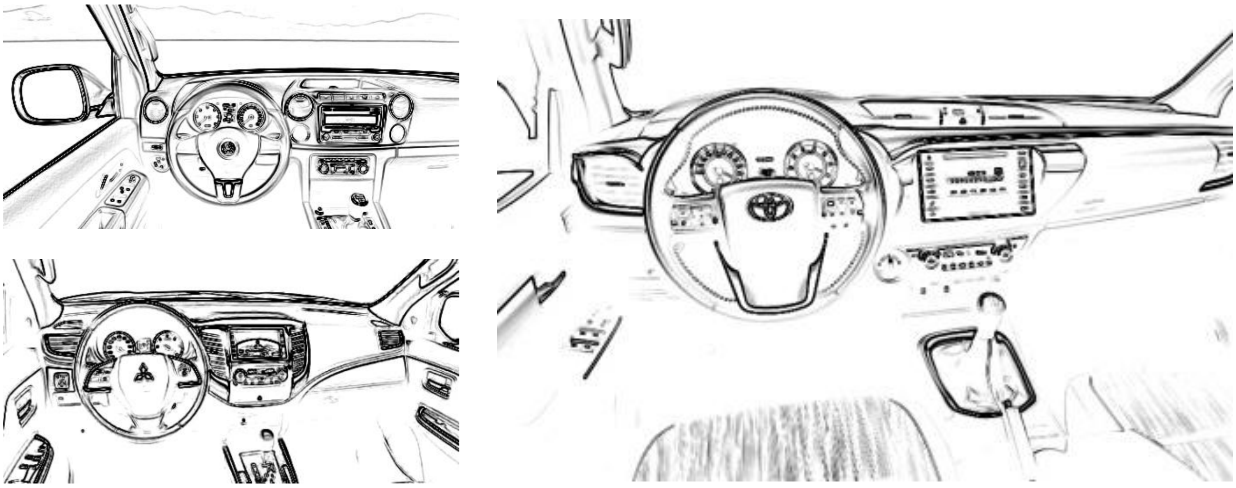

FIGURE 31: VOLKSWAGEN AMAROK (TOP-LEFT), MITSUBISHI L200 (LOW-LEFT) AND TOYOTA HILUX (RIGHT)

4.3 INTERVIEWS

Interviews were conducted with employees at Volvo, with different key positions holding information that could be useful as a major part of the background information to this project. Ten interviews were conducted with internal people with expertise in different areas. The following people participated:

- 2 Experts in Camera Monitor Systems
- 2 Experts in instrument panel design
- 1 Product designer
- 1 Expert in visibility
- 1 Product planner for driver environment
- 1 Product planner for safety
- 1 Expert in display technology
- 1 Expert in Head Up Displays

Before the interviews were carried out, questions were prepared specifically for each interview. The layout of the interview was the same for all, with open questions in the beginning and questions on a more detailed level towards the end of the interview (see complete interview guide in appendix A). All the interviews were recorded and transcribed, with consent from the interviewees. The type of information gathered from the interviews were a combination of future ideas and plans, limiting factors, important factors to consider in the development work, as well as current and future technology information.

In the following sections the key findings of the interview outcomes are presented. The information gathered has been grouped in sections according to subject area and similarities in the interviewees' responses.

4.3.1 INSTRUMENT PANEL DESIGN

In this section, information about instrument panel design is presented. The information includes both what to consider when developing new instrument panels as well as what limitations are creating constraints to the development, cost management and future visions. The ideas and input to this section are provided by the two experts in instrument panel design, the product planner for driver environment and the product designer.

Considerations

During the interviews regarding the development of the instrument panel, limitations were brought up as an important factor to consider in the development work. On a general level there are regulations that dictate the major boundaries for instrument panel development. One example of such a boundary is the length of trucks. These regulations are different in different areas in the world, which is why there are long nose truck in the North American market and flat nose trucks in Europe. Constraints are also set by ergonomic factors and the solutions located around the instrument panel, which need to fit in the cab. In order for the truck to be operated in a safe manner the constraints of the most vital controls, such as electronic park brake, the truck ignition switch and the hazard lights, must be the first to be taken into consideration. These vital controls need to be located at a reachable distance and at an intuitive placement. The ignition switch, for example, needs to not only be reachable, but also placed so that the key can be turned not hitting the knee of the driver.

The ergonomic factors that put constraints on the development work are essentially everything that makes the truck useable for humans. The interface between human and machine, the so called Human Machine Interface (HMI), is a work area that sets these requirements and makes sure the controls and displays in the cab meet them. For the instrument panel development it mostly puts constraints on the distance between the driver and the controls and switches but also things such as the fact that screens and displays should not be placed so that reflections from the screen are shown in neither the windscreen nor the side windows. Another important factor to consider is how the truck interior can be optimized for the driver to safely complete his or her task. One such factor is to keep the layout clean and calm in order for the focus of the driver to be on the road and not on the interior.

> “ **We should have these big uncluttered surfaces to create calmness.**
>
> About creating the optimum work place in the cab – expert in product design

Other features that limit the design freedom are the types of solutions and systems that have to fit geometrically inside the cab. One major system is the climate control system, commonly referred to as the HVAC (Heat Ventilation and Air Conditioning) system. Today, this is a big and bulky piece that takes up most of the space in the instrument panel. Because of the need for the driver to be able to control the climate in the cab, the control panel is a key feature to have in the cab. Due to its importance it influences the rest of the surrounding layout.

Furthermore, there are size constraints on the instrument panel to make assembly in factory possible. The instrument panel needs to be small enough to fit through either the door or windscreen openings. If the instrument panel is too big it requires lifting assistance in assembly which adds unwanted cost to the final product.

One long-haul segment specific constraint is the fit and finish. This means how the parts in the instrument panel are cut and how they look together. Since the long-haul segment is a premium segment, it is important that what the driver sees presents an unambiguous quality image. This is not as pronounced for the city distribution segment.

Cost management

In the city distribution segment it is important to keep the cost to a minimum. For the sales volumes of the distribution vehicles, symmetrical parts and layout means parts would only need to be engineered and tested once which makes a considerable difference in cost.

> “
> **Only cost. No other benefits.**
>
> Regarding the reason for symmetric layouts - expert in instrument panel design

Another way to keep cost to a minimum is standardization. Parts between brands and segments can be shared in order to save both product and development cost. Important to consider is the effects that this has on the brand distinction. For the Volvo FH truck being a premium product, none of the visible parts should be shared with products of brands within the Volvo Group. Parts inside the instrument panel can for instance be shared but the buyers of a Volvo FH truck should have separate parts to maintain the sensation of quality inside the cab. All that is visible should be unique to the Volvo premium model, but there could be shared components and technologies behind it. Especially important is to not share components between models within the same market such as Volvo and Renault or Volvo and Mack. So, with the same reasoning it is okay for Mack and Renault to share parts as these trucks are not on the same market.

Future visions

The interviewees also highlighted important factors to consider for future development of the instrument panel. Because of the size of the HVAC system, this is one major constraint for development. If this system is made into something smaller or completely rebuilt, that would open up opportunities for better packaging solutions. As for the HVAC, the placement of the Electronic Control Units (ECUs) should be reconsidered to make space for other solutions. In the Volvo FH today, the ECUs are placed inside the instrument panel together with the HVAC. These systems could be moved or somehow rebuilt or restructured to make space for storage or other solutions that better support the driver both when driving and living in the truck. Another solution that could be made possible by moving or redesigning the HVAC and ECUs is reducing the total size of the instrument panel, lowering it from the current height it has today. That would make the windscreen bigger which would improve the direct vision, something especially beneficial for a distribution type of vehicle like the Volvo FE.

Air vents are obtrusive and unnecessarily big which makes them a target for improvement. The delivery of temperature controlled air to the driver is old fashion technology which has not changed much in the past years. The problem is that the air ducts, which are routed inside the IP take up space that could be better used for other features. An improvement in order to save space would be to use similar technology as in airplanes; the air is pressurised. If the air is pressurised, both the air ducts and the vents on the instrument panel could be reduced in size, thereby making space for more driver oriented features.

An interesting area to look further into is what would happen if the steering function would not need the mechanical steering rod element that is part of it today. Perhaps that could eliminate the need for the steering column which would create more space for the driver as well as new packaging possibilities in the instrument panel.

Another opportunity for improvement is to remove the steering column which is what surrounds the mechanics behind the steering wheel function. This column takes up space for the driver and also for more features in the IC. In the future, it is likely that the steering motion from the driver will not be transferred via hydraulics but something else that takes considerably less space and eliminates the use of a steering wheel column.

> “
>
> **We really need to work more on packaging**
>
> About what needs to be solved in order to implement new technologies – expert in instrument panel design

Other things that might change in the future are city regulations. These control and push the development of systems, mostly safety applications such as increased vision around the truck to protect pedestrians in city traffic.

Something that by the interviewees seems like a future requirement is the use of increased communication systems, mainly for distribution vehicles. This communication is between the driver, the pick-up spot as well as the delivery spot. The future integration of these systems will put new constraints to the development of the instrument panel. Best is if they can be integrated in a modular fashion so that updates will not need redesigns of the entire instrument panel. This is important as communication systems tend to develop rapidly with frequent need for updates. It is also often beneficial if communication equipment can be portable, so called nomadic devices. When introducing new technologies that should be visible for the driver when driving, these technical solutions are prioritized in the packaging development. These prioritized solutions will determine and lead the development of the layout, just like the placement of the hazard light switch; electronic parking brake switch and the ignition switch dictate the packaging of current instrument panels.

One interviewee mentioned that other future constraints will occur by introducing solutions taking into consideration the variety in driver sizes. The adjustment ranges of the seat and steering wheel will be changed and these changes might affect the instrument panel design.

Finally, from the interviews about instrument panel development, it became clear from multiple interviewees that the differences between transport segments will become greater in the future. The long-haul segment of the Volvo FH will most likely keep a rather large instrument panel with features packaged inside. The driver sits high above the ground and does not, in most cases, need to see what is closest to the truck because time is mainly spent on highways. The Volvo FH driver will probably also want more storage for personal items in order for the truck to become more of a home to the driver. Due to the fact that the long-haul drivers often live in their trucks, it is also important to find a good solution for a high-performing climate system. The long-haul drivers might also need increased support for communicating with other long-haul drivers. Improved truck communication is also useful for truckers to plan transports and to check available places to spend nights at truck stops.

4.3.2 COCKPIT LAYOUTS

In this section, information about cockpit layouts is presented. The information includes what to consider when developing the cockpit layout, what limitations are creating constraints to the development as well as future visions. The ideas and input to this section have been provided by the two experts in instrument panel design, the product planner for driver environment, the product designer and the product planner for safety.

Considerations

According to the interviewees, the steering wheel is too big. The reason for the big size of the steering wheel in trucks is a regulation that says the driver must be able to steer the truck to the side of the road in case the steering servo has failed. With lower steering forces and changes to regulations as other solutions can secure the redundancy, new opportunities appear. A reduced steering wheel size would also create larger areas for controls on the instrument panel. An appropriate size seems to be that found in passenger cars.

Future visions

The biggest limitation of development freedom is length regulations of the cab. If there would be more freedom in terms of regulations for weight and dimensions of the largest trucks, there could appear even bigger differences between the transport segments. Many of the interviewees imply that regulations will change in the future. Probably the long-haul trucks will be more elongated to provide more space for driving and living, while the distribution trucks will remain the same as today. To attract distribution drivers, the trucks need to be as easy to drive as possible. The reference of how simple the distribution truck needs to be can be a scooter. Anyone can learn how to drive one within a limited time period because it has so few controls that are also intuitive. This should be the case for distribution vehicles as well. For long-haul trucks it is not the same thing because these drivers are more committed to the life style and find pride in their driving skills.

Another possibility for the future is to reduce the size of the engine tunnel, which is what encloses the engine. This is mainly applicable for the distribution trucks like Volvo FE. Because of the low position of the cab above the ground, the engine is protruding into the cab floor. This has negative consequences for space for pedals, passengers and for passing through the cab.

The reduction in engine tunnel size can also be supported by a change in source of energy from combustion engines to completely electric vehicles. This will open up new opportunities for packaging in the cab. That would possibly also open up for changed approaches to collision safety with different arrangements of crash zones, paddings and structures to distribute loads.

Direct vision improvements could be achieved by modifying the doors in a similar fashion. Making the doors lower and thereby increasing the side window size would have the same positive effects on the direct visibility. The distribution type Volvo FE layout will most likely strive towards a layout where direct vision is improved by lowering the instrument panel and doors. This is because of the dense city traffic that distribution trucks have to cope with. Furthermore, the side windows could also be extended rearwards, to further improve the direct vision.

The distribution drivers will demand better support for their nomadic devices since they in many cases are using more than one phone while working. Nomadic devices can also include bar code readers to register goods.

In order to reduce cost, the number of parts needs to be reduced. It is important to only have the things that are really needed. This is particularly true for distribution trucks because the drivers rarely own the truck so they care less about it compared to long-haul truck drivers.

One interviewee expressed an idea of not having direct vision at all. With autonomous drive as a fully introduced and mature technology, there might not be much use of seeing the road, but to have some indication that the truck is moving. In this case the truck driver might not be needed at all.

4.3.3 CAMERA MONITOR SYSTEM IMPLEMENTATION

Opportunities for the future with Camera Monitor Systems are the many possibilities that come with introducing displays instead of mirrors. Merging views and having object recognition are two examples. The ultimate goal is to have no blind spots around the truck. This can be supported with CMS thanks to the removal of the mirrors and mirror housings. In this section, information from the interviews about camera monitor systems and its implementation into trucks is presented. The information includes both what to consider when implementing this new technology as well as what limitations are creating constraints on the development, cost management and future visions. The ideas and input to this section have been provided by the two camera monitor system experts, the display technology expert and the visibility expert.

Limiting factors

The main limiting factor for the introduction of CMS today is technology. The displays within the automotive industry are being developed for passenger cars, but these are made for 12 volt systems. In trucks, the system has 24 volts which means there has to be a new kind of displays specifically for trucks. The other technology limitation is durability. It is easy to think the technology is already here because of nomadic devices such as smart phones and tablets. These items, however, are not close to fulfilling the requirements set by Volvo in order for them to be implemented in a truck – requirements which are even higher than those for passenger cars. In addition, the CMS must deliver at least the same functions with at least the same quality as the mirrors do in current trucks. This means, for example, that there needs to be a solution to the fact that the image view does not change when the driver moves his or her head, as is achieved with mirrors. It also means the technology has to be completely reliable, with no time lags of the image presented as well as coping with different light conditions during night and day. It should also be able to function in cold conditions such as during winter in the north

> “
> **The intention with CMS is to find ways to simplify the display to the driver and possibly merge views together**
>
> Regarding the introduction of CMS in trucks – expert in camera monitor systems

of Sweden as well as during hot summer days in the south of Europe. Another factor that needs further investigation is the effects of looking at monitors for extended periods of time, especially during night time.

Implementation

The introduction of CMS has to go stepwise. It will most likely be introduced as a fuel saving feature, by removing the non-aerodynamic mirrors. As the market matures, there could be more features such as combining camera views to take advantage of the system and have an all-around view of the truck. The introduction of CMS is also about user adaptation to the new system; for instance the distribution drivers need to be familiar with the systems when changing between trucks, which is common. Possibly the main problem in the introduction of such a revolutionary technology is the cab structure. The current cab is designed with mirrors in mind, both regarding the interior and the exterior. As long as the cab remains as it is today, the mirrors will continue to be the main variant and CMS an optional solution. For the future, when the cab structure is remade it is possible to make CMS the standard variant with mirrors as an option. Then both the exterior as well as the interior can be designed with the new system in mind.

> “
> **You should have the monitor at the same side as you are looking.**
>
> About placement of rear-view monitors in trucks – expert in camera monitor systems

The positions of displays need also to be researched and tested. This is essential both for the rear-views and the close-up views. A logical placement of the rear-views seems to be near the A-pillars, since the change from existing rear-view mirrors would not be too big – remembering that the same drivers would need to drive with both during a long transition period. Regarding close-up views, it is clear that the displays should be placed where they provide the best possible indirect vision without interfering with other functions. For instance, how can incoming light be handled, how to ensure that fold-down sun-visors are not getting in the way and that additional direct vision is not blocked. It is clear, that the right rear-view needs to be placed to the right hand side of the driver and vice versa for the left view.

Constraints

One important thing to consider in the introduction of CMS is that cameras will most likely be placed above the doors. This means the driver is unable to see the outer edge of the camera housing, which is the widest part of the truck. This could be a problem when going through tight spaces; there is a risk of hitting the camera and thereby losing the indirect vision. Furthermore, for CMS to be introduced it needs to comply with all valid regulations and requirements. It needs to be designed to endure the life expectancy of the truck which typically amounts to 15 years and 1.5 million kilometres.

Cost wise, the introduction of CMS will not be more cost efficient compared to the mature technology of traditional mirrors. It will definitely be more expensive than mirrors because monitors and cameras are going to be more expensive than the simple mechanics and cost efficient mirrors. However, the use of CMS can be

> “
> **Regulations will always go for the safest system**.
>
> Regarding the introduction of CMS in trucks – expert in camera monitor systems

motivated with the new possibilities that come with it. With cameras, better visibility can be achieved and the blind spots be excluded – these are major safety improvements and something that can never be accomplished with mirrors. Except from this there is also a big potential to save energy thanks to the lower air resistance. This corresponds to cut transport cost which is a very important aspect.

Future visions

The camera system can make it possible to see through parts that normally would obstruct vision, such as A-pillars and parts without windows. Mounting a camera on the outside and a monitor on the corresponding place on the inside of the cab will make that specific area appear see-through. Another possible benefit, except for increased visibility, is that being equipped with CMS might lower insurance fees because it can provide additional evidence in the case of an accident – a secondary use for surveillance. Also, the camera systems will be a good first step towards autonomous driving, since the cameras can also be used as sensors.

> “ **HUD is emerging as one of the safest HMIs on the market today**
>
> Regarding HUD technology – expert in head up display technology

Another consideration to keep in mind with future introductions of new technology and more consolidation of different functions is the balance between automatic and manual mode for example regarding changing viewing directions of cameras. This balance concerns the interaction between human and machine. If what is displayed in the displays is controlled automatically by the truck depending on the driving situation, there is little or no distraction for the driver. On the other hand, the driver might feel like not being totally in control of the vehicle, and a standard control algorithm might not cope with all specific driving situations. That is a balancing that needs to be further investigated for future HMI applications of CMS. More than one interviewee expressed a wish for having an intelligent system, something that is more towards the automatic mode. If such a system is implemented, it is using the GPS location and input about the locations of other road users to decide what to show. For instance, if driving in a city, the truck could present a bird's eye view of the truck, which is a top-view where the whole truck is seen from above, in order to optimize the vision closest to the truck.

4.3.4 DISPLAY TECHNOLOGY DEVELOPMENT

> “ **If we want to implement something that is increasing safety, we cannot think about cost.**
>
> Regarding implementing new technology in trucks – expert in Head Up Display technology

A major part of driver distractions that lead to accidents can be traced to nomadic devices such as mobile phones or tablets. If these personal systems could be better integrated in the driver environment in a smart way, this could potentially increase safety. Head Up Displays are part of this as a way of presenting information for the driver without the need of removing the eyes from the road. Although an introduction of HUD technology would not mean a cost improvement, there should not be any question of whether to implement it or not if it increases safety. This section presents information about display technologies and its implementation into trucks. The information includes both what to consider when implementing this new technology and what limitations are creating constraints to the development, cost and future visions. The ideas and input to this section have been provided by one of the camera monitor system experts, the display technology expert, the visibility expert and the product designer.

Future visions

A number of the interviewees expressed a vision of a future where HUDs play a key part in the presentation of information to the driver. The clear benefits with HUDs are that they are digital and able to get the presented information closer to the driver's line of sight as well as presenting the right information at the right time. Some even proposed a future where everything is shown virtually on see-through window surfaces which would eliminate all physical screens. Another interviewee suggested using HUD not only for the driver to fulfil his or her task when driving but also when the truck is stationary while resting or living in the cab. Having HUDs in the truck could also be useful for entertainment activities, mostly applicable in long-haul trucks when stationary at truck stops. From the interviews it is clear that one of the most challenging tasks, except from physically fitting the technology in the truck, is to decide what information to show in the HUDs. Important to consider is that the information in the HUDs could possibly block or mask the driver's direct vision. Therefore, the HUD should not be cluttered with information. Symbols should be easy to understand, using colours helps the user to receive information quicker.

> “
> **It is more relaxing the less information there is**
>
> About hiding information that the driver does not need to see – product designer

The possibilities with using HUD technology are vast, although the introduction of it in trucks needs to be the result from solving a complex design task. This design task includes factors such as how big the projected image should be, how the image can be seen by drivers of all sizes, how much packaging volume can be used to install the system, how strong the projection light should be, and how the technology should be introduced to the market for acceptance among even the most conservative drivers.

One of the interviewees stated that the way distribution trucks are used, introducing HUD will mean having small combiner glasses in order not to block the important direct field of vision. For the long-haul segment, HUD could on the other hand be projected on a wider piece of combiner glass without having as transparent glasses as in distribution trucks since the direct vision is not as critical.

The way to move forward with the introduction of HUD in trucks is most likely to start with using combiner glass technology. In the future, when the cost for HUD technology has reached more reasonable levels, it will be interesting to look at using the whole windscreen as a HUD. An important step, as mentioned earlier, is to clear up space in the instrument panel. The HUDs require space inside the instrument panel for packaging of the hardware components such as lasers and mirrors, which is something of a challenge to acquire. Nevertheless, the introduction of HUDs will most likely occur in the less cost-sensitive long-haul segment as part of a premium package. After that, the technology could continue into other segments, such as distribution transports.

4.3.5 DRIVER ENVIRONMENT

This section presents information about driver environment development. The information includes important factors to take into consideration in the development as well as what limitations are creating constraints to the development, cost and future visions. The ideas and input to this section have been provided by the product planner for driver environment, the display technology expert and the instrument panel design expert.

> “
> **Of course I should be able to have it in my truck or car because it is a part of my daily life**
>
> About integrating personal electronics in the truck – product planner in driver environment

Considerations

A major incentive on the market today is the consumer electronics which push truck manufacturers, including Volvo to deliver a way for drivers to integrate their nomadic devices into the truck. This is also happening in the passenger car industry today. Usually, the car industry is faster in implementing new technologies because of shorter development lead times compared to trucks. This is not the case for all areas but in general cars are slightly ahead of trucks. As far as branding goes, the Volvo FH would be the first model to implement the new technology because it is positioned as the premium model and should therefore be equipped with the more advanced accessories. Also, being the premium brand that Volvo is, this gives incentive to take the lead in implementing technologies that are new to the global truck market. The Volvo FH is the most premium model. This means the buyers are prepared to pay more as they also expect higher quality. Priorities are different in the distribution segment. Here drivers will not pay the extra money for the latest technology, but then they do not expect it to be in the truck either.

The three most important factors for the driver environment, according to one of the interviewees, are visibility, comfort and driver interface. One major factor that guides the development, which is also part of the brand image, is what is sometimes referred to as situation-adapted information. The situation-adapted information means that the truck presents information at the right time in the right way. An example is with the automatic gearbox. There is a possibility for the driver to take over control of the shifting. If that possibility is used, the truck should also present the engine speed, otherwise the engine speed is not of high interest for the driver and should therefore not be in the centre of attention.

> “
> **I mean it is like a Christmas tree of things compared to a Volvo FE.**
>
> About the Volvo FH regarding segment differences – product planner for driver environment

Segment differences

The interviewees stated that the differences between the two transport segments are many. There are even big differences within each transport segment. For example in the city distribution segment that the Volvo FE belongs to, the drivers do not need that many rocker switches in the instrument panel. On the other hand, the waste truck model – also provided based on the Volvo FE – needs multiple controls, sensors and monitoring devices for handling the waste as well as a control station in the centre of the cab for keeping track of billing and garbage weight etcetera. The same goes for the long-haul segment where the standard Volvo FH model has less controls and switches than, for instance a Volvo FH adapted for timber transports. These differences tell that modular systems are beneficial where additional modules can be added according to needs.

Touch screen technology

According to the interviewees the introduction of touch screens is an unavoidable trend but also a required change since it is such a widespread technology in personal electronics. Comparing it to the CMS and HUD technologies, touch screen technology will most likely be the most wide-spread technology of them all and within all transport segments. A clear benefit with the functional nature of a touch screen is that the user points at what icon/function is wanted and knows what to expect in return. Scrolling through menus with a physical knob has a certain degree of uncertainty to it since the user needs to aim the selector at the wanted function and then press to select. In addition, it is not immediately obvious how a multi-function knob should be used to manoeuvre in a menu. Another benefit and future prediction mentioned by many of the interviewees is the integration of functions with software rather than hardware.

An issue with introducing touch screen technology is what is referred to as visual manual distraction, when using the touch screen. With the touch screen technology, the driver needs to look where to push with the finger and receive a confirmation of the activated function. Since a driver is exposed to more movements and vibrations when driving a truck compared to a car, it means each function in the display has to be bigger in order for the touch screen not to require too precise finger movements. Having bigger icons and function areas means you have to swipe through menus to fit all the functions in the available touch screen area. The solution to this problem is to make sure the touch screen is big enough. It can also be helpful if proper support surfaces are provided next to the screen for resting the hand against.

Another issue that needs to be dealt with is heat transportation from processors and graphics cards. The more screens that are integrated in the instrument panels, the more components will produce heat on the inside. This is an issue especially for long-haul trucks, since those can stay on for an extended period of time, leaving time for heat to accumulate inside the instrument panel supported by surrounding weather conditions (full sunshine or need for heating from the climate system).

According to the interviewees, touch screen technology is a welcome change for clearing up the instrument panel from the many buttons that currently clutters it. For manufacturing purposes, dummy buttons and panels are traditionally filling up holes. These are placed there in order to save cost by not having to introduce different instrument panel layouts for different model specifications. Buttons and switches can be integrated in touch screens instead of taking up surface on the instrument panel which could be used for other features, typically storage which is something

> “
> **They are there, just like the cars back in the 80’s.**
>
> About dummy buttons in the IP – expert in instrument panel design

all drivers want, both in long-haul and city distribution transports. The touch screens are also providing a way to provide alternative functions only by software changes.

One interviewee said that in touch screen development, it is important to keep in mind not to have all functions as touch controls. Some functions, such as climate controls, need to be easily and directly accessed, perhaps without even taking the eyes off the road to find the specific control. Functions that could and should be integrated in the touch screen are things such as radio. This is usually something the driver configures once and afterwards just has to change radio channel, which could be performed easily and safely via the touch screen.

Future visions

For the future development, there are two alternatives since the sales volume of trucks is limited, compared to that of cars; either providing the drivers with a system that is integrated in the truck with touch screens and all the necessary software functions. The other option is to focus on providing the drivers with an effective auxiliary port for their nomadic devices since the technology is developing faster for personal electronics compared to trucks. If using the touch screen interface of the nomadic device, it becomes important that it can be installed in a good and stable position on the instrument panel.

Looking into the future, one big constraint in current vehicles is the fact that the cab is placed above the engine. In the future when the energy source has changed from big block engines to electric engines on the wheels, this will open up for many new design opportunities and improvements. Probably the Volvo FE truck will become even easier to get in and out of, perhaps with new seat solutions and instrument panel packaging to create increased space for the drivers' feet.

5 REQUIREMENT SPECIFICATION

In this chapter, the process of setting requirements as well as the requirement list are described. The necessary requirements are set in order to know what the cockpit layouts need to fulfil before entering the concept phase. These requirements are later used for screening and evaluating generated concepts.

5.1 REQUIREMENT LIST

Necessary requirements for the cockpit layouts were identified during the background research and listed in a requirement specification list. A cut out from the requirement list can be seen in figure 32 and the full list can be found in appendix J. The requirements were split into several categories. Measurable values were given for each requirement based on the information gathered in the background research.

ID	Requirement description (What?)	Value	Regulated	Justification (Why?)
1	**Internal visibility**			
1.1	Primary information shall be located in drivers line of sight	<15° vertically from central field of view		Safety / Comfort
1.2	Secondary information shall be located close to line of sight	<30° vertically from central field of view		Safety / Comfort
1.3	Warning systems shall be located where the driver can detect motions	<170° horisontally		Safety / Comfort
1.4	[illegible] shall provide the right info [illegible]			[illegible]

FIGURE 32: A CUT OUT FROM THE FULL REQUIREMENT SPECIFICATION LIST

The process of making the requirement list was iterative. In the early stages of the project, requirements were set based on a holistic perspective of what the final outcome of the thesis should be. These general requirements were updated after each project phase was completed. Each iteration loop resulted in a higher level of detail for the requirements as well as adding new requirements to the list. At the beginning of the thesis work, the requirements were of a basic nature. An example of how a requirement developed from basic to more detailed is the following, which is about direct vision:

- *Provide sufficient visibility through windscreen*
  - *Value: N/A*

After more knowledge was gained during the project, the same requirement turned into the following:

- *The driver shall be able to see the ground in front of the truck*
  - *Value: ≥24 degrees from the horizontal line and downwards*

The final requirement specification list, shown in appendix J, is based on data gathered from both the background research as well as from the theory chapter.

6 IDEA AND CONCEPT GENERATION

In this chapter, the process of generating ideas and concepts is described. The methods used in this phase were brainstorming and the Morphological matrix. The brainstorming was conducted in two sessions and generated a number of ideas as well as full solution concepts. Using the generated ideas from the brainstorming, the Morphological matrix was used in order to combine ideas into more concepts. Sketches were made of each concept in order to illustrate all concepts. All illustrations are found in appendix E.

6.1 BRAINSTORMING

Two identical brainstorming sessions were performed. The first session was performed by the authors and the second session with Volvo employees from different fields related to the topic of the thesis as well as other master thesis students at Volvo. The following people participated in the second brainstorming session:

- 1 Expert in Camera Monitor System
- 3 Ergonomics experts
- 2 Product designers
- 1 Product planner for driver environment
- 4 Master thesis students

The participants were split into two groups. One group generated ideas for the City distribution type of truck, Volvo FE, while the other group generated ideas for the Long-haul type of truck, Volvo FH.

In order to stimulate creativity the session started with a game. Both groups were provided with papers, paperclips, tape and a ruler to use to construct paper airplanes. Each group got 12 minutes to construct and select one airplane to compete with against the other team. When both groups had developed their airplane they competed against each other by throwing the airplane in a hallway. Each team got three trials and the team that threw the airplane the longest distance won. This game was conducted both in order to let people start to think in a more creative way and to create a good team spirit in both groups.

After the game, the brainstorming took place in two different rooms. The goal of the brainstorming was to create three optimum cockpit layouts for both long-haul and city distribution trucks. The session was split into five parts.

In the first part, the focus was on the direct vision where the question was raised about how the cockpit layout can be changed in order to improve direct vision. Each person got a few copies of A4-size pictures of the windows and mirrors in the current cabs, representing either the Volvo FE or the Volvo FH truck depending on group, see figure 33. The participants then described their ideas of improving direct vision by drawing or writing on the picture or by placing post-it notes on them. When the participants had brainstormed for five minutes, each person explained his or her ideas to the rest of the group. All the ideas for improving direct vision generated in both brainstorming sessions were collected in a list of ideas. Some of the ideas were the same or very similar and therefore combined. This part of the brainstorming session resulted in 27 different ideas for the Volvo FH truck and 24 ideas for the Volvo FE truck (see appendix B).

FIGURE 33: ILLUSTRATION USED IN BRAINSTORMING FOR DIRECT VISION – VOLVO FE (LEFT), VOLVO FH (RIGHT)

In the second part, the focus was on the indirect vision where a question was raised about how the cockpit layout can be changed in order to improve indirect vision. As in the first part, each person got copies of A4-size pictures to draw on. This time the picture was of the current layout either the Volvo FE or the Volvo FH without all mirrors, functions or details on the instrument panel, see figure 34. Participants were then asked to show on the pictures, how and where to place five different indirect vision views in the cockpit. The five views that were supposed to be covered were both left and right rear-views, reverse view, close-up front view and close-up kerb view (see figure 13 in section 3.3.2). As in the first part the people explained their ideas for the others after five minutes of individual brainstorming. The ideas for improving indirect vision generated in both brainstorming sessions resulted in 19 different ideas for the Volvo FH truck and 20 different ideas for the Volvo FE truck (see appendix C).

FIGURE 34: ILLUSTRATION USED IN BRAINSTORMING FOR INDIRECT VISION – VOLVO FE (LEFT), VOLVO FH (RIGHT)

In the third part of the session, the focus was on the visual in-vehicle information where a question was raised about what is the optimal placement for the visual in-vehicle information. The visual in-vehicle information was split into three categories; primary information, secondary information and active safety warnings. Each person received new copies of the same picture as in the second part which they used to show how and where to place the three different types of visual in-vehicle information. Like in previous parts the participants explained their ideas to others in the group. The number of different ideas generated in both brainstorming sessions for optimal placement of visual in-vehicle information was 22 for the Volvo FH truck and 24 for the Volvo FE truck (see appendix D).

In the fourth part, the groups combined their ideas together into complete layouts. Each group received three A1-size pictures of the current cab layout without any changes, see figure 35. The best ideas for each area were then drawn on the A1 papers to form complete and optimum layouts.

FIGURE 35: ILLUSTRATION USED IN BRAINSTORMING FOR FULL CONCEPTS – VOLVO FE (LEFT), VOLVO FH (RIGHT)
(Volvo GTT, 2016)

The groups were re-united in the fifth and last part of the session, and each group presented the three optimum layouts for their segment to the rest of the participants, see figure 36.

FIGURE 36: BRAINSTORMING SESSION - COMBINING AND PRESENTING CONCEPTS

Both the brainstorming sessions generated many ideas. When the ideas that were very similar had been combined into one and the same, the total number of different ideas generated during the whole session was 136. In total there were 9 full solution concepts generated in the brainstorming sessions, three in the brainstorming by the thesis work authors and six in the brainstorming session with the Volvo employees, see figure 37 (all concepts can be seen in appendix E).

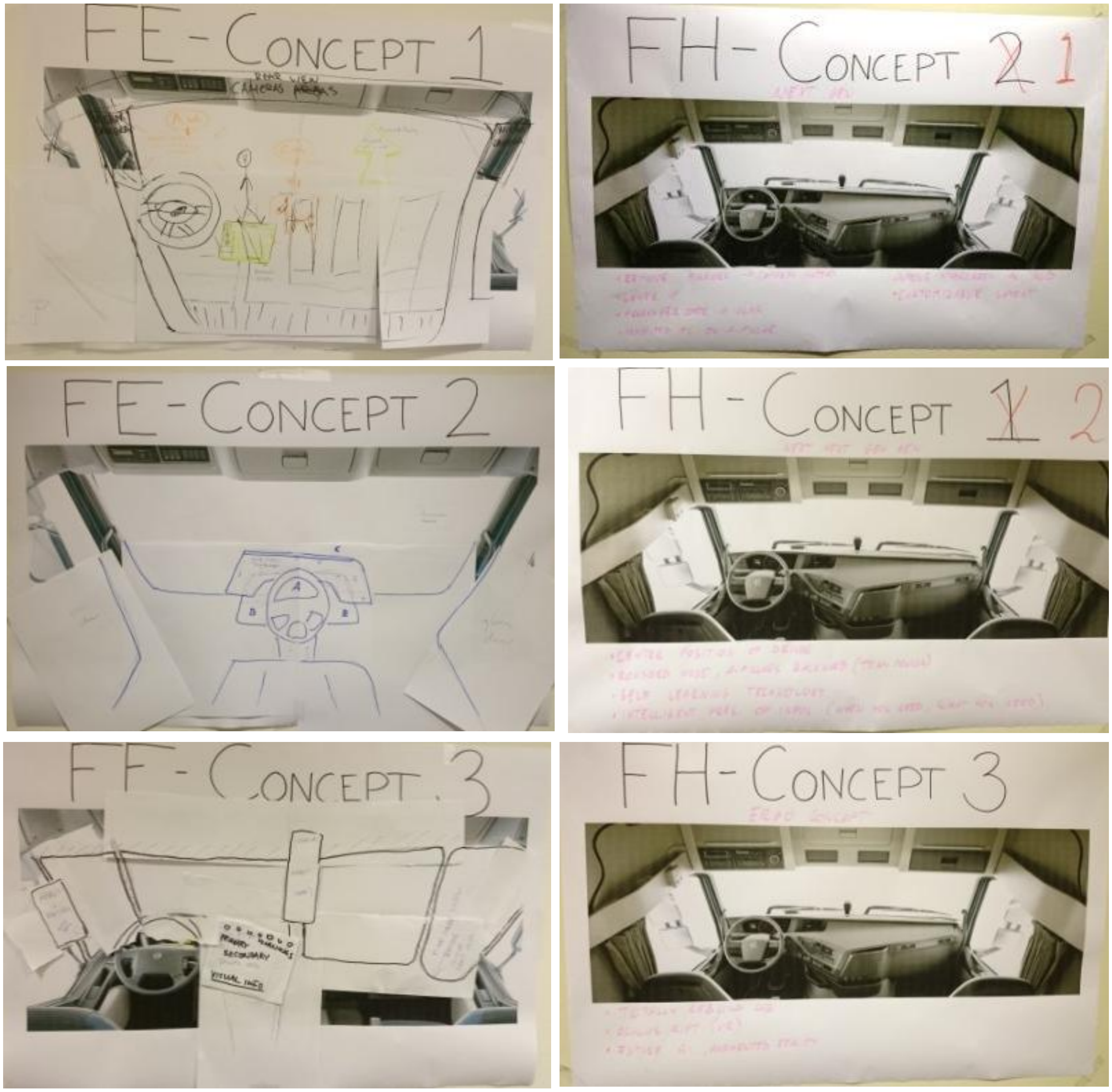

FIGURE 37: THE FULL SOLUTION CONCEPTS GENERATED IN THE BRAINSTORMING WITH THE EXPERTS

6.2 MORPHOLOGICAL MATRIX

A Morphological matrix was created and used as a method to generate full solution concepts by combining the different sub-solutions in different ways. The Morphological matrix can be seen with an example of a concept combination in figure 38. The first column of the Morphological matrix includes all the different components, views and information types of the cockpit that can be changed in order to improve direct vision, indirect vision and the positions of visual in-vehicle information. For each of these components and views, sub-solutions are placed in each row. In the cells are icons to illustrate the main aspect of each solution idea. These sub-solutions represent all the ideas generated in the brainstorming sessions as well as ideas identified from the background research.

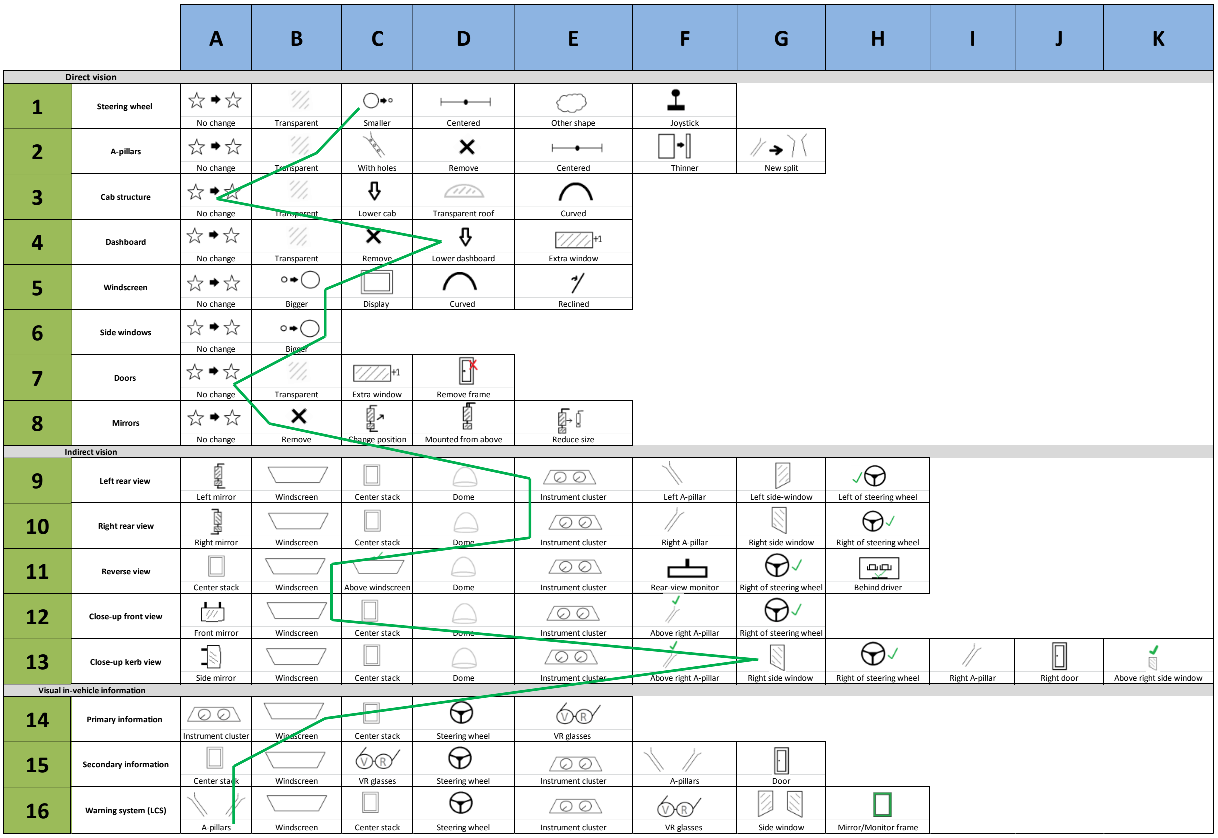

Figure 38: The Morphological matrix used to generate concepts

With all the criteria listed in one single matrix, the matrix became extensive and hard to grasp. For this reason, the matrix was divided into three parts; direct vision, indirect vision and visual in-vehicle information - one for each focus area.

Concept combinations were made independently for each focus area. All the focus area concepts were sketched by hand to further illustrate the unique features of each concept and to make it easier for the process of establishing full concept combinations.

Full concepts were created by using the sketches drawn for each focus area and combining the ones that were compatible. For instance, a concept from direct vision of having a new window split with one centred A-pillar would not be compatible with an indirect vision concept which had rear-view mirrors mounted on the A-pillars. From the Morphological matrix, 11 full solution concepts were created. The Morphological matrix contains combinations of all the previously generated ideas with differently coloured lines that combine the different ideas (see appendix F).

6.3 SKETCHES

As described in the previous section, the concepts were created by combining the different ideas listed in the Morphological matrix. Presenting the concepts solely with coloured lines in the Morphological matrix as in appendix F is not very illustrative and it makes it hard to picture what the concepts actually look like. Therefore, the use of handmade sketches has been applied. This has proven to be a quick and effective way to illustrate the result when combining feature ideas from different focus areas.

The total number of concepts created in the brainstorming as well as the concepts from the Morphological matrix was 20. In order to make these 20 full concepts easier to understand and use later in the development process, all 20 were sketched on A4 sheets, see figure 39 and appendix E.

FIGURE 39: SKETCHES OF ALL THE 20 FULL SOLUTION CONCEPTS

7 CONCEPT SCREENING

In this chapter, the initial screening of the generated concepts is described. Two Pugh matrices were created; one for the city distribution segment and one for the long-haul segment. These were used in order to grade and screen the concepts, thereby reducing the total number of concepts. In the end of this chapter, the remaining concepts after screening are described in further detail.

7.1 PUGH MATRICES

In order to evaluate the 20 full solution concepts, an initial screening was performed based on two Pugh matrices, one matrix for each segment. A cut out from one of the matrices can be seen in figure 40 and the complete matrices can be found in appendix G. All relevant requirements gathered from the background study were listed in the rows and the 20 full solution concepts in the columns. Each requirement was then weighted by the authors with value 1, 3 or 5 depending on the importance of the requirement according to the needs in each of the two transport segments. The requirement weight factors were motivated by the information gathered in the background research and theory phases. In the Pugh matrix for the long-haul concepts, the current layout of a Volvo FH truck was used as a reference concept. Likewise for the city distribution matrix, the current Volvo FE truck was used as the reference concept. Each concept was then compared to the reference for each criteria and given the number (-1), (0) or (+1) depending on if the concept was worse, equally good or better than the current layout. The net value was then calculated for each concept by summing up the number for each criterion multiplied with the weight factor value.

Criterion	Weighting	Reference	Concept 1	Concept 2	Concep
Increased front visibility for long-haul driving	5	FH cab	1	1	1
Increased passenger side visibility for long-haul driving	3	FH cab	1	1	0
Increased driver side visibililty for long-haul driving	1	FH cab	1	1	0
Reduced risk of disturbing reflections	3	FH cab	0	0	0
Conveniently placed reverse view	5	FH cab	1	1	1
Conveniently placed close-up front view	3	FH cab	1	1	0
Conveniently placed close-up kerb view	3	FH cab	1	1	0
Conveniently placed rear views LH & RH	5	FH cab	0	-1	0
A-pillars withstand ... test		...cab	-1	0	
Imp...					

FIGURE 40: A CUT OUT FROM ONE OF THE TWO PUGH MATRICES

The net value varied considerably between the concepts, and the concepts with the highest net value were different between the two transport segments, see the concepts with the highest net value in figure 41. For the long-haul segment, the three concepts that received the highest net value were concept number 2, 4 and 11. On the other hand for the city distribution segment, concepts 5, 9 and 19 were the concepts that received the highest score. The concepts are described in further detail in the next section.

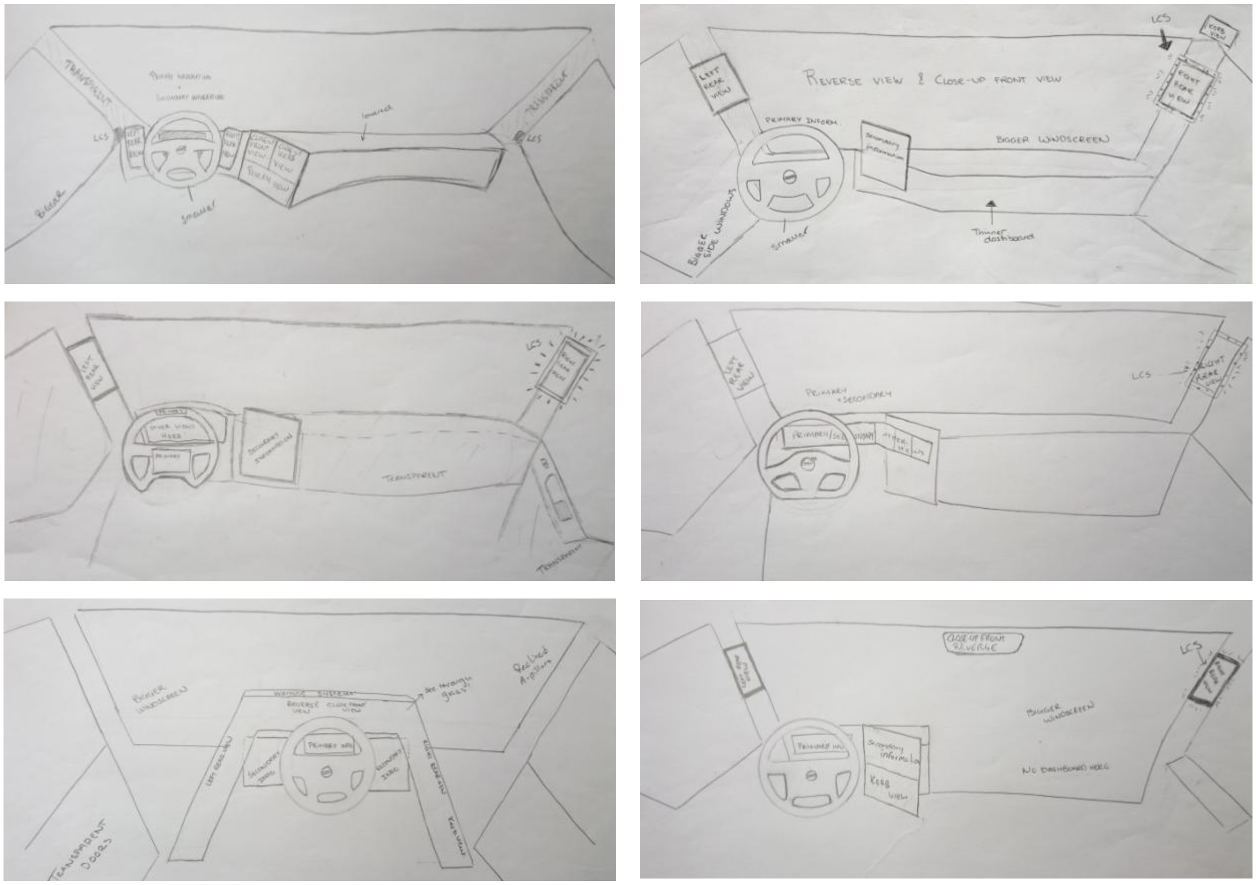

FIGURE 41: THE WINNING CONCEPTS – LONG-HAUL (LEFT), CITY DISTRIBUTION (RIGHT)

7.2 REMAINING CONCEPTS AFTER SCREENING

In this section, the concepts passing the screening process are described in detail. The concepts are presented with their respective final sketch, including descriptions of the technical features. These remaining concepts were later combined in order to create the optimum layout for each transport segment.

7.2.1 CONCEPTS FOR CITY DISTRIBUTION – VOLVO FE TRUCKS

In the following, the winning concepts for the city distribution segment are presented. Each concept has been given a work name that is somehow related to the main features of each concept. Using these three concepts and combining the most promising features, the final distribution concept was created. This concept is presented in chapter 8.

The Big windows concept (Concept 5)

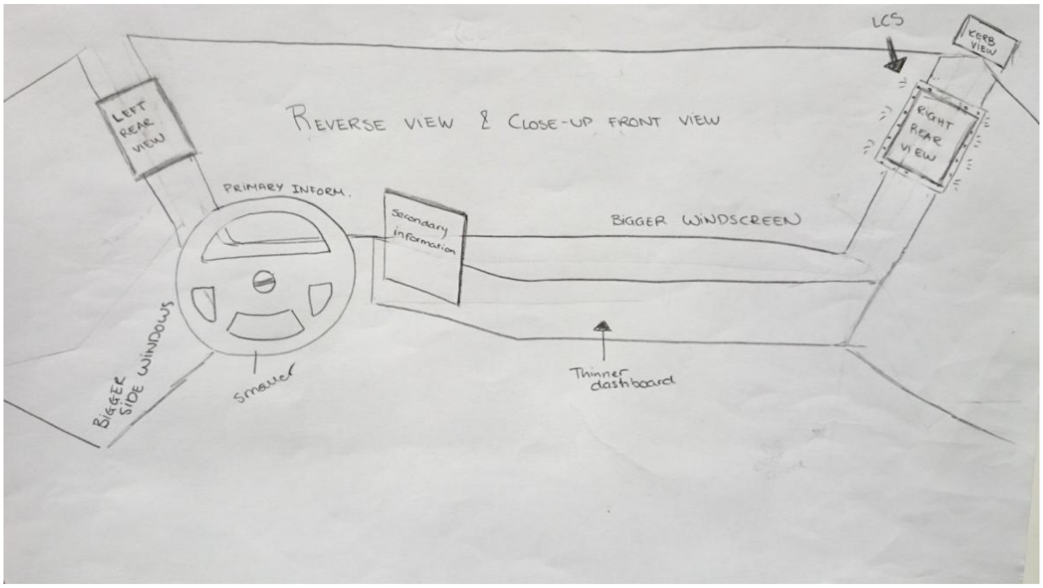

FIGURE 42: SKETCH OF CONCEPT NUMBER 5, THE BIG WINDOWS CONCEPT

As can be seen in figure 42, *The Big windows* concept has a reduced size of the steering wheel. A smaller steering wheel reduces the extent to which the steering wheel obstructs vision. This includes the area behind the steering wheel, on the instrument panel that would otherwise be covered by the steering wheel and therefore not visible and useful for the driver to provide controls or visual information. The size of the instrument panel is reduced both in height and in depth. The reduction in height gives room for an increased size of the windscreen which improves the direct vision. The instrument panel size reduction in depth gives more leg space and a more spacious feeling inside the cab. Just as the instrument panel is lowered, the doors have bigger side windows. This is an improvement of the direct field of vision to the sides of the truck.

The rear-view mirrors are replaced by a camera monitor system with monitors placed in the A-pillars. This places the views closer to the central field of view while reducing blind-spots otherwise created by the mirror housings. The reverse and close-up front views are both projected on the windscreen as Head Up Displays so that any mirror housings or camera monitors will not obstruct any extra direct vision. The reverse view is only showing when reversing the truck and the close-up front view is only showing when the situation so requires, that is when driving in slow city traffic under a certain speed. The kerb-view is shown in a display mounted above the right hand side A-pillar. Compared to the current layout this placement is closer to the centre which minimizes the required head turn. Just like the rear-views and the close-up front view, the kerb view is presented by using camera monitor systems. It is also beneficial to have this view in a rather dark place to create sufficient contrast compared to the surroundings. As the view has to be shown always, it is also beneficial to have it far away enough from the straight forward view to minimize distraction.

The primary information is projected on the windscreen as Head Up Display, in front of the driver, instead of being shown on a traditional instrument cluster behind the steering wheel. This makes the information easier to notice without any major head movements from the driver. At the same time, the removed instrument cluster gives the driver more freedom to place the steering wheel according to the specific needs in the different driving situations. This corresponds to benefits for direct vision, driving comfort as well as ease of getting in and out. The secondary information is provided in a large touch display, positioned to the right side of the steering wheel. This position is similar to the common position for secondary information displays in existing trucks. The difference is that this is closer to the driver and the touch functionality means it provides a flexible control surface that replaces different physical buttons and other controls.

The Lane Change Support (LCS) is integrated in the rear-view monitor frames. By the use of colours (red or green), the frame indicates if another road user (passenger car, motorbike, bike, pedestrian, etc.) is in the way when the driver activates the turn signals before changing lanes. Other active warning systems can be integrated in this system since the monitors are digital and thereby programmable.

A main idea of the frame warnings is that they can help to draw attention to what can be seen in the indirect vision views. As the CMS facilitates that the frames are located on the A-pillars in between the window openings representing the main direct fields of view, it should also be possible to draw attention to things happening in each of these (left side, straight forward or right side).

The Windscreen concept (Concept 9)

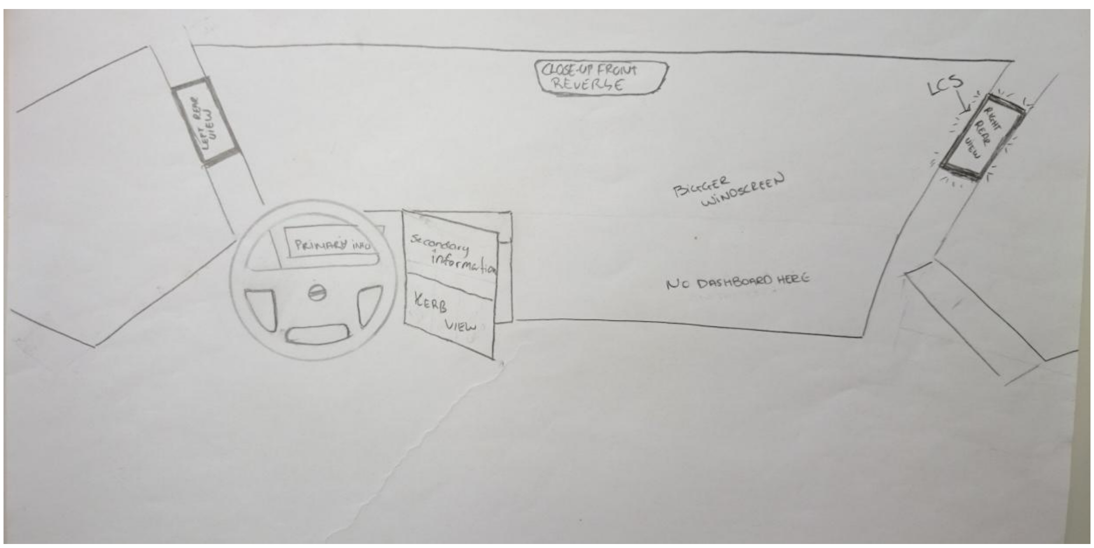

FIGURE 43: SKETCH OF CONCEPT NUMBER 9, THE WINDSCREEN CONCEPT

As the name suggests, *The Windscreen concept* has an enlarged windscreen, see figure 43. The instrument panel is partly removed to provide direct vision through the bigger windscreen. The visibility forward is dramatically improved by this and especially in the biggest blind spot area towards the passenger side. From this the need for a close-up front view should almost become redundant. However, the close-up front view together with the reverse view are both presented in a display in the upper central windscreen which bears a resemblance with the internal rear-view mirror in passenger cars. This is also necessary as the close-up front view is regulated for the ground area just in front of the truck and under speeds of 10 km/h. Just like in the previous concept, these views are alternating depending on the situation. At forward speeds below 10 km/h the close-up front view is shown and when engaging reverse gear the reverse view is shown. The kerb-view is shown on a big secondary information display next to the steering wheel in the lower half of the screen. From the regulated need to always be shown, the lower position is chosen to decrease distraction as it gets further away from the straight forward view in a similar way as the ordinary location at the passenger side window does. The upper half of the same secondary information display is dedicated to secondary information. The primary information is placed in front of the steering wheel like in the existing layout, but presented in a display. The rear-views are placed on the A-pillars in monitors using CMS and having active safety systems integrated in the monitor frames as described in the previous full solution concept.

The Continuum concept (Concept 19)

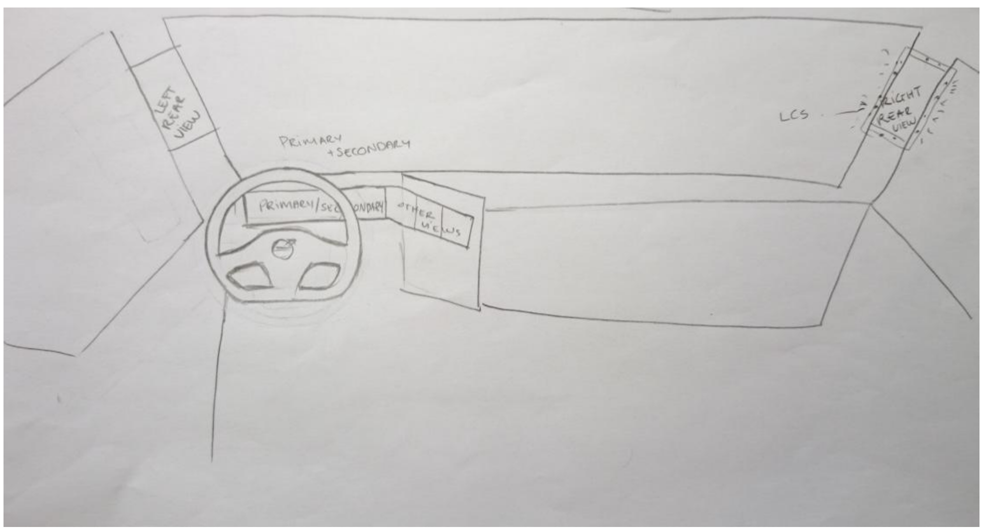

FIGURE 44: SKETCH OF CONCEPT NUMBER 19, THE CONTINUUM CONCEPT

The Continuum concept has, like the previous concepts, the rear-views presented in monitors that are placed in the A-pillars where the active safety warnings are integrated in the monitor frames, see figure 44. It has also an instrument cluster display that extends from being behind the steering wheel all the way to the right edge of the control surface in the centre of the instrument panel. In this extended information display, the primary and secondary information as well as the close-up front view, the close-up kerb view and the reverse view are shown. The locations of the different types of information are chosen according to regulated needs, detection needs, minimized distraction, and to secure visibility for all drivers independent of steering wheel position. The primary and secondary information are also partly projected on the windscreen. The parts that are shown on the windscreen and in the instrument cluster are possible to configure by the driver. The steering wheel has a non-circular shape where the lower part of the rim is removed as in some sports cars. This is to give more freedom for placing the steering wheel in relation to the body and to facilitate the entry and exit for the distribution drivers.

7.2.2 CONCEPTS FOR LONG-HAUL – VOLVO FH TRUCKS

In this section, the selected concepts for the long-haul segment are presented. Just like for the city distribution concepts, the long-haul concepts have been given work names that are somehow related to the main features of each concept. Using these three concepts and combining the most promising features, the final long-haul concept was created. This concept is presented in chapter 8.

The Sweep concept (Concept 2)

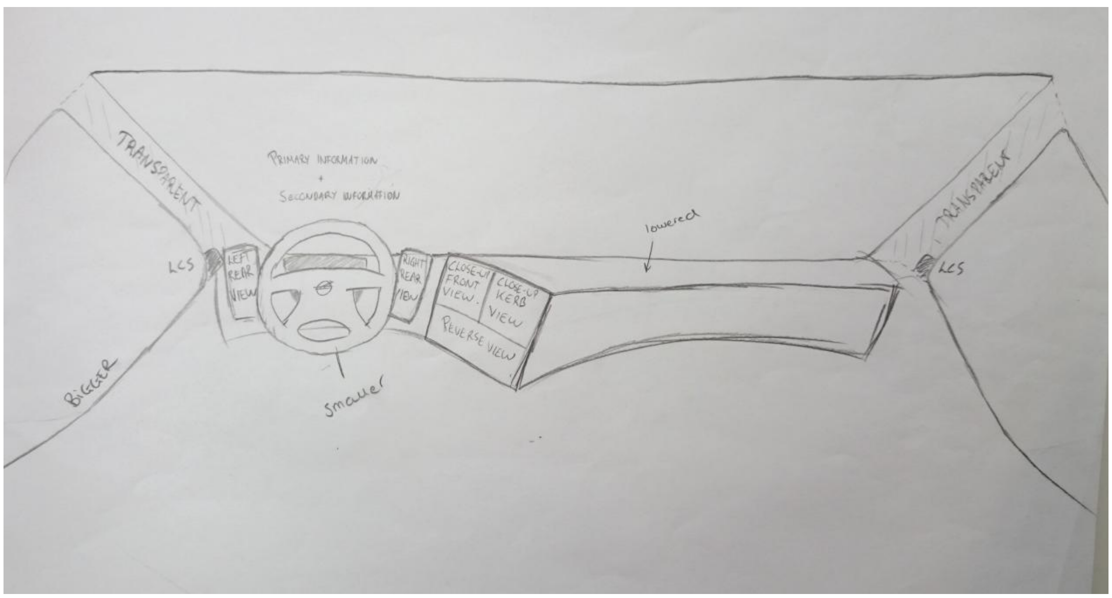

FIGURE 45: SKETCH OF CONCEPT NUMBER 2, THE SWEEP CONCEPT

The Sweep concept has a lowered instrument panel shaped in a sweeping fashion to support interior calmness, see figure 45. Because the instrument panel is lowered, the windscreen is bigger. The windscreen is also more reclined by the angle of the A-pillars. The downwards increase in windscreen size improves close-up vision downwards. The reclined A-pillars improve close-up vision upwards. The reclined A-pillars are otherwise more a result from supporting an increased aerodynamic cab shape. Getting the upper part of them closer to the driver will actually create larger A-pillar blind spots. Countermeasures to this are proposed in another concept. In order to further improve the direct vision, the door side windows are made bigger.

The conventional mirrors are removed and replaced by CMS. The rear-views are placed next to the steering wheel, one for each side respectively. The steering wheel is smaller to reduce the vision obstruction on the instrument panel and on the rear-view monitors. Thereby the available area for showing information and placing controls becomes larger. A main intention is that it will also be possible to utilize the area on the outer side of the steering wheel that is closest to the cab side. A big touch display is provided inside the steering wheel for use as control area. The reverse view is presented in the lower half of this touch display when reversing. This arrangement – compared to the previous *Big windows* and *Windows concepts* for city distribution – is chosen to secure that the reverse view can be shown at the same time as the close-up front view. This should be beneficial especially for larger vehicle combinations used in long-haul where low speed manoeuvres are more complex and take longer time. This means important observations cannot be made if only one view can be seen at a time. On the upper half is the close-up front and close-up kerb view positioned next to each other. The close-up front view is presented as required at low speeds. This means the same area can be used for other information at higher speeds or at stand-still. The close-up kerb-view is shown in the top corner furthest away from the driver to reduce distraction while driving longer distances while providing the information at all time as is needed according to regulation.

Both the primary and the secondary information are projected on the windscreen in front of the driver as Head Up Display. The layout of the content is, within certain safety and functional boundaries, possible to manage from the touch display. The active warning systems are integrated in the HUD as well as light indicators placed at the base of the A-pillars (which is similar to the existing Lane Change Support notification).

The Ghost concept (Concept 4)

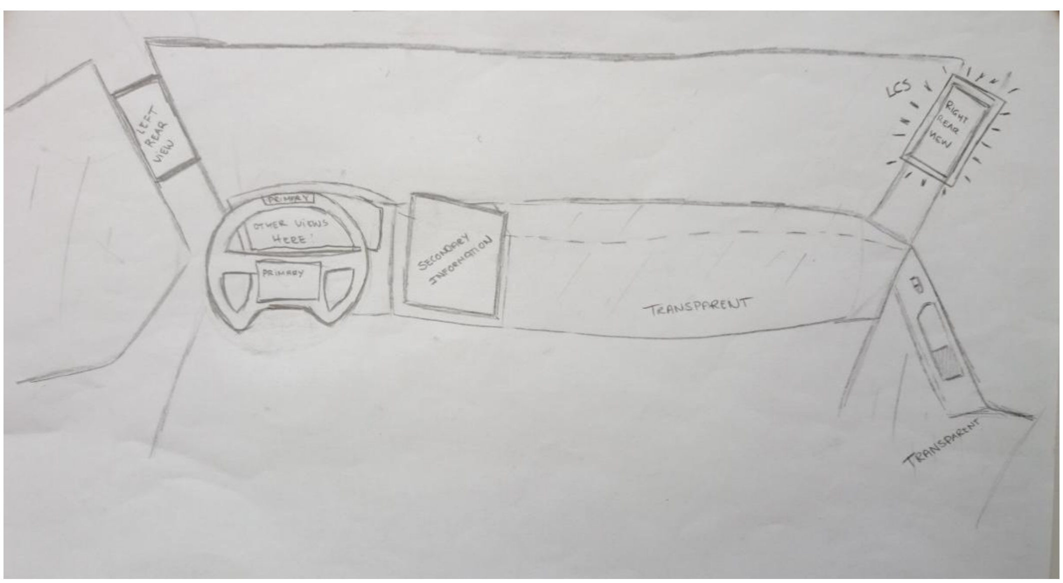

FIGURE 46: SKETCH OF CONCEPT NUMBER 4, THE GHOST CONCEPT

The Ghost concept has the focus on increasing the indirect vision, see figure 46. The instrument panel as well as the passenger side door panel are made to appear transparent. This enables the driver to see what is next to the truck as well as in front of the truck. However, the material itself is not actually transparent. The surfaces are covered by curved displays that show an image of what is outside using CMS. The image projected on the screens will therefore make the surface look transparent and the vision from the driver seat is improved. The approach is that it is the total amount of what is seen that matters, independent of whether it is via direct or indirect vision. Because of this transparency, the close-up kerb-view is integrated in the passenger door panel. Likewise, the close-up front view is integrated in the instrument panel screen and thereby eliminating the need for separate monitors. This means that the seemingly transparent parts of the interior will need to show more than exactly what is behind in order to meet the regulation requirements.

The reverse view is presented in the display behind the steering wheel. Here it will be necessary to come up with a solution to avoid obstructions of the steering wheel spokes when the steering wheel is rotated. The rear-view mirrors have been replaced by monitors in the A-pillars, together with integrated active warnings systems in the monitor frames. The primary information is presented on the steering wheel which has two displays, one of which is integrated in the steering wheel rim and one in the steering wheel centre. The steering wheel is also shaped in a non-circular way, removing the lower part of the steering wheel to provide more room and adjustment flexibility for the driver. This is considered appropriate in a long-haul vehicle where the majority of the time is spent driving more or less straight ahead and drivers also tend to be bigger with higher demands for space. The smaller space required by the steering wheel will also facilitate getting out of the seat and into the cab for access to the living area.

The secondary information is presented in a big touch display placed directly inboard of the steering wheel to be used as the main control area. The display is angled towards the driver for ease of operation. The active safety warnings are placed in different places according to need within the steering wheel display, the instrument cluster, the upper part of the touch display and in the rear-view monitor frames. Thanks to the alternative locations, warnings can be provided where they give the best effect.

The Dome concept (Concept 11)

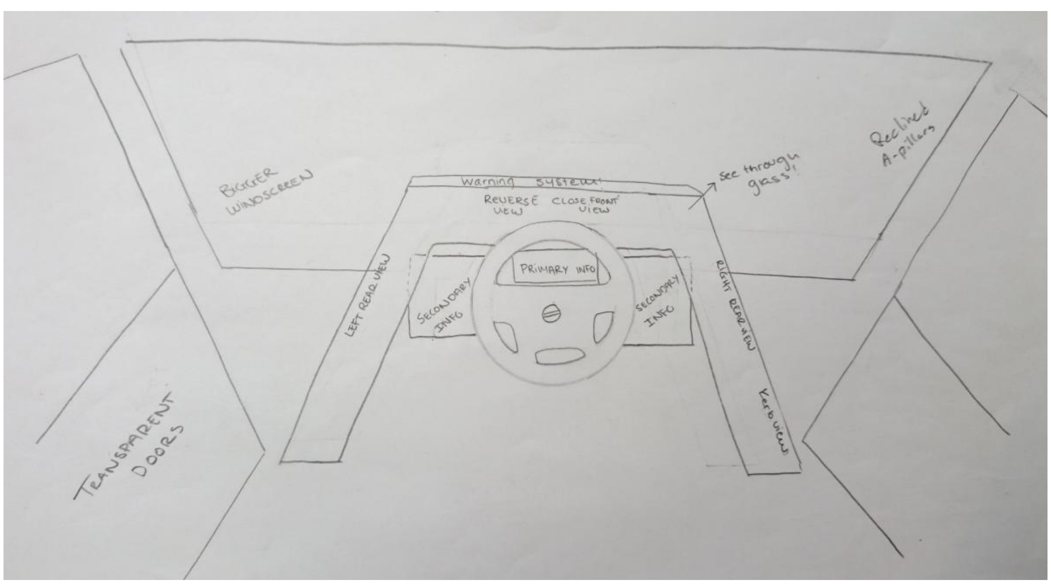

FIGURE 47: SKETCH OF CONCEPT NUMBER 11, THE DOME CONCEPT

The Dome concept has the driver placed in the centre of the truck for increased and equal visibility of both sides. As illustrated in figure 47, the driver is surrounded by a half dome like array of glass displays. This should beneficially also be free-form, e.g. like part of a sphere as long as the technology can provide it. When not showing any images, this dome is see-through because it is actually a large combiner glass of a Head Up Display. These glass displays present all the different views around the truck. The rear-views are presented on the sides, together with the close-up kerb-view which is positioned to the far right in the glass dome. In the top of the combiner glass dome there is an array made for active safety warnings that can indicate where the danger is by light signals on different locations along the array that corresponds to the location of the immediate danger outside the vehicle.

The windscreen is reclined and curved around the central driver position to further increase direct vision by bringing the drivers' eye-points closer to the windscreen and thereby making the viewing angles larger from the same size window. This can be compared with how it would be to sit in the centre of a glass sphere. The windscreen is also made bigger because of the removed instrument panel obstructions. Both the driver and the passenger doors are made transparent in a similar fashion as for the Ghost concept, that is by using curved displays and cameras that show what is behind the display.

The instrument panel has been removed all together and primary and secondary information is presented on screens next to the steering wheel below the glass dome. These work at the same time as control surfaces thanks to touch functionality and follow the steering wheel to provide best reach and visibility independent of driver size.

8 FINAL CONCEPT DEVELOPMENT

In this chapter, the final concepts for both transport segments are presented with detailed descriptions and illustrations. The concepts are a result from combining the three full solution concepts left after the screening process as described in section 7.4. The two final concepts were sketched in detail on A4-papers, implementing all the information gathered along the way. These detailed sketches were then transferred into 3D models in Catia V5. In these sections, the final concept for city distribution and long-haul will be presented. The solutions in the concept are described in detail and illustrated with both sketches and CAD model illustrations.

8.1 FINAL CONCEPT FOR CITY DISTRIBUTION – VOLVO FE TRUCKS

A more detailed sketch of the final concept for the city distribution was drawn after combining the most promising features from the three winning concepts according to the Pugh matrix evaluation, see figure 48.

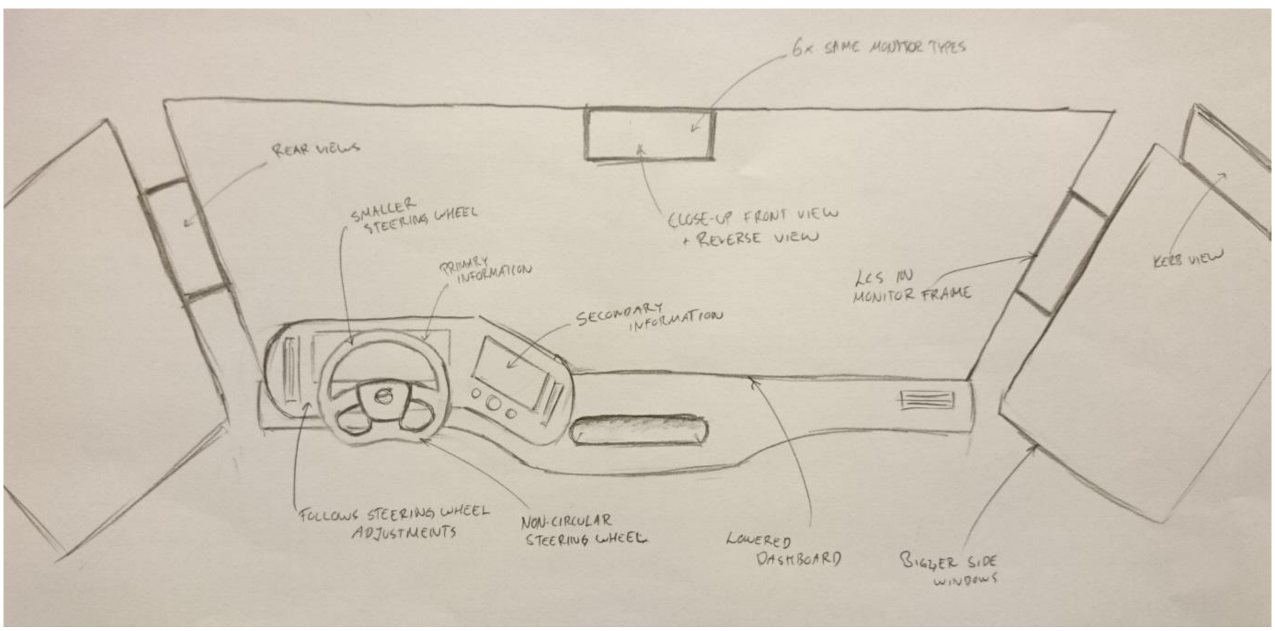

FIGURE 48: SKETCH OF THE FINAL CONCEPT FOR THE CITY DISTRIBUTION TRANSPORT SEGMENT

The direct vision, indirect vision and the area for visual in-vehicle information have been increased significantly with this concept. First of all, the instrument panel has been lowered considerably and the windscreen increased in size by extending it downwards. This results in better direct vision forward.

The instrument panel is split in one lower and structural part that is fixed and one smaller upper part that follows the steering wheel adjustments. The lower and fixed instrument panel part is symmetrical with respect to the cab centre in order to cut cost when the layout is used for left or right hand side driving, see figure 49. The upper part follows the steering wheel which means that reach and visibility of information become optimized for each driver at the same time as the obstruction of direct vision is minimized.

FIGURE 49: FULL LAYOUT OF THE VOLVO FE TRUCK

FIGURE 50: RIGHT HAND SIDE A-PILLAR OF THE VOLVO FE TRUCK CONCEPT

To increase the direct vision to the side, both side windows have been made bigger, that is extended downwards like the windscreen. Another change that has improved the direct vision even more is the deleted blind-spots from all mirror housings having been removed. This means that the area behind the existing mirrors is no longer blocked. By removing the mirrors, the truck also becomes more aerodynamic and therefore more fuel efficient. A secondary benefit is that it becomes easier for the driver to manoeuvre in tight places with smaller things sticking out from the truck.

Instead of having the main rear-view mirrors and the wide-angle rear-view mirrors, the CMS technology will be used. The displays for these views are placed on the A-pillars where they do not block any additional direct vision, see figure 50. The CMS technology will also be used instead of the other close-up mirrors. The display for the close-up kerb-view will be located slightly above the side window on the passenger side. This location follows the natural behaviour of an active distribution driver and is also in an interior area within shadow that helps reading with sufficient contrast to surrounding light.

The close-up front view together with the reverse view will be shown in a display in the top-centre location of the windscreen which is similar to the internal mirror location common in passenger cars or vans, see figure 51. These views will be automatically controlled based on speed or if the reverse gear is engaged. There will also be an opportunity for the driver to show both views simultaneously if that is needed. The area hidden behind this display will be used for sensors such as the rain sensor and sensors needed for the emergency brake system which will need to be placed there, thus there are no extra blind spots created.

FIGURE 51: THE INSTRUMENT PANEL AND CLOSE-UP FRONT VIEW MONITOR

The reason for picking a fairly traditional layout regarding the locations for the different indirect vision views is that it is very common that drivers swap vehicles and have a main experience from driving smaller vehicles like delivery vans. By using the CMS technology, bigger fields of view that are easier to understand can be shown in the display compared to what the mirrors show, thus improving the total amount and quality of indirect vision. The quality increase comes from the fact that both distortions and brightness can be controlled and adapted according to needs and surrounding light conditions. The displays are also placed closer to the driver compared to the mirrors which makes it easier for the driver to overview and notify surrounding objects.

For the city distribution trucks, it is important to keep the cost down since the truck is very much used as a work tool and customers are not that willing to pay for extra features unless they provide significant benefits in their daily life. In order to keep the cost down, all displays are therefore of the same size. 12 inch displays were found to be a suitable size to be able to see all views sufficiently well.

As mentioned initially, another noteworthy change is that the instrument cluster and the secondary information display now follow the adjustments of the steering wheel together with the upper instrument panel which also includes air vents and some main controls, see figure 52. This means that it does not matter in what position the steering wheel is regarding the visibility of the instrument cluster or the visibility out through the windscreen. Since the air ducts also follow the steering wheel adjustment they are also always well positioned for the driver. This is an important factor since the city distribution drivers are going in and out of the cab frequently and therefore need direct and good compensation both for cold and warm variations in the climate. A display will be placed behind the steering wheel as an instrument cluster and the primary information located there includes the speedometer, the fuel level, etc. The secondary information, such as navigation and audio system functions, will be in a display right beside the steering wheel directed towards the driver.

FIGURE 52: ADJUSTABLE UPPER INSTRUMENT PANEL FOR THE VOLVO FE TRUCK

The steering wheel has also been changed significantly. It is both smaller in diameter and the shape is changed with a bottom part that is more flat. This gives more comfort for the driver as smaller motions are needed when turning the wheel and as it gets easier to get in and out which is very frequent in city distribution transports. These changes enable drivers to get better opportunities to stay closer to the steering wheel. There has also been an intention to create steering wheel spokes that are more ergonomic to grip just like handle bars when going slightly longer distances.

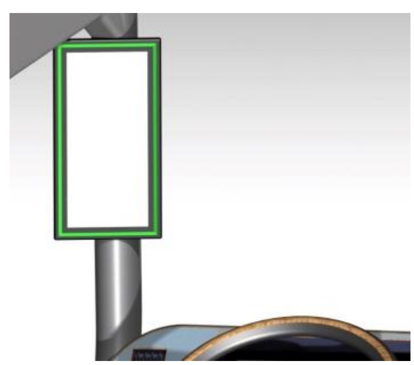

FIGURE 53: ACTIVE SAFETY WARNINGS

The last change is the active warning system for manoeuvres like changing lane. The Lane Change Support will now be positioned in the display frame of the rear-views on the A-pillars and the warning signal is indicated with green or red LED lights, see figure 53. It would also be possible to use alternative ways, such as lighting up different number of frame segments corresponding to the criticality of the situation. This means that when the driver turns on the indicator in order to change lanes, the frame around the rear-views either turns red or green depending on if there is another road-user next to the truck and how critical the situation is. If it is safe to change lanes, the frame either turns green or remains unlit but if there is a vehicle in the way the frame turns red or yellow. This feature will make it quicker for the driver to detect if it is safe to change lanes, the driver will even know before looking in the rear-view displays. This same warning strategy can also be used for other critical driving situations like object detection for front, side and rear. A short description of the final concept can be seen in table 1.

TABLE 1: SHORT DESCRIPTION OF THE FINAL CONCEPT FOR THE CITY DISTRIBUTION SEGMENT

	Components	Changes from existing layout
Direct vision	Steering wheel	Smaller, Changed shape, No buttons
	Windscreen	Bigger downwards
	A-pillars	Used for displays
	Instrument panel	Lowered and divided into a fixed lower part being symmetrical and an upper smaller part that follows the steering wheel adjustments
	Side windows	Bigger downwards
	Mirrors	Removed
Indirect vision	Rear-views	CMS, displays located on the A-pillars
	Reverse view	CMS, display located in top-centre of the windscreen
	Close-up front view	CMS, display located in top-centre of the windscreen
	Close-up kerb view	CMS, display located above the right side window
	Displays	All displays are the same size
Visual in-vehicle information	Primary information in instrument cluster	Display, visible through the steering wheel. Follows the steering wheel adjustments.
	Secondary information	Touch display located right beside the steering wheel. Follows the steering wheel adjustments.
	The active safety warnings (e.g. LCS)	Red/yellow/green light, located in the display frame of the rear-view displays

8.2 FINAL CONCEPT FOR LONG-HAUL – VOLVO FH TRUCKS

After combining the winning full solution concepts for the long-haul transport segment according to the Pugh matrix evaluation, a detailed sketch was drawn of the final concept for the Volvo FH truck, see figure 54.

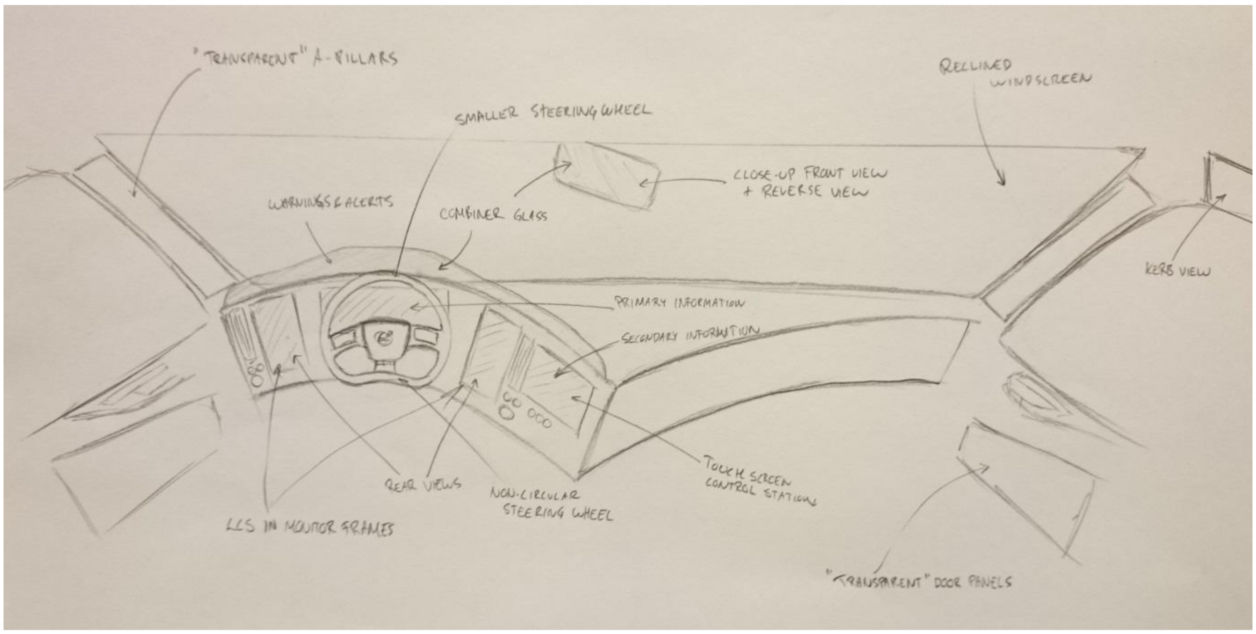

FIGURE 54: SKETCH OF THE FINAL CONCEPT FOR THE LONG-HAUL TRANSPORT SEGMENT

The final concept for the Volvo FH truck has been changed significantly from the existing layout. The windscreen is more reclined to support improved aerodynamics. This means the driver can see a larger angle upwards when it comes closer to the driver's eye-point. At the same time the vision obstructions from the A-pillars get bigger and it becomes harder to position ordinary rectangular displays on them. To compensate for these drawbacks, the driver has been moved towards the cab centre which reduces the driver side obstruction and the A-pillars are made transparent with camera displays that show what can be seen behind them. The same technology is used on the doors in this concept, making them partly transparent, see figure 55. This provides indirect vision views in areas where direct vision is hard to achieve when located high above the ground. All the blind spots behind the mirror housings have been deleted by replacing the mirrors with cameras. This is at the same time making the truck even more aerodynamic.

FIGURE 55: FULL LAYOUT OF THE VOLVO FH TRUCK

The steering wheel has been changed considerably. First of all it has been moved 14 cm to the right which means the driver is sitting more towards the centre of the cab. This reduces the blind spot from the left side A-pillar, improves the vision on the right side somewhat and above all creates space on the left side of the steering wheel for more controls and displays. The latter is also supported by a significantly reduced diameter of the steering wheel. This means it requires smaller movements for steering and obstructs a much smaller part of the instrument panel increasing the area for controls and displays even further. Finally, the steering wheel shape is non-circular, with enhanced gripping opportunities onto the spokes, and the spokes hold more control functions. These things create more comfort for the driver. According to information gathered from the interviews, long-haul drivers of today are often overweight. The removal of the lower part of the steering wheel will therefore also provide better opportunities for adjusting into a good steering wheel location with respect to the body in cases of a protruding stomach.

The instrument panel in this concept is more wrapped around the driver in order to have everything centred and close to the straight-forward field of view, see figure 56. In long-haul driving it is clear that this is the main focus area. The depth of the instrument panel has also been reduced on the passenger side to create more leg space for a passenger. The design of the instrument panel opens up opportunities for placing displays beside the steering wheel on both sides in a symmetrical fashion. The main rear-views and the wide angle rear-views will be shown in these displays by using the CMS technology. By placing the rear-views beside the steering wheel they get even closer to the straight-forward viewing direction and the CMS technology can show bigger fields of view, improving indirect vision.

FIGURE 56: FULL LAYOUT OF THE VOLVO FH TRUCK

The CMS technology will also be used for showing the kerb-view. The display will be placed above the side window on the passenger side, not creating any blind spots and staying far enough to the side for avoiding unnecessary distraction, see figure 55. Remember it has to be on at all time. The reverse view and the close-up front view will on the other hand be shown with the HUD technology in a combiner glass located in the top-centre of the windscreen, see figure 57. The high location is chosen to avoid the risk of obstructing objects on the ground. These views will only be shown when needed at lower speeds or when reverse gear is engaged. At other times it will therefore be possible to see through the glass.

The HUD technology will also be used to show important visual in-vehicle information. This will be achieved by placing a see-through combiner glass on top of the instrument panel which shows the right information at the right time and location. Other types of information will be presented in an instrument cluster display seen through the steering wheel and a big touch display located to the right of the driver. In order to save cost, all displays are of the same size as in the final city distribution concept except the touch display which is bigger in this concept to provide a main large control area. The active safety warnings will be positioned in the display frames of the rear-views beside the steering wheel, indicated with green, yellow or red LED lights. When used as Lane Changing Support the driver can quicker detect if it is safe to change lanes without even looking at the display. The display frame can be used for other alerts as well (e.g. proximity detection, etc.). In addition to this it is also likely that the A-pillar displays providing the transparency feature will also be used to show additional information to the driver. This information can also concern warnings, but also other types of information. A short description of the final concept can be seen in table 2.

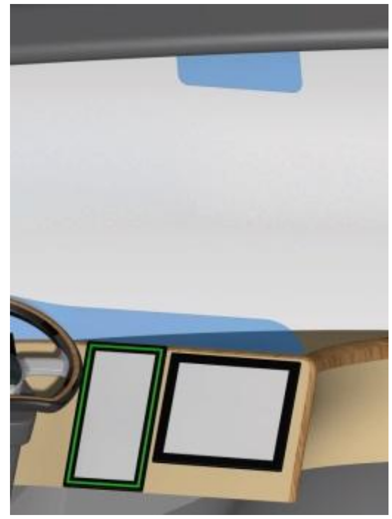

FIGURE 57: COMBINER GLASS IN THE UPPER WINDSCREEN OF THE VOLVO FH TRUCK

TABLE 2: SHORT DESCRIPTION OF THE FINAL CONCEPT FOR THE LONG-HAUL SEGMENT

	Components	Changes from existing layout
Direct vision	Steering wheel	Smaller, Changed shape, More buttons, Moved to the right, Improved grip opportunities
	Windscreen	Reclined for improved aerodynamics
	A-pillars	Transparent thanks to CMS
	Instrument panel	Designed around the driver and thinner on the passenger side
	Doors	Partly transparent thanks to CMS
	Mirrors	Removed
Indirect vision	Rear- views	CMS, displays located on both sides of the steering wheel
	Reverse view	HUD, combiner glass located in top-centre of the windscreen
	Close-up front view	HUD, combiner glass located in top-centre of the windscreen
	Close-up kerb view	CMS, display located above the right side window
	Displays	All displays are the same size, except the touch display and the transparency displays on A-pillars and doors
Visual in-vehicle information	Primary information	HUD and a display. Combiner glass located above the steering wheel and an instrument cluster display visible through the steering wheel
	Secondary information	Located in a touch display beside the right rear-view display
	Active safety warnings (e.g. LCS)	Red/yellow/green light, located in the display frame of the rear-views

8.3 EVALUATION OF THE FINAL CONCEPTS

In this section, the final concepts for both long-haul and city distribution are evaluated. The CAD models were used to test the concepts on requirements such as space for driver and visibility. These tests were performed using requirement surfaces representing different driver manikins and different vision cones to make sure the concepts comply with the main requirements from Volvo. A questionnaire was also used to get feedback on the concepts from involved experts.

8.3.1 TESTING CAD MODELS AGAINST ERGONOMIC REQUIREMENTS

The final concepts for both the Volvo FE truck and the Volvo FH truck were tested against the ergonomic requirements listed in the requirements list (see appendix J). In figure 58 below, an average size manikin is placed in the driver seat as illustration. From fulfilling the listed requirement models, the concept will fulfil leg clearance, reach and internal visibility requirements.

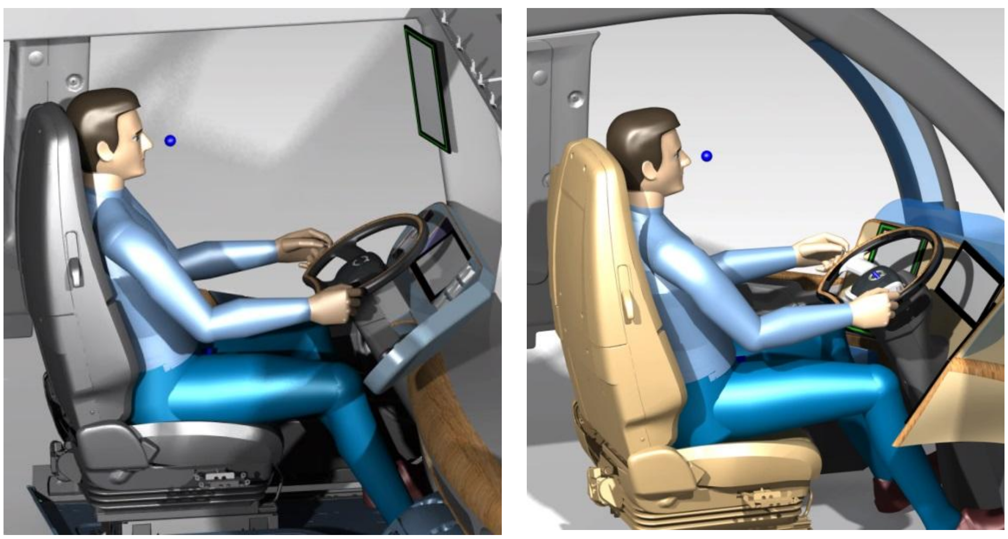

FIGURE 58: MANIKIN POSITIONED IN DRIVER SEAT – VOLVO FE TO THE LEFT AND VOLVO FH TO THE RIGHT

The combined knee clearance surface that represents the needs for all driver sizes are included in figure 59 and figure 60. As a result the knee clearance was not interfering with the instrument panel, door panel or steering wheel in neither of the concepts. This means that this requirement was fulfilled for both layouts.

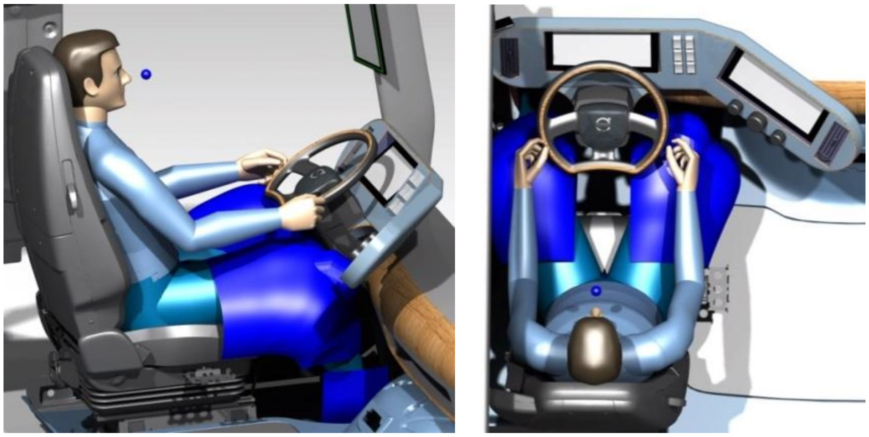

Figure 59: Knee clearance for the Volvo FE truck

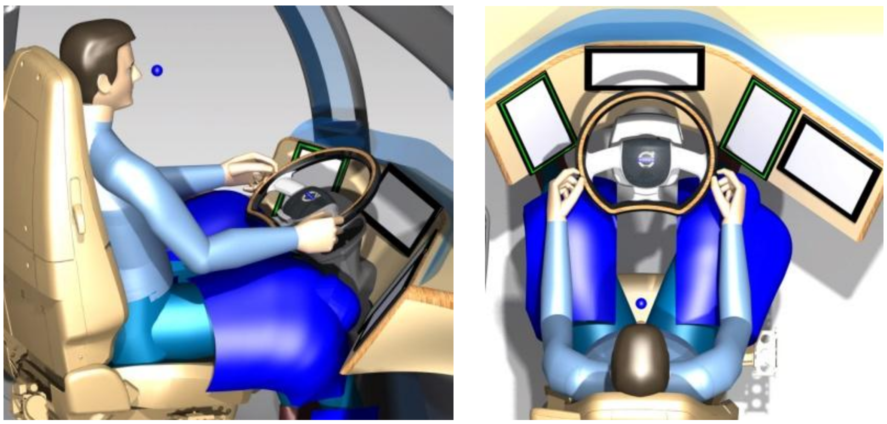

Figure 60: Knee clearance for the Volvo FH truck

The detection cone for visual information can be seen in figure 61. The instrument cluster ended up inside the cone in both concepts and therefore this requirement was fulfilled for both layouts.

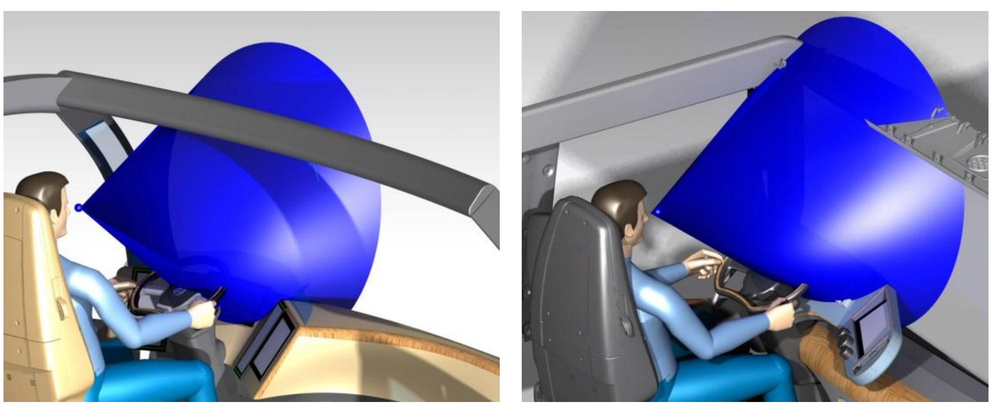

Figure 61: Detection cone – Volvo FH (left) Volvo FE (right)

8.3.2 EVALUATION QUESTIONNAIRE

In order to evaluate the final concepts, an evaluation was carried out based on a questionnaire (see appendix H). The participants were the same experts within different fields that had participated earlier in the thesis work, either in the interviews (see section 4.3) or in the brainstorming sessions (see section 6.1). Together with the questionnaire, descriptions of the final concepts and pictures of the CAD models were sent out to the participants. The questionnaire consisted of six questions considering both the final concept for long-haul and city distribution transport segments. Each question consisted of both a grading scale with space for comments and open ended questions. Six experts responded to the questionnaire and the data was analysed and illustrated in the following graphs. The answers to the questionnaire can be seen in appendix I.

The responses for the first question show that all participants found the vision of the surroundings to be either good or very good for both segments, see figure 62. Participants also turned out to be satisfied with the position of the visual in-vehicle information for both segments according to the second question where the answers ranged from good to excellent, see figure 63.

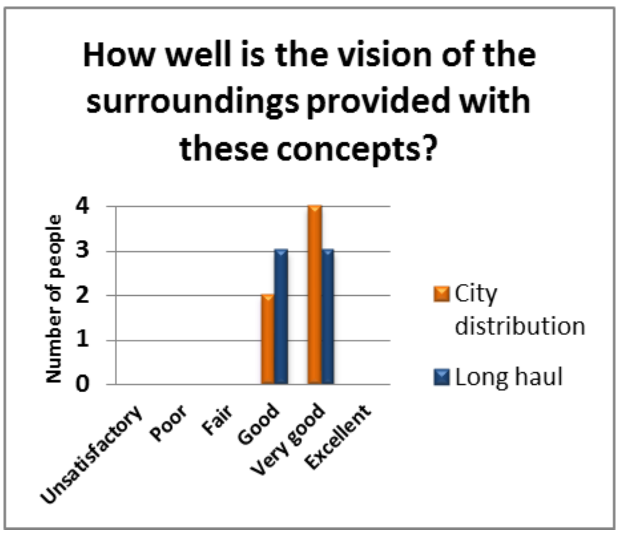

FIGURE 62: QUESTION 1 IN QUESTIONNAIRE

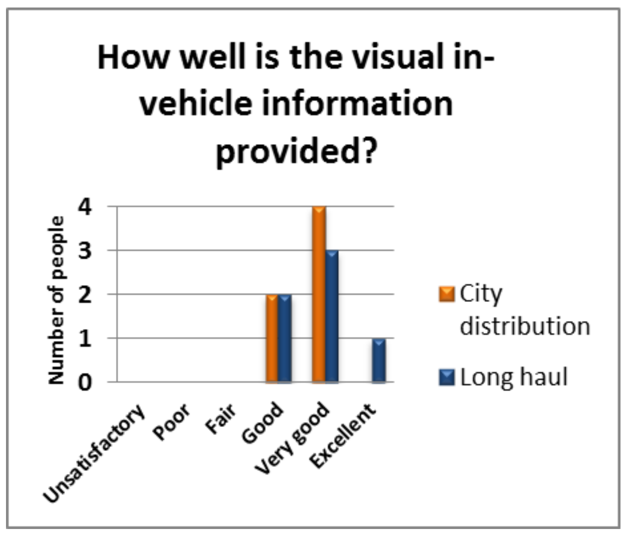

FIGURE 63: QUESTION 2 IN QUESTIONNAIRE

The answers for the third question showed that both concepts were on average found to be suiting future visions of development from the experts' point of view, see figure 64. However, one of the participants found the final concept for the long-haul segment to be only fair. According to the responses from question number four, the opinion of the cost efficiency of the concepts varied between respondents for both segments, see figure 65. The answers ranged from fair to excellent for both city distribution and long-haul.

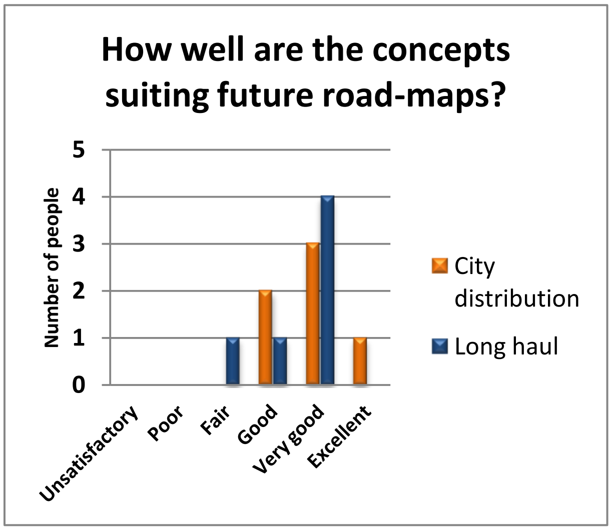

FIGURE 64: QUESTION 3 IN QUESTIONNAIRE

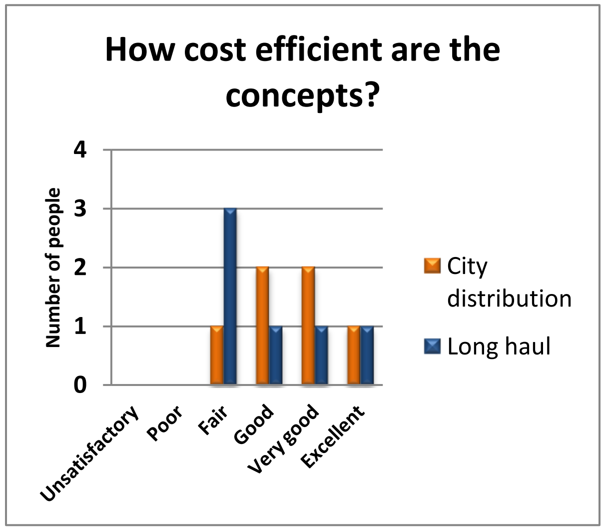

FIGURE 65: QUESTION 4 IN QUESTIONNAIRE

The answers from the fifth question show that both concepts are well adapted for their transport segments, see figure 66. Most of the participants found the concepts being very well adapted to their respective segment. However one person found the concept for the long-haul poorly adapted. The sixth question showed that most participants found the visual information well positioned for both segments in order to increase safety or comfort, see figure 67. Only one participant found the position poor in the concept of the long-haul.

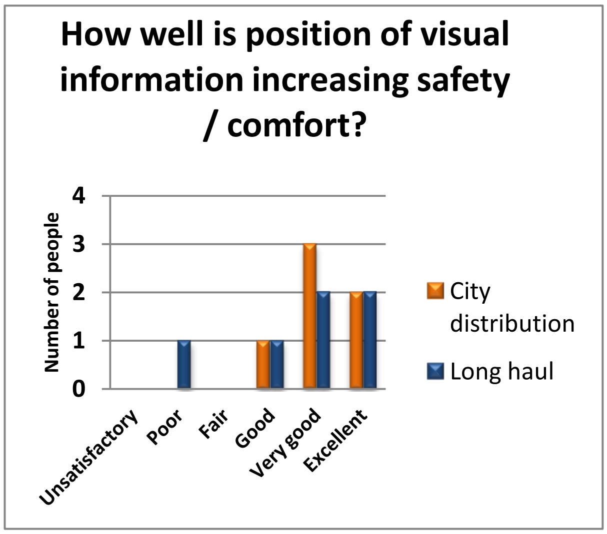

FIGURE 66: QUESTION 5 IN QUESTIONNAIRE

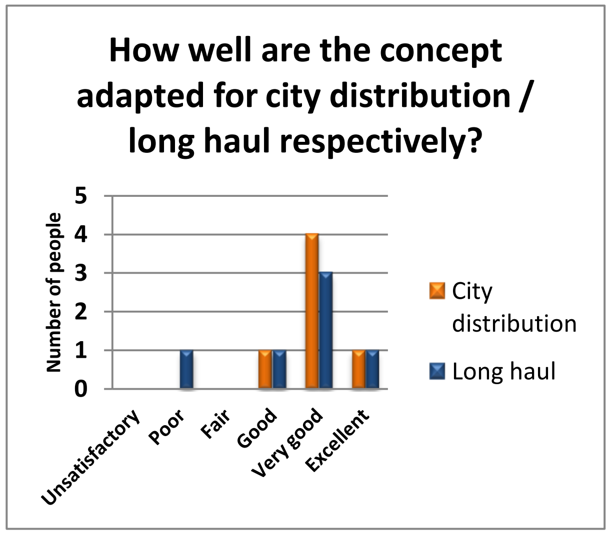

FIGURE 67: QUESTION 6 IN QUESTIONNAIRE

All the questions had space for an open-ended answer in order for participants to give feedback for both of the concepts. These considerations can be seen in the following paragraphs.

First question – how vision of the surrounding is provided with the concepts

For the city distribution concept two of the participants praise the extended windscreen and the side windows, stating that it improves direct vision. However, two others pointed out that it might be beneficial to have a window on the doors as well. Some design factors were mentioned like making the instrument cluster part more symmetric and smaller and make the instrument panel even smaller. One of the participants liked that the CMS is closer to the line of side compared to the mirrors while providing similar indirect vision. It was also mentioned how good it is to increase similarities with smaller vehicles since the drivers often drive both. The layout was found to be far better than today, having logical and clear improvements.

For the long-haul concept two of the participants mentioned that they liked the transparency in the truck both the doors and the A-pillars. They were said to be beneficial, improving the direct vision sideways. One of the participants, however, questions the display on the driver side. The rear-view displays were found to be placed too low according to three of the participants and one person found the SID too big and intrusive. The layout was found logical regarding choice of layout, technology and balanced to needs.

Second question – how the vision of the visual in-vehicle information is provided with the concepts

For the city distribution concept, two of the participants mentioned that it is beneficial to have the instrument cluster part following the steering wheel to secure that much more is visible for all driver sizes. The CMS was also found to have relevant positions. It was also mentioned by one participants the possibility of providing a detachable display at the left A-pillar or also having a HUD also in this concept.

For the long-haul concept the wrapped around HUD was mentioned as a good improvement of a few participants. Having symmetric layout around the driver was also seen to be right for the long-haul application. There were, however, different opinions about the display locations on the HMI panels, one person found it good while two others said there were too many displays on the HMI panel which might cause confusion for new drivers. One participant found that more information should be provided on the A-pillars.

Third question – How well the concepts support future road-maps

The city distribution concept was found to resolve the main problems in simple ways and reduce cost by thinking differently. This concept was also found to be in line with the development of the CMS regarding display positions and the warning system in the display frame was found to be a good idea.

For the long-haul concept, the opinions about the display location of the rear-views varied between participants. One person found it key for the concept of how symmetric they were arranged and providing opportunities for using the A-pillars for other information while another person did not like the position of the rear-view monitors.

Forth question – How cost efficient the concepts are considered to be

The city distribution concept was seen as cost efficient mentioned specifically by three participants. The choice of multifunctional controls and SID was mentioned as an appropriate and simple solution. It was pointed out that the upper instrument panel module could have been made more symmetric with alternative installation of a SID on the left hand side. One participant pointed out the fact that the number of plastic parts is reduced which saves investment cost in tooling.

For the long-haul concept, three participants assumed this concept to be expensive with the amount of displays, the reclined windscreen, the A-pillar solution and the HUD. One mentioned on the other hand that the CMS together with aerodynamic benefits due to reclined windscreen should make driving more cost efficient which can perhaps justify a higher price. The number of plastic parts reduced was seen as cost beneficial since, again, it saves cost in tooling.

Fifth question – How well adapted the concepts are for city distribution/long-haul respectively

For the city distribution concept, it was mentioned to be well adapted to city distribution thanks to the improved direct vision. One participant, however, argued that it might be better with an extra window on the passenger side and perhaps also further to the rear. It was found to be good to use the same display for the close-up front view and the reverse view. The smaller steering wheel was also mentioned as a benefit in order to easily enter and exit the cab. Another participant found that this concept covered the main issues for the city distribution segment such as improving direct vision, being cost efficient and making it easy to get in and out.

The long-haul concept was mentioned by one person as well adapted due to aerodynamic benefits which will attract more drivers. This layout was also considered to be accepted by drivers and the driver position appropriate for long distance driving. The proposals of the concepts were found to show a clear understanding of the priorities among the different aspects in long-haul such as improving direct and indirect vision and minimizing distractions.

Sixth question- How well the position of visual information increases safety/comfort

For the city distribution concept it was mentioned that having the primary and secondary information displays following the adjustments of the steering wheel should mean big improvements as the relation to the drivers stays the same. Two persons said that the position of the indirect vision views are all safer than in the current layout and a proper SID was seen as good improvements for the Volvo FE truck. Everything was seen to be in a reasonable distance and the layout found to be clean with less unnecessary information and interfaces that should increase safety and reduce cognitive workload.

For the long-haul concept, it was stated that the symmetric cockpit module has good potential as well as the transparent A-pillars. The LCS light in the frame of the CMS displays was also thought as interesting. One person found the solution for the HUD realistic and that it is appropriate to have most information close to the line of sight.

9 DISCUSSION

In this chapter, the thesis work is discussed regarding what methods were used, the final concepts that were chosen and what makes the results viable. In the end of this chapter there is a discussion about what could be suitable for future development work.

9.1 METHODS

In this section, the methods used in this thesis are discussed. The aspects considered in these discussions are mainly why the methods were used, how using the method worked out and a general explanation as to the different decisions taken.

9.1.1 BACKGROUND RESEARCH

The theory and background research were conducted in order to gain sufficient insight of the topic in order to be able to contribute to this field of research. The chosen methods for gaining this knowledge in addition to the literature study were observations, benchmarking and interviews. This provided the necessary starting point of the thesis. The following sections describe the most relevant aspects of each method used within the background research study.

Observations

The cab observations were executed by the authors in loan trucks provided by Volvo GTT. It gave the authors valuable insights into the truck both when stationary and during driving. The target was to identify problems within the three interest areas; direct vision, indirect vision and visual in-vehicle information.

The outcome of the observations might have given more if the truck drivers would have been asked what they would like to improve with the layout. This approach was considered but not implemented due to the fact that previous user studies involving truck drivers for Volvo had shown that the input from truck drivers is not always valuable for this type of study. It can be beneficial to get the truckers input, but for the topic of this thesis, while interesting their responses would most likely be more concerned with the present and not so much future ideas for improvement of cockpit layouts.

Benchmarking

The different segments investigated in the benchmarking were future trucks, cars, sports cars, vans and pickup trucks. These five segments were selected based on the authors' own experience as well as on input from colleagues about what segments could be interesting to learn from. The aim was to learn what elements influence how the cockpits are designed. A collection from each segment was grouped to find common traits. These traits were analysed and used as conclusions for what drives the development in different transport segments based on the different user needs.

Knowing how different usages affect the layout of cockpits was used in the remainder of the development project as both inspiration and as a means of screening concept in the concept generation and screening. Also knowing what is on the market today, and what different manufacturers predict as possible trends for the future were useful pieces of information in order to decide on how far in the future the outcome of this thesis would be aimed for.

Interviews

The ten interviews that were conducted resulted in a considerable portion of useful information as input to this thesis. The interview form was a mixture of face-to-face and Skype interviews. The authors do not believe the outcome would change considerably if all interviews would have been conducted with the interviewees in the interview room. The reason for the mixture is of a practical nature, since many of the interviewees were located in France or Brazil.

As can be seen in the interview guides, all the interviews were of a semi structured nature (see appendix A). The interviewees had different backgrounds as well as areas of expertise which motivated different questions. Additionally, the reason for conducting the interviews was to find out the perspectives from all the different occupations included in the interview stage which is why different questions seemed appropriate.

The outcomes from the interviews were different views on development within the cab department, as well as on limitations regarding development and technology. It was also interesting to learn about the considerations in development as well as future ideas and trends that the different interviewees provided.

Common for the interviewees is that they all had development roles within Volvo GTT. Because this is a development project that eventually is aimed at improving the user experience, it might seem appropriate to conduct user interviews. This was, however, considered to not be as productive as interviewing development roles within Volvo. According to previous studies at Volvo, interviewing truck drivers about their wishes of improvement for the future is not always beneficial. Since the thesis scope included a considerable amount of different features and components, it would have been difficult to get any specific answers. As for many other development projects, the end users do not know what they want until they get it which was also the case here. Therefore, it was decided to continue with internal information and input until there were presentable suggestions for improvements. Having suggestions for improvements makes interviewing drivers easier since they can simply decide whether they like what is presented to them or not. This is why it would be suitable to include drivers at this stage and moving forward.

During the project, making the transcriptions of all the interviews took a considerable amount of time. Instead of putting this effort into transcribing, perhaps the time could have been used to focus on collecting more interviewees. Most of all it would have been interesting to interview people working with Human Machine Interface to create an even wider knowledge base for the project.

9.1.2 REQUIREMENT SPECIFICATION

In order to deliver realistic concepts and to keep the project within the project limits, requirements were listed as guidelines for the project. The requirement specification list was updated regularly during the thesis process as new knowledge was gained about the different aspects of developing new cockpit layouts. The list of requirements was used mainly in the Pugh matrix for screening out concepts that did not fulfil the set requirements and to benefit the ones that did. The requirements were also used in the evaluation of the final concepts in order to check with the ergonomics requirements.

9.1.3 IDEA GENERATION

Because of the creative nature of idea generation by brainstorming, people working with product development might argue that it is a non-scientific method that lacks evidence of being an effective tool to be used in development projects. On the contrary, the brainstorming session conducted in this thesis were highly productive and are believed by the authors to have suited the purpose of the project exquisitely because of the many different ideas and holistic concepts generated.

The reason for choosing this creative method as the means of generating new ideas was simple. The nature of the, in some ways, conservative truck development and the nature of this exploratory thesis undermined the importance of generating out of the box thinking. Although the screening requirements sorted out the wildest ideas, the aim was to start the selection process with as many ideas as possible in order not to miss out on any potential winning concepts. Since the delivery of this thesis was aimed for future trucks and development it was essential to have ideas that traversed the current common practices.

The idea of having participants with different backgrounds and levels of truck experience worked out well. Also, dividing the group in the second brainstorming session into two separated groups doing the same work resulted in an interesting outcome. Not only did the groups come up with diverse individual ideas, but also different views on how to present the final total concepts. This led to an inspiring discussion at the end of the brainstorming session.

9.1.4 CONCEPT GENERATION AND SCREENING

In this section, the three methods of the generation and screening process are discussed. The following sections discuss the most relevant parts of each method.

Morphological matrix

This method for generating more concepts based on previously generated ideas has been proven to be an effective tool for both authors in previous projects. It is a simple tool that works well in combination with ideas generated from brainstorming sessions.

Because of the wide spectrum of focus areas considered in the thesis and the large amount of ideas from the brainstorming, the matrix became too large to be effective. This is why it was divided into smaller parts, as described in section 7.1. Already from start, the Morphological matrix is an effective way to make many concepts out of ideas. The drawback is that the amount of concepts that can be generated is usually astronomic. This case was no different because of the many ideas in addition to the many components included in the matrix. Therefore, an element of uncertainty exists as to whether or not the optimum concepts are part of the final outcome from the Morphological matrix. However, despite the number of possible combinations, this number is not actually true. There was a portion of judgement based on knowledge from the background research that determined what ideas where possible to combine into a single concept.

Sketches

Sketches were used as the main means of illustration during the concept generation and screening process. Albeit requiring a certain degree of talent to complete, sketches proved to be an effective way to illustrate ideas and concepts in order to understand how promising different concepts are.

Pugh matrices

In order to screen the concepts, Pugh matrices were used; one for each segment. Using Pugh for screening out concepts with requirements worked well. A Pugh matrix is not always used with weighting factors, but the authors found it suitable to include these because of the many requirements with different importance that were included in the matrices. By introducing weighting in the matrix, some concepts get leverage against the others depending on the requirement importance. This means the weighting factors have to be carefully chosen, as these may have a major impact on the result. The weighting factors were set based on the identified differences between the segments. Because of the leverage caused by the weighting values, they constitute a source of error. The authors were aware of this fact and took this into consideration while evaluating the results from the Pugh matrices. This was considered by carefully choosing weight factors by the respective importance of each requirement. The benefit with Pugh is that it is possible to see what features generate the higher grades as well as the lower grades. By monitoring this, the highly rated features can be identified and integrated in the final concepts.

Since people working with product development may argue that Pugh does not provide the absolute truth in selecting one winner, the authors compensated for this drawback by including the three concepts with the highest scores in each matrix. These were subsequently combined into the two final concepts. This way, the highest rated features were carried on into the final concept, thereby reducing the risk of discarding any potential winning ideas.

9.1.5 FINAL CONCEPT DEVELOPMENT AND EVALUATION

In this section, the methods included in the final concept development and evaluation phase are discussed. The section is divided into parts, each discussing the methods used.

CAD models

The final concepts were created in CAD for illustration purposes as well as for testing. Having the layouts as a 3D model instead of a 2D sketch or image makes describing features easier. The models proved efficient for achieving realistic looking concepts. It would have been interesting to see how the concepts would look if they were refined and optimized even further. The models of the concepts could have been compared to the models of the existing cockpit layouts to see the differences.

The reason for choosing to model the concepts with CAD was simple. There are alternatives such as making physical prototypes. In this case, where future concepts which potentially could be very different from the existing solutions, the process of making physical prototypes would be neither time nor cost efficient. For this reason it was decided to make the concepts in CAD.

Testing against ergonomic requirements

After the CAD models were created, it was easy to test the ergonomics requirements to make sure these were fulfilled. The ergonomic requirements were expected to be fulfilled since the concepts were created with the current layouts used as geometrical guidelines.

The process of testing against ergonomic requirements within the CAD environment is relatively quick. Therefore it is easy to implement to make sure the concepts are within the required measurements. It would have been interesting to include more requirements in the evaluation to confirm the pros and cons with both concepts and make changes accordingly.

Questionnaire

The questionnaire aimed at providing feedback from the people involved in the thesis in previous activities. Because these individuals were already acquainted with the project, it was considered sufficient to use a questionnaire mailed to each one rather than inviting people to a presentation for instance. Returning to the same individuals who had been involved previously in the project also seemed like a proper way to close the loop.

The thesis involves multiple different components and features and the participants in the questionnaire represent their field of expertise and development. It is only reasonable to assume that the participants would pay more attention to their own component or feature. One common trait among the replies is that higher grades were given to the features in the concepts that fulfilled their future roadmaps than those that did not.

The number of possible answers was deliberately chosen to be an even number, in this case six, so that participants had to choose if the answer would be positive or negative. In hindsight, the different answer options could be revised in order to make the outcome more valid. Important would be to make sure that the three positive grading options have the same nuance as the three negative.

For the questionnaire to have a more substantial importance, it would require more participants. Not everybody replied to the questionnaire. About one-third of the recipients returned their questionnaire. The reason for this relatively low answer rate could have to do with the formatting of the questionnaire. To receive more replies it could be an idea to make it even easier for participants to fill out the questionnaire, especially since many of the requested participants in this questionnaire have busy schedules. It would also have been interesting to not only receive more answers, but from more disciplines within Volvo to get as many views and perspectives on the concepts as possible.

9.2 FUTURE WORK

Before Volvo decides to implement the two concept suggestions, there is a need for further studies and development. In this section, the most relevant steps to consider for further development are presented.

With 3D-models of the suggested cockpit layouts, it is suitable to conduct more evaluation activities. In addition or as an alternative to questionnaires, focus groups could be a productive way of analysing the concepts. Drivers from the two segments could be invited and discuss the different aspects of the concepts in groups and thereafter provide feedback in the form of grading together with comments. In this way, the groups could come up with individual solutions to the segment by hearing what other views and ideas other truck drivers have.

The idea for the handover of this project to Volvo is for the department to conduct user reviews in a driving simulator. This is used as an inexpensive way to try out future ideas without the need for prototyping, which in this case most likely will be expensive. Before the simulator studies can begin, the concepts presented need to be further refined in order to meet all the requirements. It could also be interesting to put the CAD models of the two concepts in different critical traffic scenarios. When doing so, a side by side comparison with the existing layouts should be made to illustrate the actual improvements for each concept. There should also be studies to quantify the improvements based on measurable requirements with the concepts.

In order for the concepts to be possible to implement, there needs to be further development of the HVAC system. In both concepts, the instrument panel has been reduced in size which is possible only if the climate system is reduced in size. One idea that seems interesting to look more into is to redo the system from scratch and let it be pressurised like in airplanes. This way, both the air ducts transporting the air as well as the air vents would take less space making it possible to reduce the size of the instrument panel. In line with this idea is for the Volvo FH to have the air vents placed above the driver. If the climate system is under pressure, the temperature control of the cab will be more effective and thereby reducing the need to have the air flowing directly on to the face of the driver.

Furthermore, the details about the monitors included both in the city distribution and in the long-haul concepts need to be studied further. The studies need to treat cost and longevity as well as display technology and the long term effects for drivers of using displays during night time.

In order to further develop the concept suggestions, it would be interesting to see what possibilities would arise if the steering wheel column was no longer needed. As mentioned in section 4.3, the idea of having the steering wheel not connected by hydraulics should make space for other features and/or more space for the driver. Generally, the concepts presented need to be further refined in order to meet all the requirements.

10 CONCLUSION

The results from this thesis will be used for further development within this field of research. The two CAD models will be used fully or partly in the future research of the optimum cockpit layouts and solutions to include in the future for Volvo Trucks. This chapter will answer the three research questions posted as a base for this thesis work in section 1.3.1.

What are the differences between the two market segments that need to be considered when developing new cockpit layouts?

The most apparent conclusion to be drawn about the segment differences is the positioning on the market. The Volvo FE truck is a distribution truck that is used as a tool with price sensitive buyers. Technology and other extra features are kept to a minimum in order to make the truck as an effective working tool as possible. The distribution truck drivers spend almost more time outside the truck than in it. Frequent stops at delivery and pick-up destinations mean the drivers are constantly getting in and out of the truck. Consequently, development that is improving the ease of entry and exit is needed. Because the Volvo FE truck is used as a tool, it is important for the cockpit to support the driver with work related supporting features. In practice, this means the cockpit should have space for storing documents, pens, order handling tools and other common items that are part of the distribution work. A general problem for the Volvo FE concept is that it is hard to attract drivers to the distribution truck driving business. In the development work, this means making the cockpit layout attractive as well as simple and intuitive. Another important aspect that is specific to the distribution segment is the need for direct visibility. This is motivated by the city traffic and common traffic jams that surround the truck. In many cases, unprotected road users are also part of the city traffic. These can easily be hidden in front of or by the side of the truck which means the driver has to pay close attention to what is happening around the truck.

The Volvo FH truck is positioned as a premium model. This means the truck buyers are less price sensitive and expect more features to aid the driver in the work. The Volvo FH drivers spend most of their work day inside the truck driving for long stretches without breaks. It is therefore important to make the environment in the Volvo FH truck as pleasant as possible to support living in it, bearing clear resemblances to the needs of an actual home. In practice, these needs means offering a calm, spacious and comfortable environment in the cockpit, an instrument panel adapted to the driver as well as providing storage for personal items. Another need that distinguishes the Volvo FH truck segment from the Volvo FE one, is the importance of fuel consumption, which for the cab development means improving the aerodynamics.

How should visual information be positioned to increase safety/comfort/ease of use for the driver?

Visual information should be positioned differently depending on what transport segment is considered. If considering the long-haul segment, the direct vision is important but not as critical as for the city distribution segment. This means the driver position can be moved slightly to the right to provide a better overview around the truck. Consequently the space between the left side door and the driver has increased. This makes it possible to have an instrument panel that surrounds the driver on both sides of the steering wheel without compromising ease of entry and exit of the vehicle. This position supports the long-haul driving in both comfort and ease of use.

The safety is increased by having the rear-views positioned closer to the line of sight, which for the long-haul segment is mainly forward. Along the top of the instrument panel that surrounds the driver there is an extended combiner glass that supports head-up display technology. This glass is transparent when not in use and, thus, does not impair the direct vision. The combiner glass can project warnings and alerts to the driver in different positions along the glass, thereby indicating in an intuitive way where the danger is coming from. There is also a combiner glass mounted in the centre, directed towards the driver. In this display, the front close-up view as well as the reverse view are presented. Since these views are only needed in special situations (driving slowly and when reversing) the display does not obstruct direct vision while driving on the highway. Additionally, the safety has increased by improving the indirect vision by having what appears as see-through A-pillars and see-through door panels. Both these components are covered by a screen projecting the view from a camera mounted on the opposite side on the outside of the truck.

For increasing the direct visibility at the same time as lowering the fuel consumption, the A-pillars are reclined. This creates a bigger windscreen and the driver’s eye-point is closer to the windscreen which improves the direct field of vision. Furthermore, the cockpit layout is designed in a sweeping motion around the driver with uncluttered surfaces which provides a calm atmosphere in the cockpit. This increases safety as it lowers the cognitive load on the driver who directs the focus on the road instead of the interior.

For the city distribution, safety has benefitted by increasing the direct visibility. This is accomplished by lowering both the instrument panel and the doors. This was identified as a wish and a trend for distribution vehicles because of the close traffic that the distribution vehicles experience when in use. The rear-view mirrors are placed closer to the driver, although not as close as for the long-haul concept. In the city distribution the driver is more active in looking out for surrounding traffic by using both direct and indirect vision. Therefore, having the rear-views placed on the A-pillars will improve safety not only by bringing the views closer to the driver but also by removing the current mirrors and thereby increasing the direct visibility. Active safety systems are integrated with the frames of the rear-view monitors on the A-pillars, colour coded light emitted from a bar around the monitor display.

The reverse and close-up front views are both presented in a display mounted in the same place as rear-view mirrors in cars. This placement is intuitive which makes the operation of the truck easier. The ease of use for the city distribution concept has also been improved by reducing the size of the steering wheel as well as giving it another shape for easier entry and exit for the driver. The instrument cluster is attached to the steering wheel column which means the instrument cluster is always in the same place relative to the steering wheel. This feature eliminates the problem of the steering wheel obstructing the view of the instrument cluster at certain adjustment positions. The primary information is visible through the steering wheel in the display located in front of the driver. The secondary information is presented in a display to the right of the steering wheel.

What measures in the development work can be taken in order to keep cost to a minimum?

Implementing new technologies will cost more than the older technology solutions they are replacing. When the technology is new, it will always be costly to implement it in the trucks regardless of segment position. Depending on the technology, the maturation process might take several years which could make the implementation tough to motivate from a cost perspective. Nevertheless, the new technologies are in most cases developed in order to increase safety for the driver. According to one of the interviewed experts in Head Up Displays, if the new technologies improve safety, that is an argument that weighs heavier than the argument of cost.

To optimise the cost of the final concepts, certain measures have been taken into consideration during the development work. The steering wheels are the same for both concepts. The only difference is that the Volvo FE truck has no controls on the steering wheel while on the Volvo FH truck, a control module is attached to the steering wheel.

The rear-view mirrors with active safety warnings are the same for both concepts. In the concept for the Volvo FE truck, all the displays in the cockpit are of the same type and size in order to save cost. Another cost saving in the Volvo FE truck is the instrument panel that has a symmetric layout as well as uncluttered surfaces thanks to the integration of touch functions instead of physical buttons. To conclude, the Volvo FE concept is more cost efficient than the concept for the Volvo FH truck. However, this is in line with the expected outcome. The Volvo FH truck is allowed to cost more than the Volvo FE because of its market position as a premium model which is why high tech solutions are implemented in the final solution.

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APPENDICES

A. INTERVIEW QUESTIONS

Instrument panel design specialist

1. What are the main requirements that limit the design?
2. What are the main factors (systems/components) that drive the general geometric layouts (both for Volvo FE and Volvo FH)?
3. Symmetry, what drives and what are the benefits of how symmetric the design can be made?
4. What are the main components/systems that put restrictions to the design?
5. What dictates the total size of the largest components that needs to be packaged within the instrument panel
6. What are the differences in design approaches that need to be applied for long-haul and city distribution vehicles?
7. What would be the most beneficial changes to optimize the design and cost levels – are there differences for long-haul and distribution vehicles
8. What would be the most wanted changes to surrounding parts of the cab in order to optimize the instrument panel design even further?
9. What beneficial standardization opportunities can you see – related both to part cost and development cost?
10. What are the main interesting new technologies that would make a change to the design work?
11. What needs to be solved in order to implement new known technologies in the most optimum way? (Head Up Displays / large monitors for showing information / touch displays / new air bag solutions / etc.)
12. Do you have any ideas of how future optimized instrument panel layouts should look like in a distribution and in a long-haul vehicle?
13. Are there other things that we have missed to talk about regarding instrument panel designs?

Camera Monitor System specialist

1. What camera views should be implemented?
2. What are the main requirements that limit the design of Camera Monitor Systems?
3. What are the alternative concepts for providing the indirect views for the driver?
4. What are the main things that need to be solved in order for Camera Monitor Systems to be implemented in the vehicle?
5. What are the main cost benefits you can foresee when replacing mirrors with Camera Monitor Systems (development and product cost as well as reduced drag effects on fuel consumption)?
6. Are there certain design opportunities that could be utilized in order to drastically lower cost?
7. When the regulation allows, what do you think are the natural steps for introducing Camera Monitor Systems replacing mirrors within trucks?
8. What type of monitors would you like to use (LCD / OLED, Touch screens, curved, what material, HUD?)?
9. How big do the monitors need to be – how are automotive standards developing?
10. What factors affect the choice of monitor (impact/scratch resistance, glare, durability)?
11. What would be the most wanted changes to surrounding parts of the cab in order to optimize the instrument panel design even further?
12. What is your future vision of monitor placement both in distribution and long-haul vehicles?
13. What are the main added functionalities that the introduction of Camera Monitor Systems will facilitate?
14. Are there other things that we have missed to talk about regarding Camera Monitor Systems?

Advanced cockpit concepts specialist

1. What are the main design opportunities you can see for future cockpit designs?
2. What are the main factors/systems/components that drive the layout of an advanced cockpit design (both distribution and long-haul vehicle)?
3. What are the main differences in needs between long-haul and city distribution?
4. What are the main designs limitations that you think need to be taken into consideration? (product design, technologies, manufacturing, cost, etc.)
5. Are there main things about the cockpit layout that should be explored further in order to optimize the design according to needs? (Symmetry, the way parts are arranged or grouped etc.)
6. What would be the most beneficial changes to drastically reduce the cost levels?
7. Do you see any cost benefit with making larger standardized modules? (Think: big monitor/touch screen. No need to change panel layout for every update of infotainment system, etc.)
8. How should the included components within the cockpit be arranged in order to get a significant improvement to the layout opportunities?
9. What are the main interesting new technologies that would make a change to the cockpit design work?
10. What needs to be solved in order to implement new known technologies in the most optimum way? (Head Up Displays / large monitors for showing information / touch displays / new air bag solutions / etc.)
11. Do you have any ideas of how future cockpit layouts should look like in distribution and long-haul vehicles?
12. Are there other things that we have missed to talk about regarding advanced cockpit designs?

Display technologies specialist

1. What is the latest in display technologies?
2. Can new display technologies provide additional functions for the drivers?
3. Are there cost benefits with introducing new known technologies (product cost as well as development cost)?

Regarding HUD designs:

4. What are the main functions that a HUD can provide better for the drivers?
5. What options exist regarding HUD – are there radically different alternatives that can be looked into?
6. What needs to be solved in order to implement HUD in the vehicle?
7. What is possible to include in the HUD (performance wise)? Colours? HD? Overlays?
8. What are the main systems/components/factors limiting the implementation of HUD?
9. What are the main benefits / drawbacks of projecting the image on the windscreen or on an internal combiner glass?
10. What is the optimum combiner glass type to use for HUD?
11. What in the HUD design would mean a radical cost reduction?
12. What information is most common to place in the HUD now and in the future?
13. Are there any regulations that govern what can be shown in a HUD?
14. What about concepts where a larger-scale see-through HUD could replace most of the instrument panel?
15. Where is the HUD concepts and technology heading in the future?

Regarding touch displays:

16. What do you see as the main benefits of touch technologies?
17. What plausible options exist regarding touch technology?
18. What are the main design requirements that must be considered when implementing touch displays?

19. What about the design freedom with touch displays? (Curved monitors, integration in existing physical controls, etc.)

20. What are the opportunities for handling reflections and glare?

21. What in the touch display design and implementation would mean a radical cost reduction?

22. What do you see at the future applications of touch displays in distribution and long-haul vehicles?

23. Are there other things that we have missed to talk about regarding display technologies?

Head Up Display (HUD) development specialist

1. What are in your opinion the most important benefits of introducing HUD technologies in trucks?
2. What are the main alternative ways that HUDs can be implemented into trucks?
3. Are there some key obstacles that need to be solved in order to facilitate implementation of HUDs in trucks?
4. Where is the HUD technology heading in the future?
5. What is possible to include in the HUD (performance wise)? Colours? HD?
6. How big projection picture is possible – what would facilitate larger scale projection areas?
7. What are the main systems/components/factors limiting the development of HUD?
8. What would be the best opportunities for reducing cost of HUD technologies?
9. What is your opinion about a concept where the entire upper instrument panel is replaced by a wrap-around see-through HUD where the driver can still see through the windscreen behind it?
10. How should the surrounding cockpit develop in order to support HUD integration in the best possible way?
11. Do you see modularization opportunities that would support the integration of HUD technologies?
12. Are there other things that we have missed to talk about regarding HUD implementations?

Product Designer

1. When designing a cockpit in a truck, what do you consider to be the most important aspects to remember?
2. Can you illustrate the previous with an overview of some previously considered advanced cockpit layouts?
3. What do you consider as the most interesting new ideas to explore for future cockpit layouts?
4. Are there ways in which cockpit designs could become more flexible to support different usages (that might also work for coming automated vehicles)?
5. Are there ideas for modularization that you think are important to keep in mind in cockpit designs?
6. Are there different approaches that should be used when designing cockpits for long-haul trucks compared to distribution trucks?
7. What are your intentions for how new technologies like HUDs, CMS and touch screens should become used in the best possible ways?
8. What would be the optimum cockpit designs for implementing new technologies?
9. Are there certain approaches that you consider useful in order to design to cost?
10. Are there other things that we have missed to talk about regarding cockpit designs?

Camera Monitor System specialist

1. What do you consider to be the biggest benefits of turning to Camera Monitor Systems instead of mirror technologies?
2. What are the key aspects that need to be solved in order for this technology to be implemented?
3. What are the main limiting factors/system/components for the placement of monitors?
4. What are the key things to remember when trying out layouts of visual information in a driving simulator?
5. What would be your future dream scenario for an optimum installation of Camera Monitor Systems in trucks?
6. How could the entire cockpit get better adapted for integrating Camera Monitor Systems?
7. Do you see additional usages of camera monitors except from showing vision views?
8. Are there other things that we have missed to talk about regarding the implementation of Camera Monitor Systems?

Visibility considerations specialist

1. How does visibility from the driver position need to be improved according to you?
2. What are your future views or impressions of how the visibility will change for the future?
3. What factors drive the development of visibility?
4. How are you trying to improve the visibility?
5. What are the limiting factors when developing/improving the visibility?
6. What are the differences in visibility between a distribution truck and a long-haul truck?
7. Do you have ideas for how future layouts should look like in distribution and long-haul trucks in order to optimize visibility?
8. What would be your dream scenario for providing the best visibility in a truck?
9. How should the instrument panel, steering wheel, indirect vision devices, window openings develop in order to provide the best possible direct and indirect vision?
10. Are there other things regarding visibility that we should have asked about?

Specialist in product planning for driver environment

1. What are the main driving factors for driver environment development according to you?
2. What do you see as the key user needs for driver environments when it comes to cockpit designs?
3. When you think about cockpit layouts, are there any differences in user needs between long-haul and city distribution transports?
4. What do you see as the key user needs for driver environments regarding visual information?
5. How do you think new technologies like CMS, HUD and touch displays can be introduced for best driver acceptance?
6. Are there ways that new technologies like CMS, HUD and touch displays could be introduced to avoid adding cost?
7. In your view, how is the future cockpit going to look like?
8. Are there certain trends that need to be remembered when designing the future cockpits?
9. Are there future alternative approaches that would make cockpit designs more cost efficient?
10. Are there other things regarding driver environments in relation to cockpit layouts that we should have asked about?

Specialist in product planning for safety

1. What are the main driving factors behind current safety development according to you?
2. What are the key factors to consider to provide the best possible safety when driving a truck?
3. How could safety from the driver position be further improved in the future?
4. What do you consider as the main safety aspects to consider when developing cockpit layouts?
5. When you think about cockpit layouts in relation to safety, are there any differences in user needs in terms between long-haul and city distribution transports?
6. How could future cockpit layouts be more optimized regarding safety?
7. What do you see as the key developments for providing drivers with better vision?
8. How do you think new technologies like CMS, HUD and touch displays can be introduced for best driver acceptance?
9. In your view, how is the future cockpit going to look like?
10. Are there certain trends that need to be remembered when designing the future cockpits?
11. Are there future alternative approaches that would make cockpit designs even safer?
12. Are there other things regarding the safety in relation to cockpit layouts that we should have asked about?

B. LIST OF IDEAS FOR IMPROVING DIRECT VISION

Ideas for improving direct vision in Volvo FE truck

- Remove mirrors
- Bigger windscreen
- Remove instrument panel
- Bigger side windows
- Full glass doors
- Small instrument panel
- Driver centred
- Curved cab (like an excavator)
- Not a circular steering wheel (joystick like an excavator)
- Remove/thinner A-pillars
- Panorama windscreen
- Extra window in doors
- A-pillar in centre
- Make new window split
- Reclined windscreen (getting the driver closer to windscreen)
- Minimize mirror supports
- Minimize mirror frames
- Remove/thinner door frame
- Transparent a-pillar
- Transparent instrument panel
- Remove half of the instrument panel (Remove the passenger side of the instrument panel)
- The passenger side of the instrument panel is transparent
- See through cab frame
- Transparent doors

Ideas for improving direct vision in Volvo FH truck

- Driver in the centre of the cab
- Remove mirrors
- Transparent A-pillars
- Bigger windscreen
- Lower cab
- Bigger side windows
- Windscreen as a display for full front view
- Curved windscreen - A-Pillars moved back
- Fibre glass cab
- Smaller steering wheel
- Window in passenger door
- Virtual Reality Google glasses to see through pillars
- Lower the instrument panel - Make windscreen bigger
- Change position of the main mirrors
- Holes in the A-pillars
- Window in the instrument panel
- Glass roof
- Transparent steering wheel
- Remove A-Pillars
- Full glass door at passenger side
- No roof
- Remove A-pillars and replace by centre pillar
- Lower instrument panel on right side
- Remove dash, extend windscreen to floor
- Extend side windows to floor on doors
- Mirror mounts coming from above instead of the sides
- Remake steering wheel (smaller, not circular, like an F1-car)

C. LIST OF IDEAS FOR IMPROVING INDIRECT VISION

Ideas for improving indirect vision in the Volvo FE truck

	Ideas for technology to achieve placements of different views	Position of different views				
		1. Left rear-view	2. Right rear-view	3. Reverse view	4. Close-up front view	5. Close-up kerb view
1	-	Left A-pillar	Right A-pillar	-	-	-
2	Physical displays	Left A-pillar	Right A-pillar	SID	SID	Above right A-pillar
3	Physical displays	Left A-pillar	Right A-pillar	SID	High centre windscreen	Above right A-pillar
4	Reflective cover to see what is close to the truck front	-	-	High centre windscreen	Along the top of the windscreen	-
5	For curved cab: Project in the windscreen top	Left high corner of curved windscreen	Right high corner of curved windscreen	High centre windscreen	-	Right side door
6	Active display showing what is necessary at the right time	Left side window	Right side window	-	Along lower windscreen	-
7	See-through over-size display behind steering wheel	Behind steering wheel	Behind steering wheel	Behind steering wheel	Behind steering wheel	Behind steering wheel
8	Left and right of the steering wheel	Lower left A-pillar	To the right of the steering wheel	To the right of the steering wheel	To the right of the steering wheel	To the right of the steering wheel
9	No instrument panel from the centre to the right A-pillar	Left A-pillar	Right A-pillar	Above steering wheel, high windscreen	Just above steering wheel, on the windscreen	In the instrument panel, to right of the steering wheel
10	Customizable layout on touch display	Centre stack	Centre stack	Centre stack	Centre stack	Centre stack
11	Big screen in the centre	-	-	Centre stack	-	-
12	Display	-	-	Centre above windscreen line	-	-
13	-	Lower left A-pillar	Lower right A-pillar	SID right next to steering wheel	SID right next to steering wheel	Above right A-pillar
14	Screen in centre makes that area "see through"	Along left side of windscreen	Along right side of windscreen	High centre windscreen	Big SID	Right side door
15	The placement of all views is fully customizable across the whole windscreen	-	-	-	-	-
16	-	-	-	Instrument cluster	Instrument cluster	Instrument cluster
17	-	High up in the corner of the left side window	High up in the corner of the right side window	-	In top of the windscreen in front of the passenger seat	-
18	Instrument cluster split in two displays for main view, Big central touch display	Left side of instrument cluster	Right side of instrument cluster	In SID	In SID	In SID
19	-	Left A-pillar	Right A-pillar	Over the whole windscreen	Over the whole windscreen	-
20	-	Left A-pillar	Right A-pillar	Big SID	Big SID	Big SID

Ideas for improving indirect vision in the Volvo FH truck

	Ideas for technology to achieve placements of different views	Position of different views				
		Left rear-view	Right rear-view	Reverse view	Close-up front view	Close-up kerb view
1	-	Left A-Pillar	Right A-Pillar		Above right A-Pillar	Above right side window
2	-	Left A-pillar	Right A-pillar	-	-	-
3	Everything placed in a centre display	SID	SID	SID	SID	SID
4	VR glasses to show all view	-	-	-	-	-
5	Projector	-	-	Behind the driver	-	-
6	Panoramic view	SID	SID	SID	-	-
7	Dome around the driver showing all views	Dome	Dome	Dome	Dome	Dome
8	HUD	In windscreen-Left side of centre field of view	In windscreen-Right side of centre field of view	-	In windscreen - Above the central field of view	-
9	Bird's eye view in HUD	-	-	-	-	-
10	While reversing:	Left side window	Right side window	Full windscreen	-	-
11	Slow driving	Left A-pillar	Right A-pillar	SID	Centre in windscreen	Right side window
12	HUD	Low-Left windscreen corner	Low-Right windscreen corner	-	Top-centre of the windscreen	On the right door
13	HUD	High-Left windscreen corner	High-Right windscreen corner	Behind the driver	Low centre in windscreen	High Right side window
14	All views placed in Instrument cluster	Instrument cluster	Instrument cluster	Instrument cluster	Instrument cluster	Instrument cluster
15	HUD at lower part of the windscreen when instrument panel is lowered	Low-Left windscreen corner	Low-Right windscreen corner	-	Low centre in windscreen	Low Right side window
16	One big instrument cluster screen	Left part of instrument cluster	Right part of instrument cluster	Centre high stack -Old SID	Centre high stack -Old SID	Centre part of instrument cluster
17	While reversing in a curved cab:	Left side window + 1/4th of windscreen	Right side window + 1/4th of windscreen	Centre part of windscreen	Centre part of windscreen	Right side window + 1/4th of windscreen
18	All are displays	Upper left corner of windscreen	Upper right corner of windscreen	SID	Above centre of windscreen	Above side door
19	3 & 4 only shown when needed	Left of the steering wheel	Right of the steering wheel	Projected in high centre windscreen	Projected in high centre windscreen	Projected on high side window

D. LIST OF IDEAS FOR THE POSITION OF VISUAL IN-VEHICLE INFORMATION

Ideas for the position of visual in-vehicle information in the Volvo FE truck

	Ideas for technology to achieve placements of different information	Position of visual in-vehicle information		
		A. Primary information	B. Secondary information	C. Active warning system
1	All in HUD	On the windscreen in the central field of view	In the top of central field of view in windscreen	RHS of windscreen and RHS of the left side window
2	All in HUD	On windscreen in the central field of view	On the windscreen in the centre	On the windscreen to the right
3	Different placement of C (Active warning system)	-	-	On LHS A-pillar/low central windscreen/RHS of the window
4	Cantered driver	Instrument cluster	SID on the right and left side of the steering wheel	On A-pillars
5	Virtual reality glasses	VR glasses	SID or VR glasses	VR glasses
6	-	On windscreen in the low central field of view	Instrument cluster and SID	In windscreen in low central field of view
7	Display around the driver both instrument cluster and SID	Instrument cluster	SID	Instrument cluster
8	Use own smart phone device for SID and HUD	On the windscreen in the central field of view	SID	On the windscreen in the central field of view
9	Combine all in the same display	SID	SID	SID
10	-	-	-	LCS On A pillars or on both side of the driver
11	HUD	Windscreen	Windscreen	-
12	Array of light warnings leading focus to the areas where risk appears	Only in windscreen in central field of view	SID (bigger screen)	Over the whole lowest part of the windscreen
13	In HUD and touch display	On the windscreen in the central field of view	SID	On the windscreen in the central field of view
14	HUD and Portable display, No instrument cluster	On the windscreen in the central field of view	SID	On the windscreen in the central field of view
15	Active (selective information) windscreen, no cluster	Instrument cluster	SID	Instrument cluster
16	Tesla 3 style, everything in a big touch display in the centre	SID	SID	SID
17	Customizable touch SID	-	-	-
18	Blinking Lane change warning	-	-	Upper middle along A-pillars
19	Highlighting dangers on the windscreen	-	-	Windscreen
20	Map indicators (arrows) projected on windscreen	-	-	Windscreen
21	HUD and big central display	On windscreen in front of the driver	SID	LCS on A pillars
22	Warning system flash in the SID when needed	On steering wheel	SID	SID
23	No central stack. Warning system in mirror frame or monitor frame	In instrument cluster	In windscreen in front of driver	On mirror frame or monitor frame
24	Big instrument cluster like BMW i3	Left side of instrument cluster	Right side of instrument cluster	On mirror frame or monitor frame

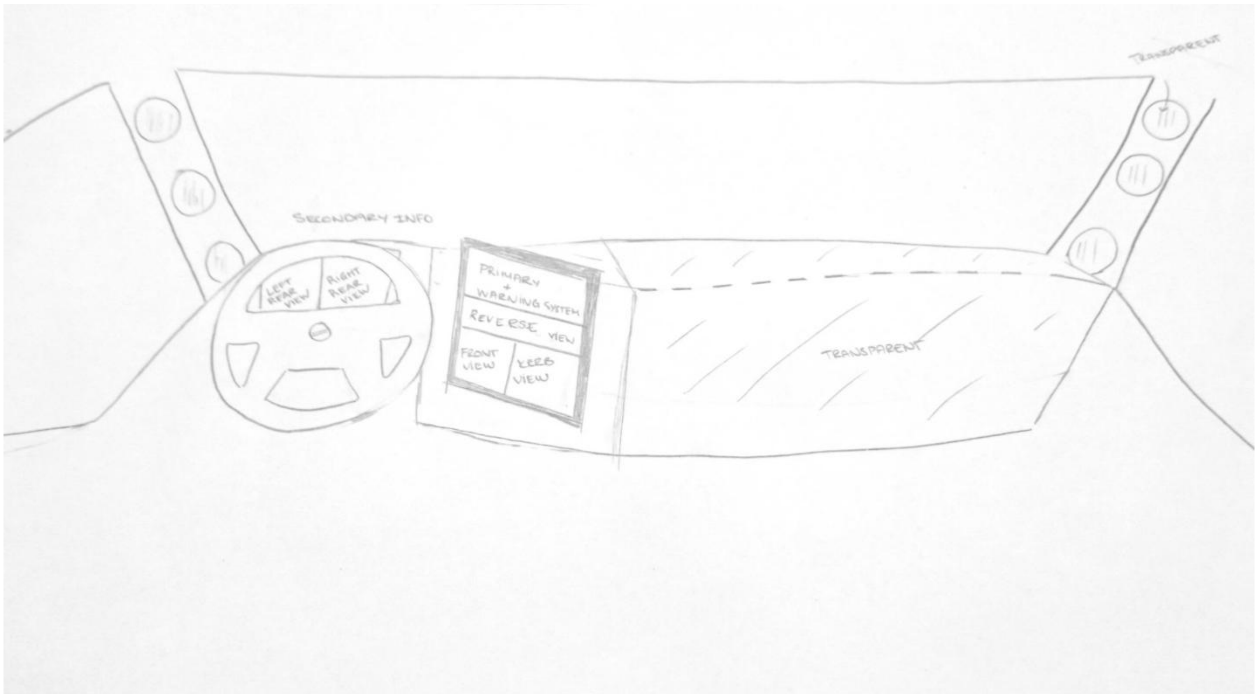
Ideas for the position of visual in-vehicle information in the FH truck

	Ideas for technology to achieve placements of different information	Position of visual in-vehicle information		
		A. Primary information	B. Secondary information	C. Warning system
1	-	Instrument cluster	SID	In windscreen in central field of vision
2	HUD for changes, different speed, incoming call, turn by turn navigation	I windscreen in front of driver	In windscreen in front of driver	-
3	-	-	-	CWS: Windscreen- front of driver. LCS-on the side area
4	Most important info displayed which truck automatically choose	Use surface of steering wheel	Use surface of steering wheel	Use surface of steering wheel
5	-	In windscreen at the low-front of driver	In old SID	-
6	-	Fuel indicator on steering wheel	NAV in windscreen, Audio in door panels	-
7	-	Voice sensor	Fuel on the windscreen	-
8	-	-	Navigation on both side of windscreen	-
9	Driver can position the information in the windscreen	-	-	Safety warnings on steering wheel
10	Dynamic instrument cluster	Instrument cluster	Instrument cluster	Instrument cluster
11	Windscreen projected with augmented reality	In windscreen	In windscreen	In windscreen
12	Very important info projected when needed in the windscreen	In front of steering wheel	SID	In front of steering wheel
13	-	In front of driver in windscreen	A-pillars	In front of driver in windscreen
14	-	Behind steering wheel	SID	A-pillars
15	All is projected in windscreen depending on situation	-	-	-
16	Lane change support projected on A-pillars	-	-	Centre low windscreen
17	Primary information + navigation in front of driver	In front of driver in windscreen	SID	Projected on all windows
18	All are projected in steering wheel	-	-	-
19	All are projected behind steering wheel	-	-	-
20	Dynamic centre display (like new Audi), enlarges what´s important, other info smaller	-	-	-
21	Lowered instrument panel, in the new space given there is projected image only when needed	In front of driver in windscreen	SID	In side window corners
22	When object is in front of truck, the instrument panel becomes see through	-	-	See through instrument panel

E. FULL SOLUTION CONCEPTS

Concept 1 - Created with Morphological Matrix

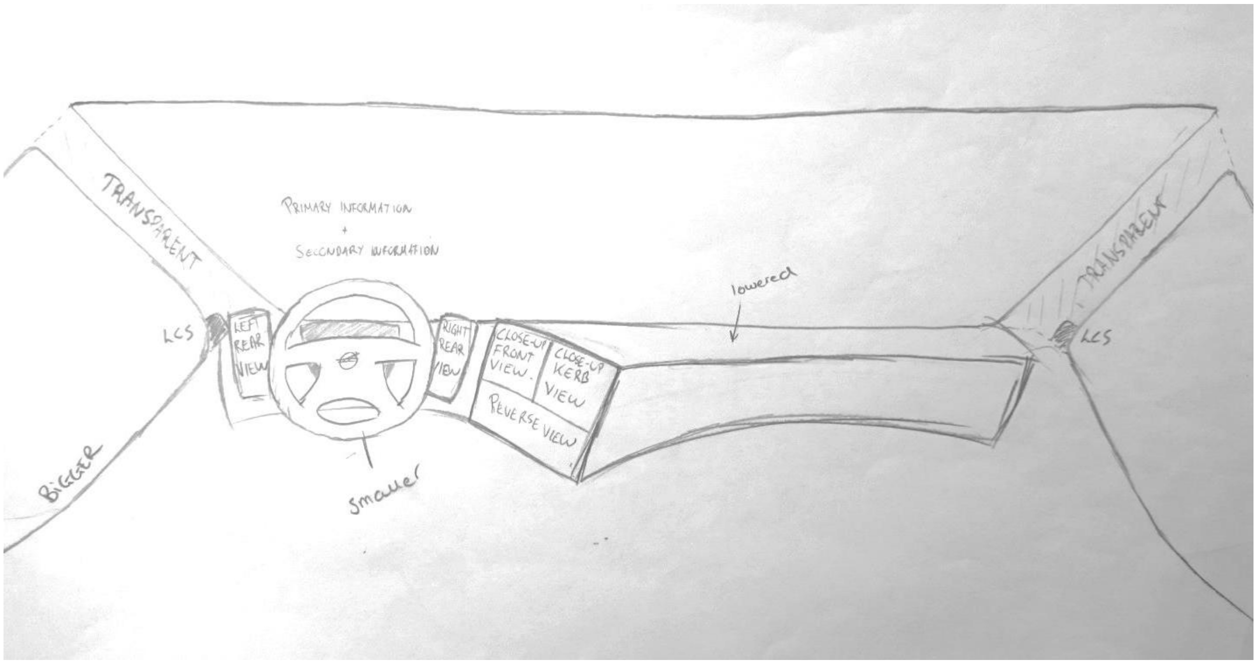
Combination in the Morphological Matrix: 1A-2C-3A-4B-5A-6A-7A-8A-9E-10E-11A-12C-13C-14C-15B-16C



- **Direct vision:**
  - A pillars with peek holes (glass)
  - Instrument panel is transparent
  - Mirrors are removed
- **Indirect vision:**
  - Both the rear-views are shown inside the instrument cluster
  - Reverse view, close-up kerb view and close-up front view are placed in a display in the centre stack
- **Visual in-vehicle data:**
  - Primary information and warning system are placed in the same display in the centre
  - Secondary information is placed in the windscreen

Concept 2 - Created with Morphological Matrix

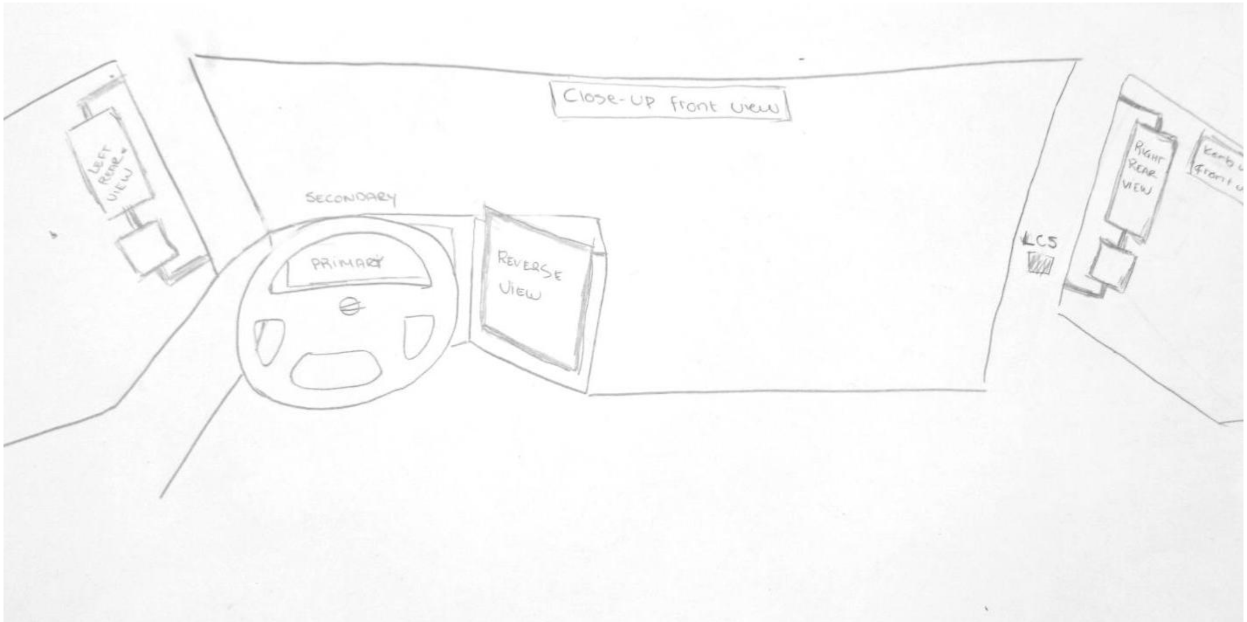
Combination in the Morphological Matrix: 1C-2B-3A-4D-5E-6B-7A-8B-9H-10H-11A-12C-13C-14B-15B-16C



- **Direct vision:**
  - Smaller steering wheel
  - A-pillars are transparent
  - Instrument panel is lowered
  - The windscreen is reclined
  - Side windows are bigger
  - Mirrors are removed
- **Indirect vision:**
  - Left rear-view is left beside the steering wheel
  - Right rear-view is right beside the steering wheel
  - Reverse view, close-up kerb view and close-up front view are placed in a display in the centre stack
- **Visual in-vehicle data:**
  - Primary and secondary information are placed in the windscreen

Concept 3 - Created with Morphological Matrix

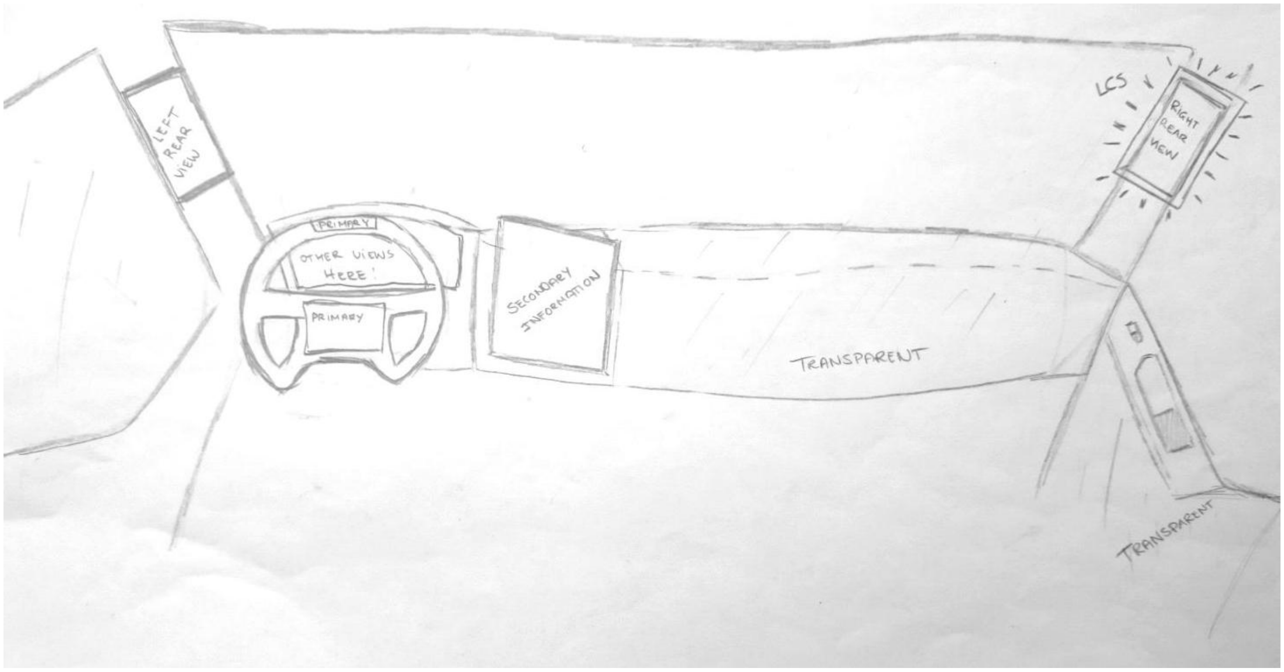
Combination in the Morphological Matrix: 1A-2A-3A-4C-5B-6A-7A-8A-9A-10A-11B-12C-13G-14A-15B-16A



- **Direct vision:**
    - The size of the instrument panel has been reduced; hence there is no instrument panel on the passenger side
    - The windscreen is bigger
- **Indirect vision:**
    - The reverse view is shown in a display in the centre stack
    - The close-front view is shown in a display in the top centre of the windscreen
    - The kerb-view is shown in top of the right side window
- **Visual in-vehicle data:**
    - Secondary information are placed in the HUD

Concept 4 - Created with Morphological Matrix

Combination in the Morphological Matrix: 1E-2A-3A-4B-5A-6A-7B-8B-9F-10F-11E-12E-13E-14D-15A-16H



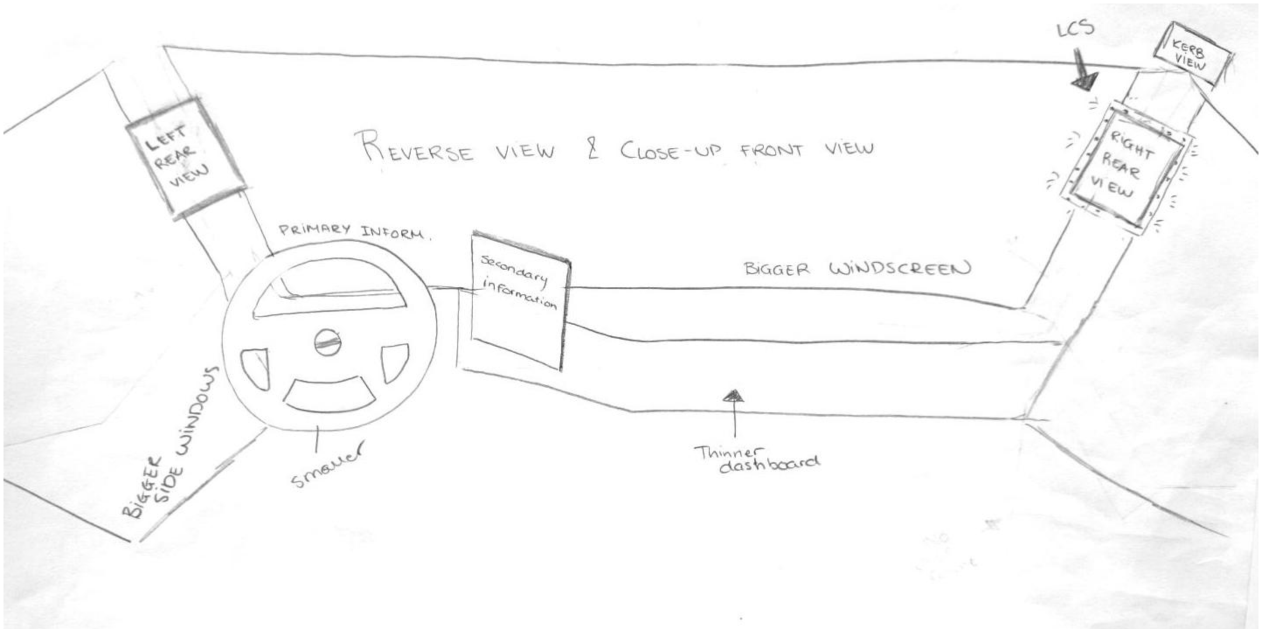
Direct vision:

- Non-circular steering wheel
- Instrument panel is transparent
- The windscreen is bigger
- Doors are transparent
- Mirrors are removed

- **Indirect vision:**
  - Both the rear-views are placed on the A-pillars as displays
  - Reverse view, close-up kerb view and close-up front view are placed in a display in the instrument cluster
- **Visual in-vehicle data:**
  - Primary information are placed on the steering wheel
  - Secondary information are placed in bigger display in the centre stack
  - The warning system (LCS) is placed in the display frame of the rear-view displays

Concept 5 - Created with Morphological Matrix

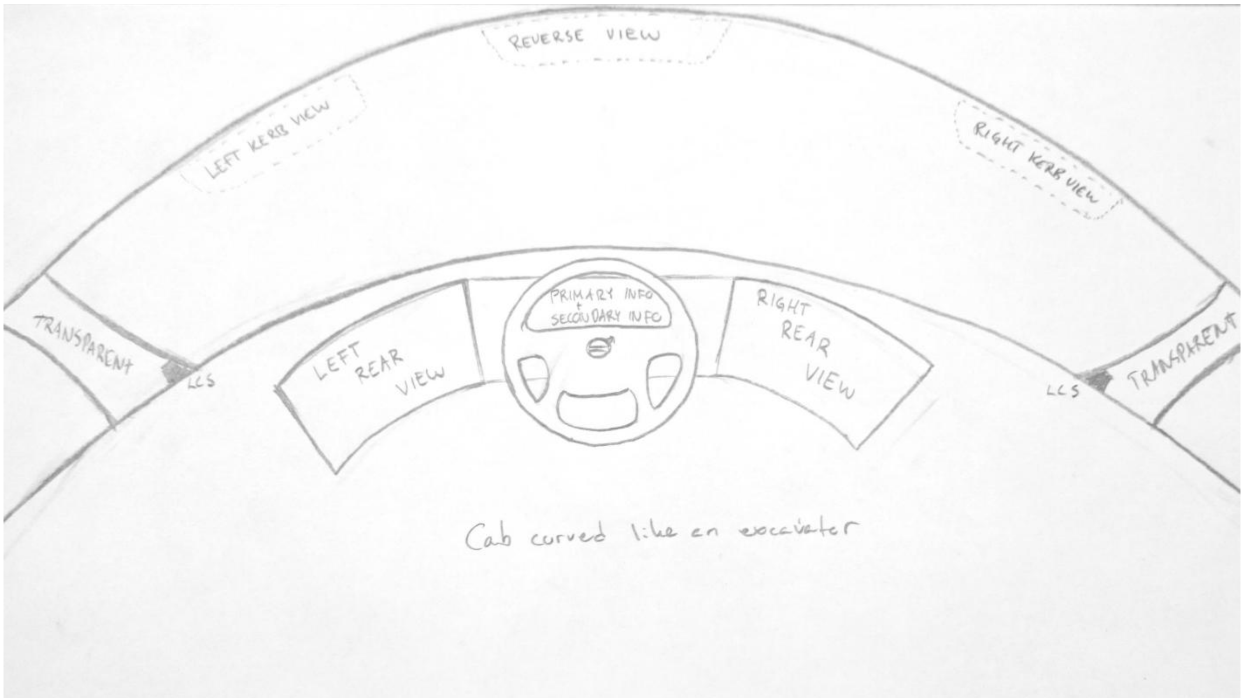
Combination in the Morphological Matrix: 1C-2A-3A-4D-5B-6B-7A-8B-9F-10F-11B-12B-13F-14B-15A-16H



- **Direct vision:**
  - Smaller steering wheel
  - Instrument panel is lowered
  - Windscreen is bigger
  - Side windows are bigger
  - Mirrors are removed
- **Indirect vision:**
  - Both the rear-views are placed on the A-pillars as displays
  - The reverse view and close-up front view are shown in the windscreen as HUD
  - The close-up kerb view is shown above the right A-pillar
- **Visual in-vehicle data:**
  - The primary information are placed in the windscreen as HUD
  - The warning system (LCS) is placed in the display frame of the rear-view displays

Concept 6 - Created with Morphological Matrix

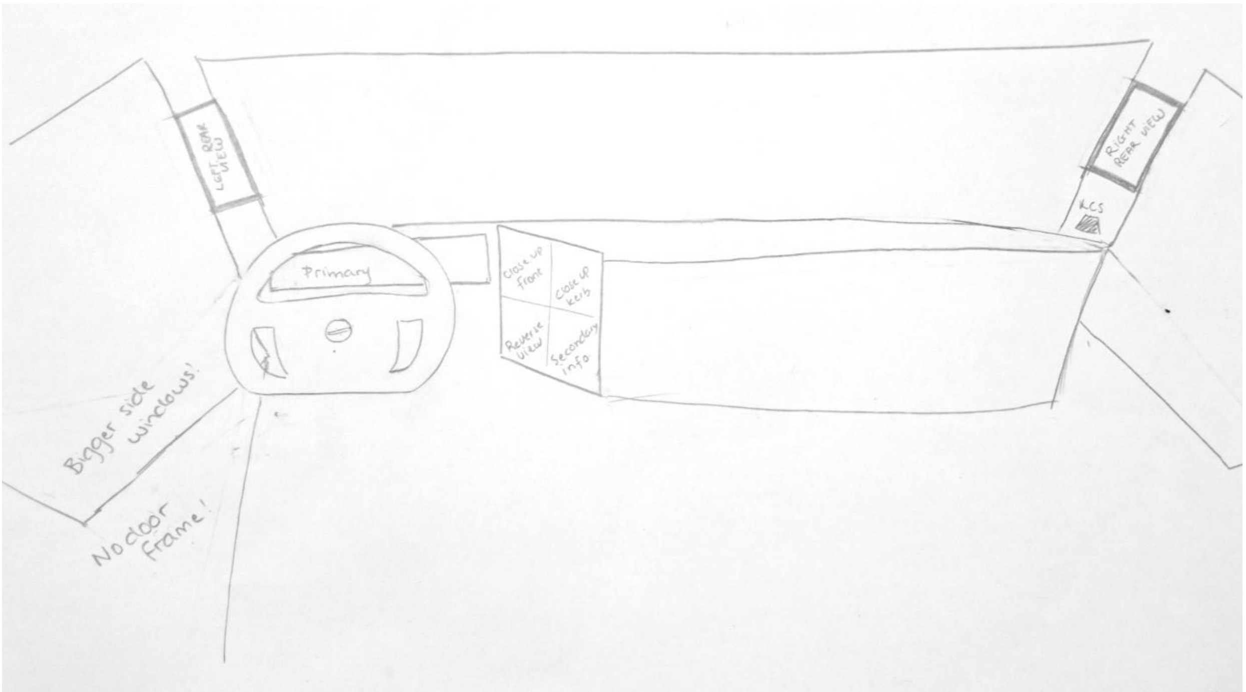
Combination in the Morphological Matrix: 1D-2B-3E-4A-5D-6A-7A-8B-9H-10H-11B-12B-13B-14A-15E-16A



- **Direct vision:**
    - The steering wheel is in the centre of the cab so the driver has been moved to the right
    - The A-pillars are transparent
    - The structure of the cab is curved
    - The windscreen is curved
    - The mirrors are removed
- **Indirect vision:**
    - The left rear-view is left beside the steering wheel
    - The right rear-view is right beside the steering wheel
    - The reverse-view, close-up kerb view are in the windscreen as HUD
    - The close-up front view is not needed
- **Visual in-vehicle data:**
    - Secondary information are placed in the instrument cluster

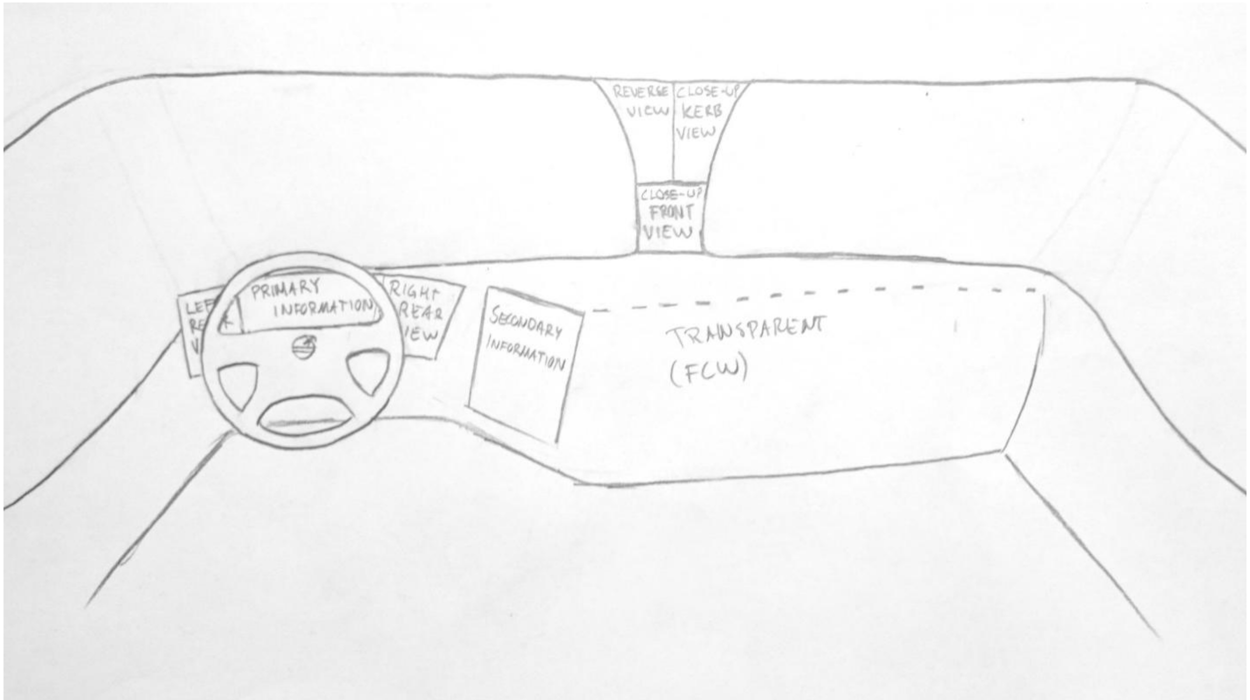
Concept 7 - Created with Morphological Matrix

Combination in the Morphological Matrix: 1E-2A-3A-4A-5A-6B-7D-8B-9F-10F-11A-12C-13C-14A-15A-16C



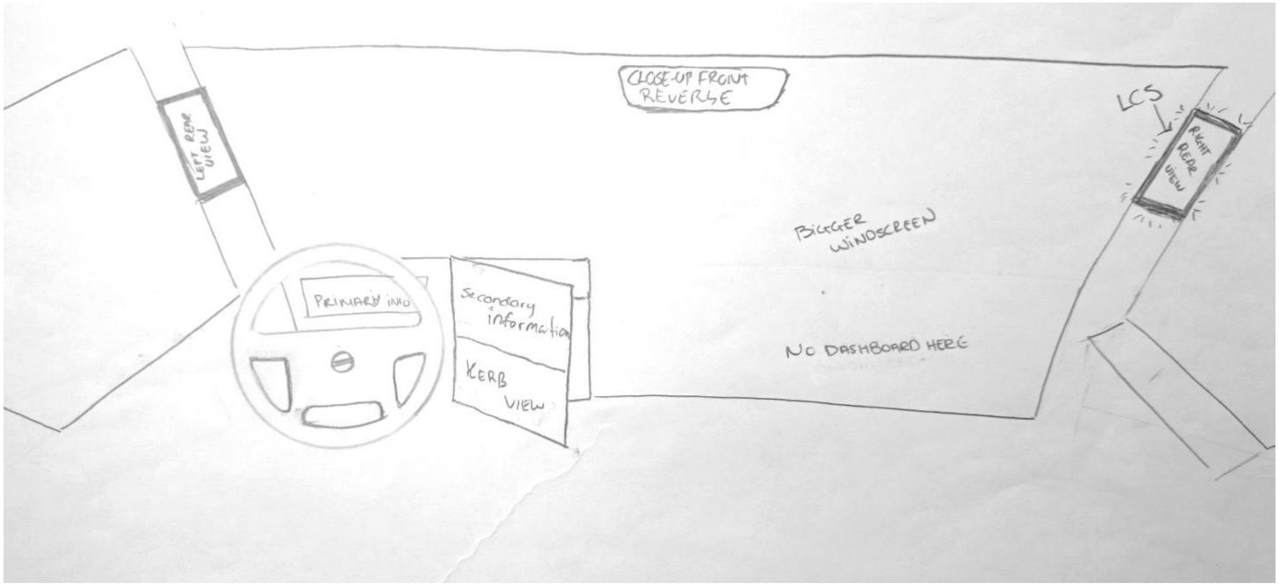
- **Direct vision:**
  - The steering wheel is not rounded, it has flat surface on the top and at the bottom.
  - The side windows are bigger
  - The doors have no frame
- **Indirect vision:**
  - Both the rear-views are placed on the A-pillars as a displays
  - Reverse view, close-up front view and close-up kerb view are placed in a display in the centre stack
- **Visual in-vehicle data**
  - Secondary information placed in a bigger display in the centre stack

Concept 8 - Created in the brainstorming by the authors



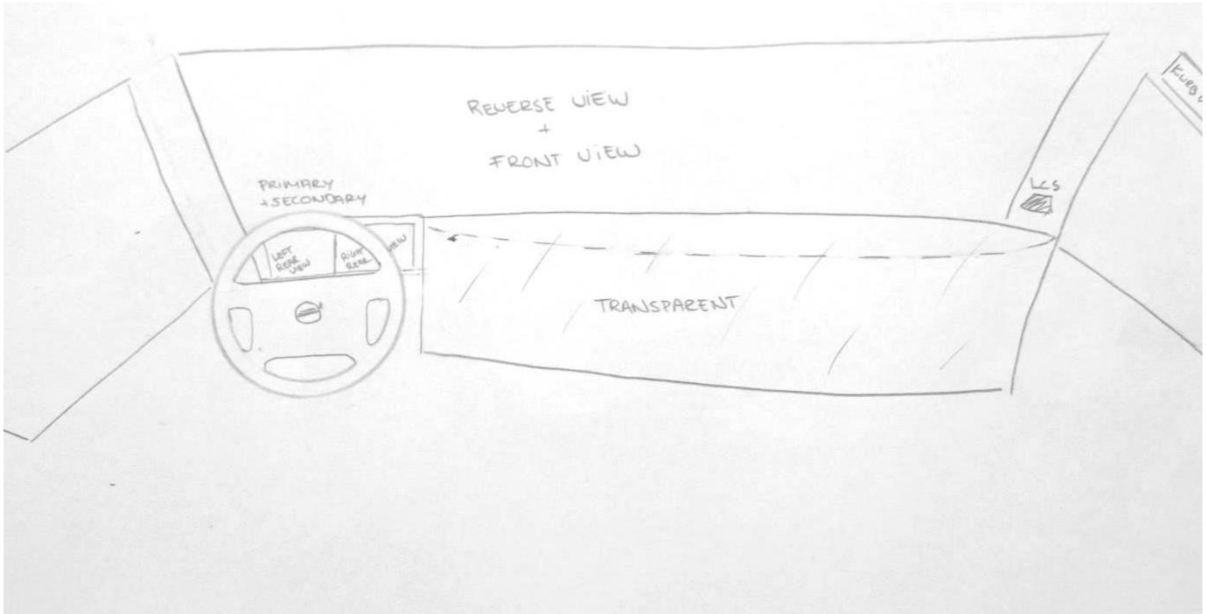
- **Direct vision:**
  - The A-pillars have been removed and one centred A-pillar placed instead
  - The instrument panel has been made transparent with a display
  - Mirrors have been removed
- **Indirect vision:**
  - Left rear-view is placed left beside the steering wheel
  - Right rear-view is placed right beside the steering wheel
  - Reverse view, close-up front view and close-up kerb view are all placed on the centred A-pillar
- **Visual in-vehicle data:**
  - The warning system (FCW) is place on the transparent instrument panel display

Concept 9 - Created in the brainstorming by the authors



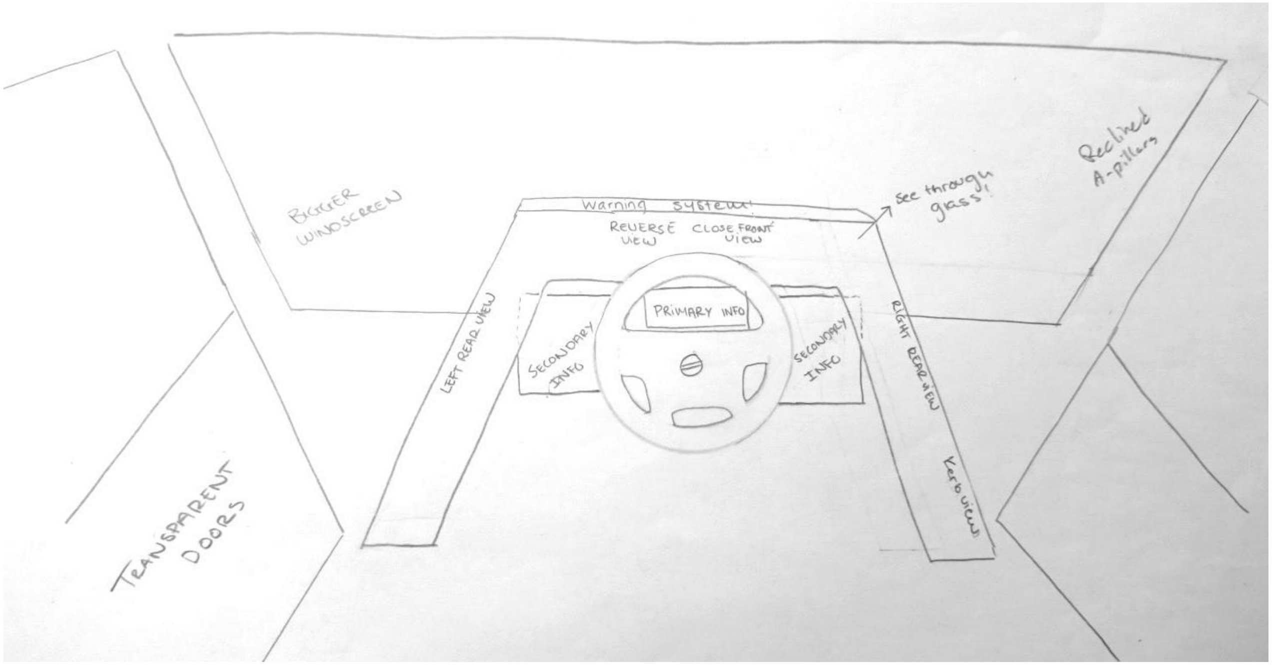
- **Direct vision:**
  - The instrument panel has been removed on the passenger side
  - The windscreen is bigger
  - Mirrors have been removed
- **Indirect vision:**
  - Both rear-views are placed on the A-pillars as displays
  - Reverse view and close-up front view are placed in the top centre of the windscreen in a display
  - The close-up kerb view is placed in a display in the centre stack
- **Visual in-vehicle data:**
  - The warning system (LCS) is in the display frame of the rear-view displays

Concept 10 - Created in the brainstorming by the authors



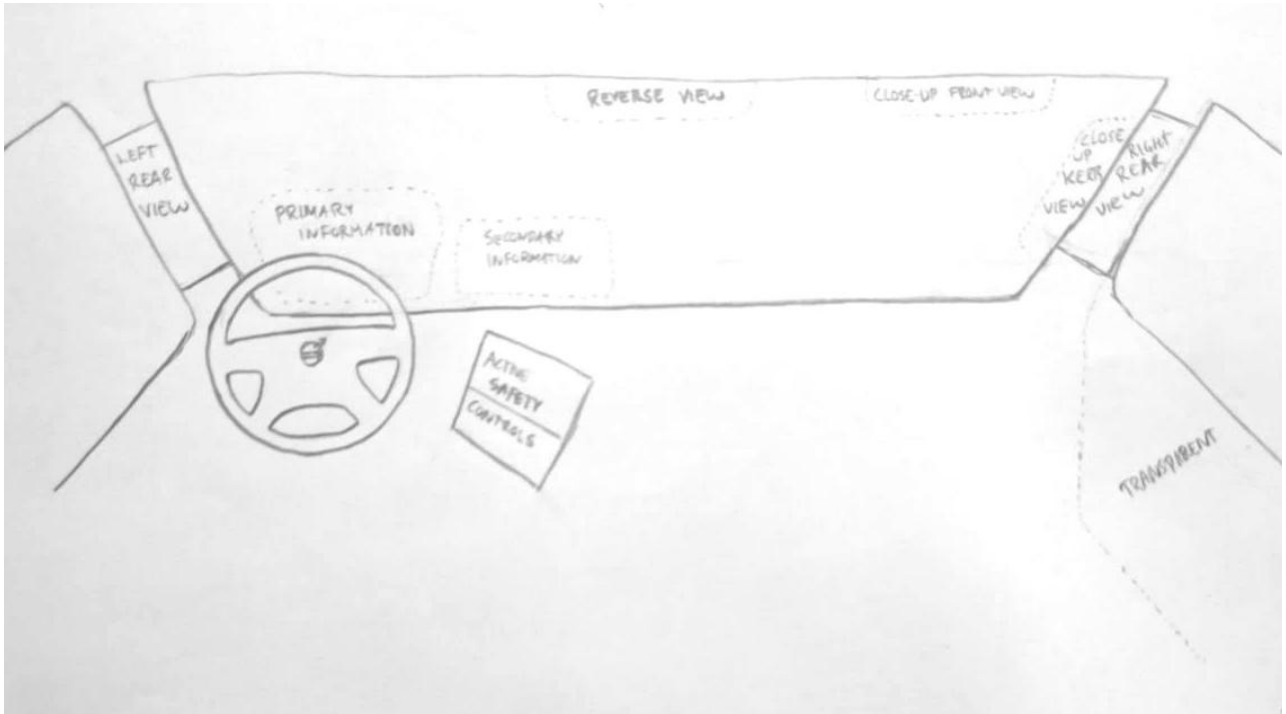
- **Direct vision:**
    - The instrument panel has been made transparent with a display
    - The windscreen is bigger
- **Indirect vision:**
    - The rear-views are placed inside the instrument cluster and viewed through the steering wheel
    - Reverse-view and the close-up front view are shown in a HUD over the whole windscreen when needed
    - The close-up kerb view is placed in a display above the side window on the passenger side
- **Visual in-vehicle data:**
    - Both primary and secondary information are placed in the windscreen in front of the driver as a HUD

Concept 11 - Created in the brainstorming with experts



- **Direct vision:**
    - Steering wheel placed in the centre
    - Instrument panel is removed
    - The windscreen is reclined
    - Doors are transparent
    - Mirrors are removed
- **Indirect vision:**
    - Both rear-views are shown as HUD in a combiner glass wrapped around the driver
    - Reverse view, close-up kerb view and close-up front view are also shown as HUD in a combiner glass wrapped around the driver
- **Visual in-vehicle data:**
    - Primary information are shown in the instrument cluster
    - Secondary information are placed beside the steering wheel on both sides
    - The active warning system is placed in top of the combiner glass as an array of light warnings leading focus to the areas where risk appears

Concept 12 - Created in the brainstorming with experts

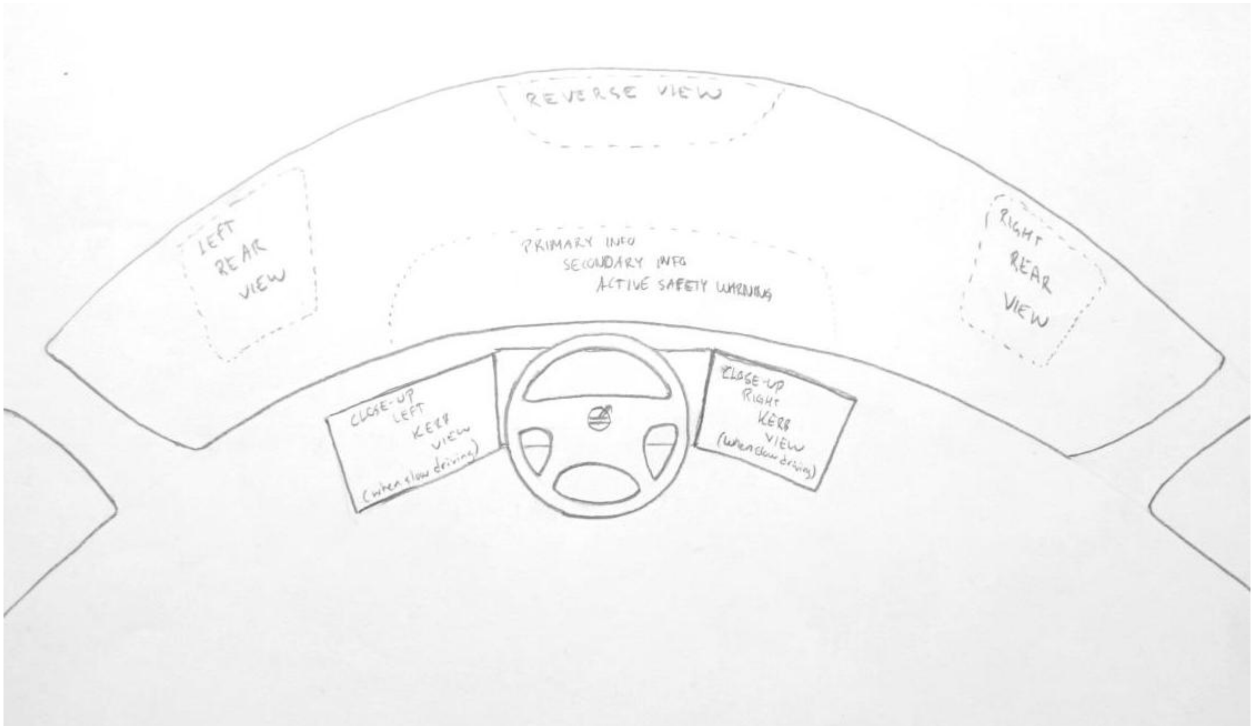


- **Direct vision:**
  - Instrument panel is removed
  - The windscreen is bigger
  - Doors are transparent
  - Mirrors are removed
- **Indirect vision:**
  - Both rear-views are placed on the A-pillars as displays
  - Reverse view and close-up front view are placed in the top of the windscreen as HUD
  - The close-up kerb view is also shown as a HUD in the windscreen
- **Visual in-vehicle data:**
  - Primary information and secondary information are shown as HUD in the windscreen.
  - The active safety warnings are placed in a display in the centre stack

Concept 13 - Created in the brainstorming with experts

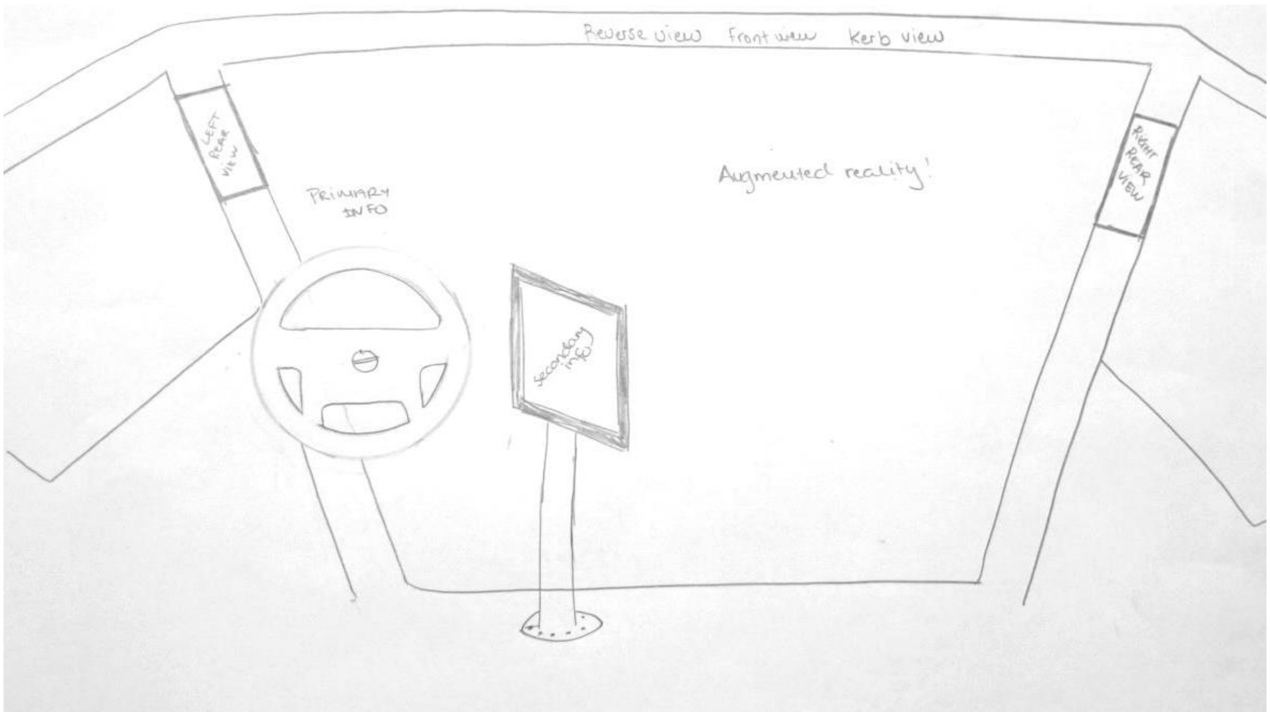
- **Direct vision:**
  - A-pillars have different split
  - Instrument panel is removed
  - Windscreen is split into smaller parts
  - There is an extra side window
  - Mirrors are removed
- **Indirect vision:**
  - The left rear-views are placed on the left A-pillars as a display
  - The right rear-view and the front view is placed on the centred A-pillar as a display
- **Visual in-vehicle data:**
  - Primary information, secondary information and the active safety warning system are placed in a display in the centre stack

Concept 14 - Created in the brainstorming with experts



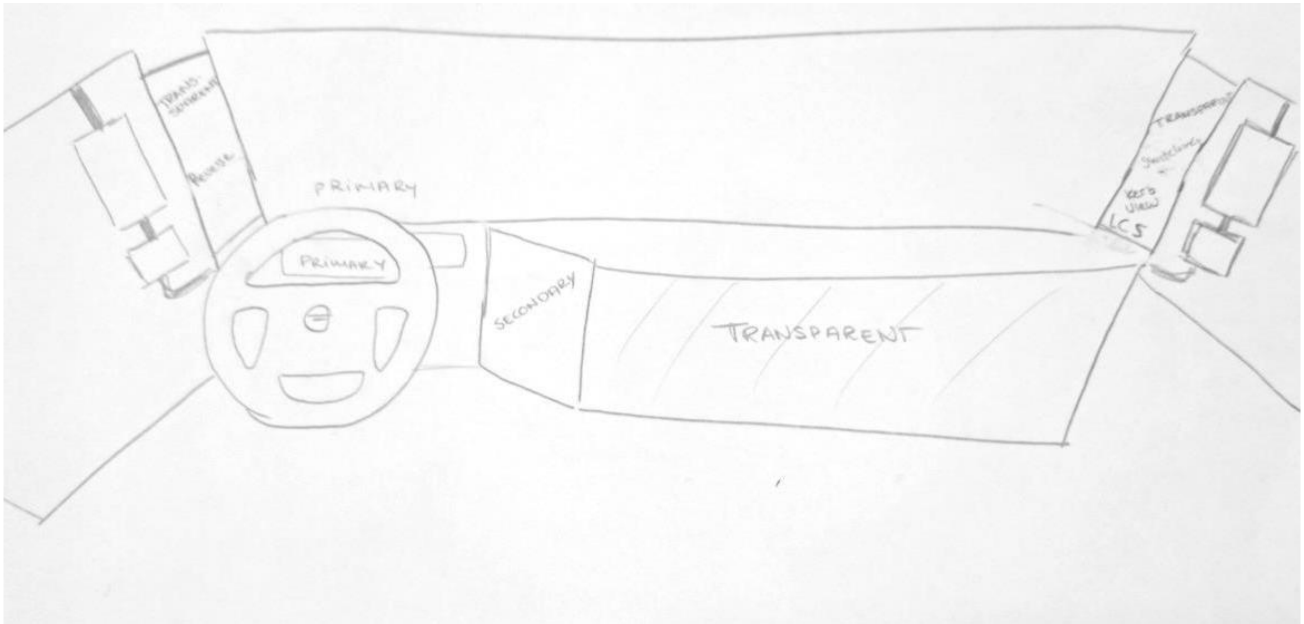
- **Direct vision:**
  - The steering wheel is moved to the centre
  - The cab structure is curved
  - Instrument panel is removed
  - Windscreen is curved
  - Mirrors are removed
- **Indirect vision:**
  - Both rear-views are shown as HUD in the windscreen on both sides
  - The reverse view is shown as HUD in the top of the windscreen
  - The close up right kerb view is shown beside the steering wheel on the right side
  - The close up left kerb view is shown beside the steering wheel on the left side
- **Visual in-vehicle data:**
  - Primary information, secondary information and the active safety warning system are shown as HUD in the windscreen

Concept 15 - Created in the brainstorming with experts



- **Direct vision:**
  - Instrument panel is removed
  - Windscreen is bigger and shows augmented reality
  - Mirrors are removed
- **Indirect vision:**
  - Both rear-views are placed on the left A-pillars as displays
  - The reverse view , close up kerb view and close-up front view are shown slightly above the windscreen
- **Visual in-vehicle data:**
  - Primary information is shown as HUD in the windscreen
  - Secondary information are placed in big display beside the steering wheel

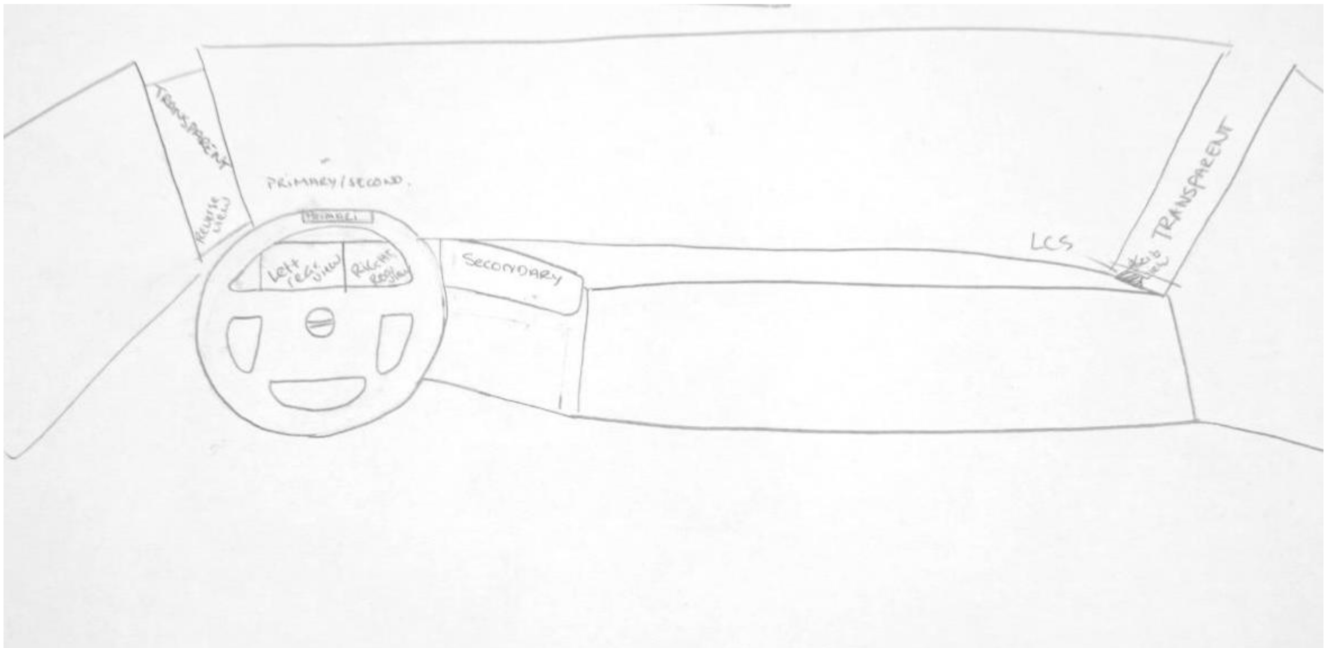
Concept 16 - Created in the brainstorming with experts



- **Direct vision:**
  - A-pillars are transparent and also showing different views by switching between
  - Instrument panel is transparent
- **Indirect vision:**
  - Reverse view is shown on the left A-pillar
  - Kerb-view is shown on the right A-pillars
- **Visual in-vehicle data:**
  - Primary information are placed in the windscreen as HUD and in the instrument cluster
  - Secondary information are in big display in the centre stack

Concept 17 - Created with Morphological Matrix

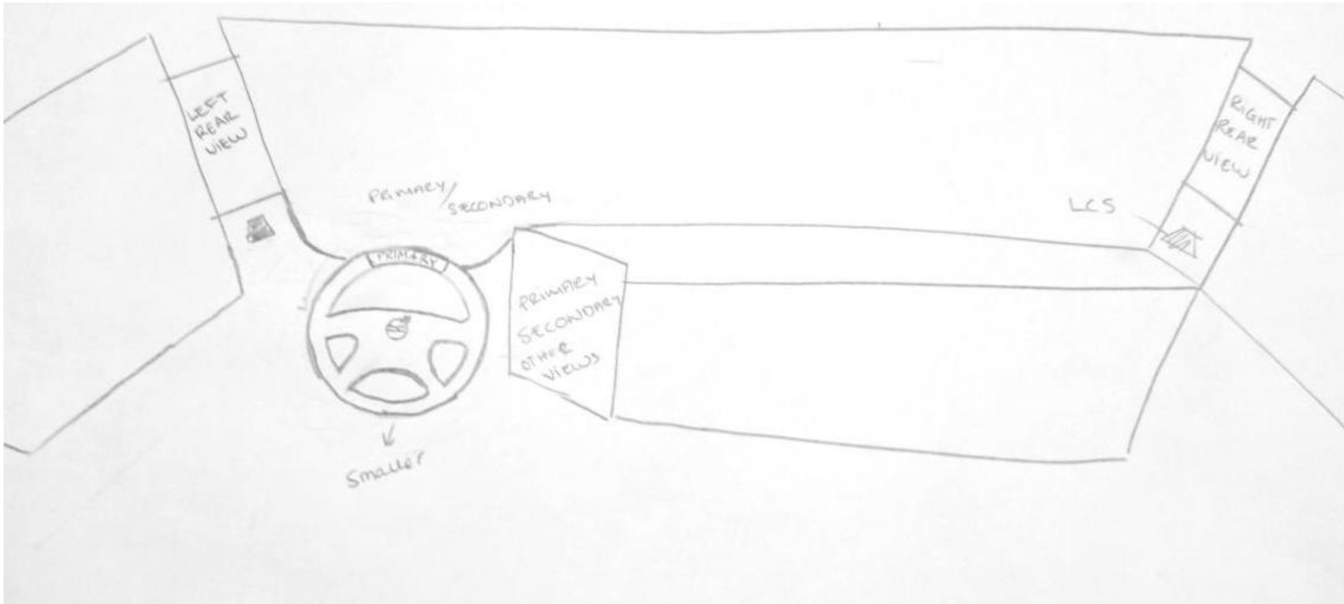
Combination in the Morphological Matrix: 1A-2B-3A-4A-5A-6A-7A-8B-9E-10E-11B-12B-13B-14B-15A-16A



- **Direct vision:**
  - A-pillars are transparent
  - Mirrors are removed
- **Indirect vision:**
  - Both the rear-view are placed inside the instrument cluster
- **Visual in-vehicle data:**
  - Primary and secondary information are placed in the windscreen
  - Primary information are also located on the steering wheel
  - Secondary information are also located in a display on the centre stack

Concept 18 - Created with Morphological Matrix

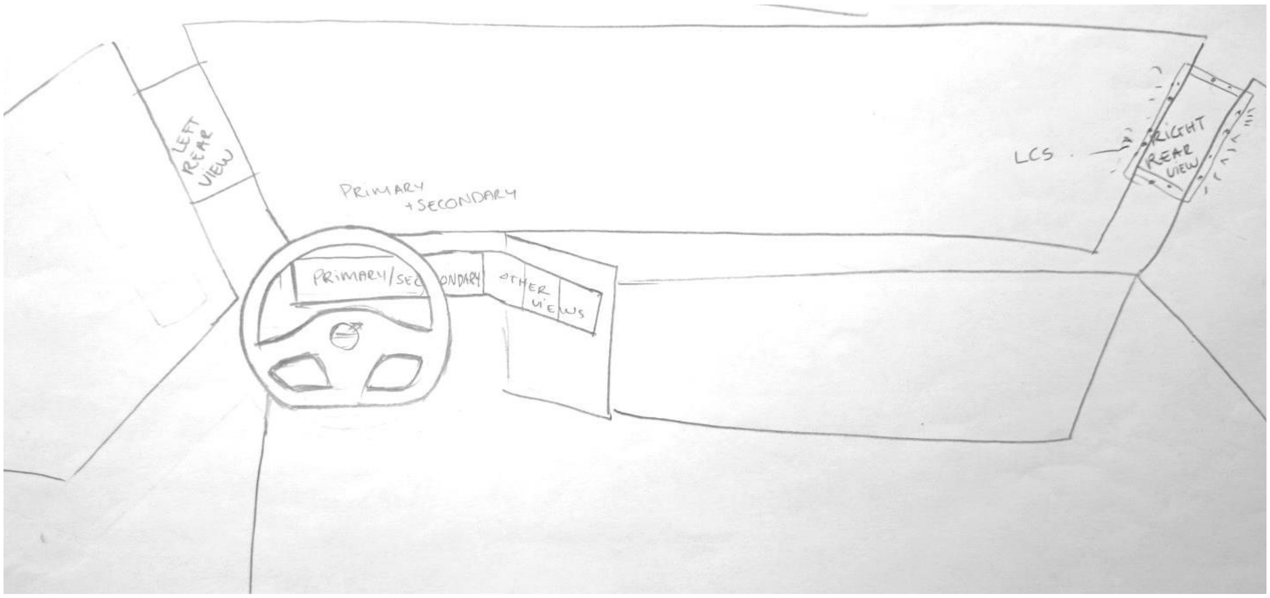
Combination in the Morphological Matrix: 1C-2A-3A-4A-5A-6A-7A-8B-9F-10F-11A-12C-13C-14B-15A-16A



- **Direct vision:**
  - Smaller steering wheel
  - Instrument cluster is removed
  - Mirrors are removed
- **Indirect vision:**
  - Both rear-view are shown on the A-pillars in displays
  - Reverse view, close-up kerb view and close-up front view are placed in a display in the centre stack
- **Visual in-vehicle data:**
  - Primary and secondary information are placed in the windscreen, in the display in the centre stack and on the steering wheel

Concept 19 - Created with Morphological Matrix

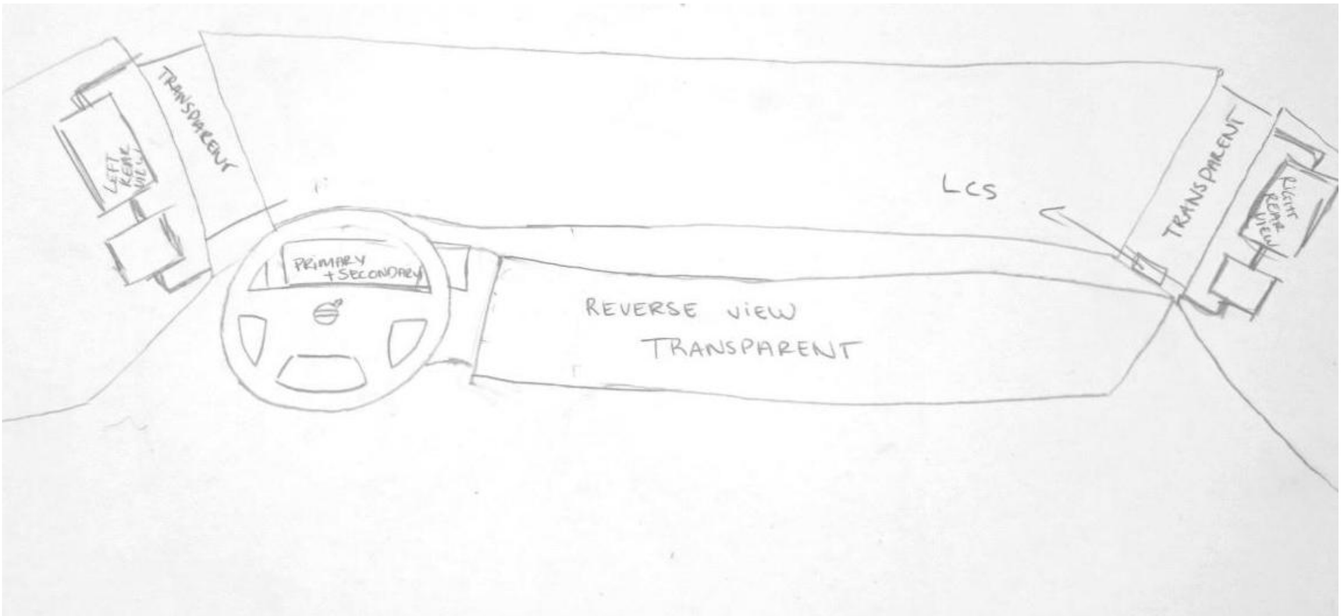
Combination in the Morphological Matrix: 1E-2A-3A-4A-5A-6A-7A-8B-9F-10F-11A-12C-13C-14B-15E-16H



- **Direct vision:**
  - Non-circular steering wheel
  - Mirrors are removed
- **Indirect vision:**
  - Both rear-view are shown on the A-pillars in displays
  - Reverse view, close-up kerb view and close-up front view are placed in a display in the centre stack
- **Visual in-vehicle data:**
  - Primary and secondary information are placed in the windscreen and in the instrument cluster
  - The active warning system (LCS) is placed in the display frame of the rear-views

Concept 20 - Created with Morphological Matrix

Combination in the Morphological Matrix: 1A-2B-3A-4B-5A-6A-7A-8A-9A-10A-11A-12A-13A-14A-15E-16A



- **Direct vision:**
    - A-pillars are transparent
    - Instrument panel is transparent
- **Indirect vision:**
    - Reverse view is showed in the transparent instrument panel when needed
- **Visual in-vehicle data:**
    - Primary and secondary information are located in the instrument cluster

F. MORPHOLOGICAL MATRIX WITH CONCEPTS

Concept 1	Yellow
Concept 2	Red
Concept 3	Green
Concept 4	Blue
Concept 5	Orange

		A	B	C	D	E	F	G	H	I	J	K
Direct vision												
1	Steering wheel	No change	Transparent	Smaller	Centered	Other shape	Joystick					
2	A-pillars	No change	Transparent	With holes	Remove	Centered	Thinner	New split				
3	Cab structure	No change	Transparent	Lower cab	Transparent roof	Curved						
4	Dashboard	No change	Transparent	Remove	Lower dashboard	Extra window						
5	Windscreen	No change	Bigger	Display	Curved	Reclined						
6	Side windows	No change	Bigger									
7	Doors	No change	Transparent	Extra window	Remove frame							
8	Mirrors	No change	Remove	Change position	Mounted from above	Reduce size						
Indirect vision												
9	Left rear view	Left mirror	Windscreen	Center stack	Dome	Instrument cluster	Left A-pillar	Left side-window	Left of steering wheel			
10	Right rear view	Right mirror	Windscreen	Center stack	Dome	Instrument cluster	Right A-pillar	Right side window	Right of steering wheel			
11	Reverse view	Center stack	Windscreen	Above windscreen	Dome	Instrument cluster	Rear-view monitor	Right of steering wheel	Behind driver			
12	Close-up front view	Front mirror	Windscreen	Center stack	Dome	Instrument cluster	Above right A-pillar	Right of steering wheel				
13	Close-up kerb view	Side mirror	Windscreen	Center stack	Dome	Instrument cluster	Above right A-pillar	Right side window	Right of steering wheel	Right A-pillar	Right door	Above right side window
Visual in-vehicle information												
14	Primary information	Instrument cluster	Windscreen	Center stack	Steering wheel	VR glasses						
15	Secondary information	Center stack	Windscreen	VR glasses	Steering wheel	Instrument cluster	A-pillars	Door				
16	Warning system (LCS)	A-pillars	Windscreen	Center stack	Steering wheel	Instrument cluster	VR glasses	Side window	Mirror/Monitor frame			

Concept 7	orange
Concept 17	purple
Concept 18	light blue
Concept 19	grey
Concept 20	dark red

		A	B	C	D	E	F	G	H	I	J	K
Direct vision												
1	**Steering wheel**	No change	Transparent	Smaller	Centered	Other shape	Joystick					
2	**A-pillars**	No change	Transparent	With holes	Remove	Centered	Thinner	New split				
3	**Cab structure**	No change	Transparent	Lower cab	Transparent roof	Curved						
4	**Dashboard**	No change	Transparent	Remove	Lower dashboard	Extra window						
5	**Windscreen**	No change	Bigger	Display	Curved	Reclined						
6	**Side windows**	No change	Bigger									
7	**Doors**	No change	Transparent	Extra window	Remove frame							
8	**Mirrors**	No change	Remove	Change position	Mounted from above	Reduce size						
Indirect vision												
9	**Left rear view**	Left mirror	Windscreen	Center stack	Dome	Instrument cluster	Left A-pillar	Left side-window	Left of steering wheel			
10	**Right rear view**	Right mirror	Windscreen	Center stack	Dome	Instrument cluster	Right A-pillar	Right side window	Right of steering wheel			
11	**Reverse view**	Center stack	Windscreen	Above windscreen	Dome	Instrument cluster	Rear-view monitor	Right of steering wheel	Behind driver			
12	**Close-up front view**	Front mirror	Windscreen	Center stack	Dome	Instrument cluster	Above right A-pillar	Right of steering wheel				
13	**Close-up kerb view**	Side mirror	Windscreen	Center stack	Dome	Instrument cluster	Above right A-pillar	Right side window	Right of steering wheel	Right A-pillar	Right door	Above right side window
Visual in-vehicle information												
14	**Primary information**	Instrument cluster	Windscreen	Center stack	Steering wheel	VR glasses						
15	**Secondary information**	Center stack	Windscreen	VR glasses	Steering wheel	Instrument cluster	A-pillars	Door				
16	**Warning system (LCS)**	A-pillars	Windscreen	Center stack	Steering wheel	Instrument cluster	VR glasses	Side window	Mirror/Monitor frame			

G. PUGH MATRICES

Pugh matrix for the city distribution concepts and motivation for criterion weighting factors

Criterion	Weighting	Reference	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Concept 11	Concept 12	Concept 13	Concept 14	Concept 15	Concept 16	Concept 17	Concept 18	Concept 19	Concept 20
		Alternative																				
Increased forward visibility for distribution driving	5	FE cab	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	0	0	1
Increased passenger side visibility for distribution driving	5	FE cab	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0
Increased driver side visibililty for distribution driving	3	FE cab	1	1	0	1	1	-1	1	1	1	1	1	0	0	0	1	1	1	1	1	0
Risk of disturbing reflections	1	FE cab	0	0	0	0	0	-1	0	0	0	0	0	0	-1	0	0	0	0	0	0	0
Conveniently placed reverse view	5	FE cab	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1
Conveniently placed close-up front view	5	FE cab	1	1	0	1	1	1	1	0	1	1	1	0	0	1	-1	0	0	1	1	0
Conveniently placed close-up kerb view	5	FE cab	1	1	0	0	0	1	1	1	1	0	1	-1	1	1	-1	1	1	1	1	0
Conveniently placed rear views LH & RH	5	FE cab	0	-1	0	1	1	1	1	-1	1	-1	1	1	1	-1	1	0	0	1	1	0
A-pillars withstand crash pendulum test	5	FE cab	-1	0	0	0	0	0	0	-1	0	0	0	0	-1	-1	0	0	0	0	0	0
Impact safety of interior components	3	FE cab	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
Fuel economy considerations (aerodynamics)	1	FH cab	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0
Cost efficient (product development to support frequent product updates)	5	FE cab	-1	-1	-1	-1	-1	-1	0	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Cost efficient (low product cost thanks to architecture, modular approach and part number reduction)	5	FE cab	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1
Appropriate use of new technology (so it facilitates previously impossible in a smart way)	1	FE cab	1	1	0	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1	1
Climate considerations (risk for temperature variations and poor air quality, etc)	1	FE cab	0	0	-1	0	-1	-1	-1	-1	-1	0	0	0	-1	-1	-1	-1	0	0	0	0
Interior calmness to minimize cognitive load on the driver	3	FE cab	1	1	1	0	0	1	1	0	1	1	1	0	0	1	1	1	1	0	0	0
Sensation of spaciousness and flexibility to change posture	1	FH cab	1	1	1	1	1	0	1	1	1	1	1	0	1	0	-1	1	0	0	0	1
Supported reach for controls	3	FE cab	0	0	0	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0
Support for relaxing activities in the driver seat (watching TV, etc).	3	FH cab	1	1	1	1	1	0	1	1	0	0	1	1	1	0	1	1	0	1	1	0
Support for frequently getting in/out (nothing in the way, ease of bringing equipment, etc)	5	FE cab	0	0	0	1	1	-1	0	0	0	0	-1	0	0	-1	0	0	0	0	0	0
Support for working activities in the driver seat (order handling, route planning, etc).	5	FE cab	0	-1	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	0	0	1	0
Steering wheel that supports visibility of information	3	FE cab	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Primary information close to common gazing directions	5	FE cab	-1	1	0	0	1	0	0	0	0	1	0	1	-1	1	1	1	1	1	1	0
Secondary information is easy to monitor	5	FE cab	1	1	1	0	0	1	0	0	0	1	1	1	0	1	0	0	1	1	1	1
Warnings are easy to detect	5	FE cab	1	1	0	1	1	0	0	1	1	0	1	1	-1	1	1	0	0	0	1	0
Net value			37	45	21	47	51	36	43	23	48	40	35	30	16	27	16	35	38	46	53	17
Ranking			**10**	**6**	**17**	**4**	**2**	**11**	**7**	**16**	**3**	**8**	**12-13**	**14**	**19-20**	**15**	**19-20**	**12-13**	**9**	**5**	**1**	**18**
Further development			**NO**	**NO**	**NO**	**NO**	**YES**	**NO**	**NO**	**NO**	**YES**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**YES**	**NO**

	Criterion	Weighting	Reasoning for weight factor
Direct vision	Increased forward visibility for distribution driving	5	Equally important for FE & FH - High importance
	Increased passenger side visibility for distribution driving	5	Higher for FE - city traffic
	Increased driver side visibility for distribution driving	3	Higher for FE - city traffic, not as important since it is good today
	Risk of disturbing reflections	1	Higher for FH - driving during night time
Indirect vision	Conveniently placed reverse view	5	Equally important, high importance since it is bad today
	Conveniently placed close-up front view	5	Higher for FE - city driving -> frequent stops with close traffic
	Conveniently placed close-up kerb view	5	Higher for FE - city driving -> frequent stops with close traffic
	Conveniently placed rear views LH & RH	5	Equally high importance - need to see behind the cab
Technical considerations from background research	A-pillars withstand crash pendulum test	5	Equally high importance - need to pass crash requirements
	Impact safety of interior components	3	Eqully medium importance - to not have sharp edges inside
	Fuel economy considerations (aerodynamics)	1	High importance FH - small improvements have big impact on long driving
	Cost efficient (product development to support frequent product updates)	5	Higher for FE - PD costs need to be low, FH is less price sensitive
	Cost efficient (low product cost thanks to architecture, modular approach and part number reduction)	5	Higher for FE - modular approach to keep total cost down, FH is less price sensitive
	Appropriate use of new technology (so it facilitates previously impossible in a smart way)	1	Higher for FH - should be using more advanced solutions than FE
	Climate considerations (risk for temperature variations and poor air quality, etc)	1	More important for FH to keep the preferred climate inside, FE more a work tool
General Ergonomics	Interior calmness to minimize cognitive load on the driver	3	Higher for FH - during long drives to keep the driver calm and focused on the task
	Sensation of spaciousness and flexibility to change posture	1	Higher for FH because of longer drives
	Supported reach for controls	3	Equally medium importance to be able to reach controls
	Support for relaxing activities in the driver seat (watching TV, etc).	3	Equally medium importance
	Support for frequently getting in/out (nothing in the way, ease of bringing equipment, etc)	5	Higher importance for FE because of frequent stops
	Support for working activities in the driver seat (order handling, route planning, etc).	5	Higher for FE - handling orders on the go
Visual in-vehicle information	Steering wheel that supports visibility of information	3	Equally medium importance
	Primary information close to common gazing directions	5	Information more varying in FE than FH - not as important to see it all the time
	Secondary information is easy to monitor	5	Information more varying in FE than FH - not as important to see it all the time
	Warnings are easy to detect	5	Equally high importance

The winning concepts for the FE-truck are number 5, 9 and 19

Pugh matrix for the long-haul concepts and motivation for criterion weighting factors

Criterion	Weighting	Reference	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10	Concept 11	Concept 12	Concept 13	Concept 14	Concept 15	Concept 16	Concept 17	Concept 18	Concept 19	Concept 20
			Alternative																			
Increased front visibility for long-haul driving	5	FH cab	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	0	0	1
Increased passenger side visibility for long-haul driving	3	FH cab	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0
Increased driver side visibililty for long-haul driving	1	FH cab	1	1	0	1	1	-1	1	1	1	1	1	0	0	0	1	1	1	1	1	0
Reduced risk of disturbing reflections	3	FH cab	0	0	0	0	0	-1	0	0	0	0	0	0	-1	0	0	0	0	0	0	0
Conveniently placed reverse view	5	FH cab	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1
Conveniently placed close-up front view	3	FH cab	1	1	0	1	1	1	1	0	1	1	1	0	0	1	-1	0	0	1	1	0
Conveniently placed close-up kerb view	3	FH cab	1	1	0	0	0	1	1	1	1	0	1	-1	1	1	-1	1	1	1	1	0
Conveniently placed rear views LH & RH	5	FH cab	0	-1	0	1	1	1	1	-1	1	-1	1	1	1	-1	1	0	0	1	1	0
A-pillars withstand crash pendulum test	5	FH cab	-1	0	0	0	0	0	0	-1	0	0	0	0	-1	-1	0	0	0	0	0	0
Impact safety of interior components	3	FH cab	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
Fuel economy considerations (aerodynamics)	5	FH cab	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0
Cost efficient (product development to support frequent product updates)	3	FH cab	-1	-1	-1	-1	-1	-1	0	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Cost efficient (low product cost thanks to architecture, modular approach and part number reduction)	3	FH cab	1	1	1	1	1	1	1	1	1	1	-1	1	1	1	1	1	1	1	1	1
Appropriate use of new technology (so it facilitates previously impossible in a smart way)	3	FH cab	1	1	0	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1	1
Climate considerations (risk for cold draft, need for ventilation, etc)	5	FH cab	0	0	-1	0	-1	-1	-1	-1	-1	0	0	0	-1	-1	-1	-1	0	0	0	0
Interior calmness to minimize cognitive load on the driver	5	FH cab	1	1	1	0	0	1	1	0	1	1	1	0	0	1	1	1	1	0	0	0
Sensation of spaciousness and flexibility to change posture	5	FH cab	1	1	1	1	1	0	1	1	1	1	1	0	1	0	-1	1	0	0	0	1
Supported reach for controls	3	FH cab	0	0	0	1	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0
Support for relaxing activities in the driver seat (watching TV, etc).	3	FH cab	1	1	1	1	1	0	1	1	0	0	1	1	1	0	1	1	0	1	1	0
Support for frequently getting in/out (nothing in the way, ease of bringing equipment, etc)	1	FE cab	0	0	0	1	1	-1	0	0	0	0	-1	0	0	-1	0	0	0	0	0	0
Support for working activities in the driver seat (order handling, route planning, etc).	1	FE cab	0	-1	0	0	0	0	0	0	0	0	-1	0	0	0	-1	0	0	0	1	0
Steering wheel that supports visibility of information	3	FH cab	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Primary information close to main line of sight	3	FH cab	-1	1	0	0	1	0	0	0	0	1	0	1	-1	1	1	1	1	1	1	0
Secondary information is easy to monitor	3	FH cab	1	1	1	0	0	1	0	0	0	1	1	1	0	1	0	0	1	1	1	1
Warnings are easy to detect	5	FH cab	1	1	0	1	1	0	0	1	1	0	1	1	-1	1	1	0	0	0	1	0
Net value			41	49	21	47	45	36	39	23	46	42	49	32	16	27	16	31	36	40	43	21
Ranking			8	1-2	16-17	3	5	10-11	9	15	4	7	1-2	12	18-19	14	18-19	13	10-11	9	6	16-17
Further development			NO	YES	NO	YES	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO

	Criterion	Weighting	Reasoning for weight factor
Direct vision	Increased forward visibility for distribution driving	5	Equally important for FE & FH - High importance
	Increased passenger side visibility for distribution driving	3	Higher for FE - city traffic
	Increased driver side visibility for distribution driving	1	Higher for FE - city traffic, not as important since it is good today
	Risk of disturbing reflections	3	Higher for FH - driving during night time
Indirect vision	Conveniently placed reverse view	5	Equally important, high importance since it is bad today
	Conveniently placed close-up front view	3	Higher for FE - city driving -> frequent stops with close traffic
	Conveniently placed close-up kerb view	3	Higher for FE - city driving -> frequent stops with close traffic
	Conveniently placed rear views LH & RH	5	Equally high importance - need to see behind the cab
Technical considerations from background research	A-pillars withstand crash pendulum test	5	Equally high importance - need to pass crash requirements
	Impact safety of interior components	3	Equilly medium importance - to not have sharp edges inside
	Fuel economy considerations (aerodynamics)	5	High importance FH - small improvements have big impact on long driving
	Cost efficient (product development to support frequent product updates)	3	Higher for FE - PD costs need to be low, FH is less price sensitive
	Cost efficient (low product cost thanks to architecture, modular approach and part number reduction)	3	Higher for FE - modular approach to keep total cost down, FH is less price sensitive
	Appropriate use of new technology (so it facilitates previously impossible in a smart way)	3	Higher for FH - should be using more advanced solutions than FE
	Climate considerations (risk for temperature variations and poor air quality, etc)	5	More important for FH to keep the preffered climate inside, FE more a work tool
General Ergonomics	Interior calmness to minimize cognitive load on the driver	5	Higher for FH - during long drives to keep the driver calm and focused on the task
	Sensation of spaciousness and flexibility to change posture	5	Higher for FH because of longer drives
	Supported reach for controls	3	Equally medium importance to be able to reach controls
	Support for relaxing activities in the driver seat (watching TV, etc).	3	Equally medium importance
	Support for frequently getting in/out (nothing in the way, ease of bringing equipment, etc)	1	Higher importance for FE because of frequent stops
	Support for working activities in the driver seat (order handling, route planning, etc).	1	Higher for FE - handling orders on the go
Visual in-vehicle information	Steering wheel that supports visibility of information	3	Equally medium importance
	Primary information close to common gazing directions	3	Information more varying in FE than FH - not as important to see it all the time
	Secondary information is easy to monitor	3	Information more varying in FE than FH - not as important to see it all the time
	Warnings are easy to detect	5	Equally high importance

The winning concepts for the FH-truck are concepts 2, 4 and 11

H. EVALUATION QUESTIONNAIRE

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						
Long-haul						

Comment- Please comment about both concepts:

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						
Long-haul						

Comment- Please comment about both concepts:

3. **According to your area of responsibility, how well does it support your future road-maps?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						
Long-haul						

Comment- Please comment about both concepts:

4. How cost efficient do you consider these concepts to be?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						
Long-haul						

Comment- Please comment about both concepts:

5. How well adapted do you think the concepts are for city distribution / long-haul respectively?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						
Long-haul						

Comment- Please comment about both concepts:

6. How well do you think the position of the visual information increases safety /comfort?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						
Long-haul						

Comment- Please comment about both concepts:

I. ANSWERS TO EVALUATION QUESTIONNAIRE

Participant no. 1

Evaluation questions

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

No comments.

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

Ratings – Please add an ***X*** *for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul						X

Comment- Please comment about both concepts:

City: the high number of screens might cause confusion on new drivers.

3. **According to your area of responsibility, how well does it support your future road-maps?**

Ratings – Please add an ***X*** *for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

No comments.

4. How cost efficient do you consider these concepts to be?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						X
Long-haul						X

Comment- Please comment about both concepts:

Detachable gadgets are simple to install and could be used in both concepts, as platform. It seems that the number of plastic parts on dashboard will be reduced, what is good. Plastic parts demands huge investments in tooling.

5. How well adapted do you think the concepts are for city distribution / long-haul respectively?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						X
Long-haul						X

Comment- Please comment about both concepts:

Both will be well accepted by drivers.

6. How well do you think the position of the visual information increases safety /comfort?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						X
Long-haul						X

Comment- Please comment about both concepts:

Through screens close to the central field of view drivers, they will not neglect advices from the system. With a set of young drivers emerging on the truck industry, the lack of experiences might be filled by the technology, provided by these concepts.

Participant no. 2

Evaluation questions

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul				X		

Comment- Please comment about both concepts:

Distribution: Nice with bigger windows.
Long haul: Might be a bit cumbersome to have the CMS displays as low as in the concepts (eye and head movement), otherwise good.

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul			X			

Comment- Please comment about both concepts:

Distribution: Curious how a touch screen would stand against a regular button layout.
Long haul: A lot of displays to switch focus in-between.

3. **According to your area of responsibility, how well does it support your future road-maps?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul				X		

Comment- Please comment about both concepts:

Distribution: Don´t really know
Long haul: Don´t really know

4. How cost efficient do you consider these concepts to be?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul			X			

Comment- Please comment about both concepts:

Distribution: Seems quite cost efficient to me, but don't really know.
Long haul: Seems expensive with the amount of displays and a curbed windshield.

5. How well adapted do you think the concepts are for city distribution / long-haul respectively?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul				X		

Comment- Please comment about both concepts:

Distribution: Going for bigger windows (increased direct vision) to me seems like the right way to go for city use.
Long haul: A more aerodynamic cab would benefit and attract many haulers.

6. How well do you think the position of the visual information increases safety /comfort?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul					X	

Comment- Please comment about both concepts:

Distribution: Everything seems to be in a reasonable distance to the driver and easy to read on relatively big displays.
Long haul: Interesting with LCS lights in the frame of the CMS displays!

Participant no. 3

Evaluation questions

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul				X		

Comment- Please comment about both concepts:

FE: Extended windscreen and windows provide improved direct vision. CMS provide similar indirect vision as mirrors, but closer to line of sight. Would be a benefit to have window in passenger side door.

FH: Direct vision sideways improved due to window in doors. Transparent A-pillar good, but not sure if realistic due to collision safety issues?

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul					X	

Comment- Please comment about both concepts:

FE: Good that cluster follows steering wheel adjustment. CMS provided in natural positions, although A-pillar displays seem a bit high.

FH: Information collected around driver seat, which is good. Good idea with the combiner glass. But.. Concerned that the indirect vision rearwards will be covered by driver's arms!

3. **According to your area of responsibility, how well does it support your future road-maps?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul				X		

Comment- Please comment about both concepts:

FE: In line with development of CMS regarding display positions. Good idea with light info around displays.

FH: Interesting to place the class II and IV views beside steering wheel, but need to look into obstruction by driver's arms, as commented before.

4. How cost efficient do you consider these concepts to be?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul			X			

Comment- Please comment about both concepts:

FE: Beneficial to use same displays for several uses, and I guess material cost is reduced due to cleaner dashboard.

FH: Would guess that combiner glass and A-pillar solutions are quite costly, but CMS together with aerodynamic benefits due to reclined windscreen should make driving more cost efficient which can perhaps justify a higher price.

5. How well adapted do you think the concepts are for city distribution / long-haul respectively?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

FE: The concept seems well adapted to distribution thanks to the improved direct vision. However, it would be even better with a window in the passenger door, and perhaps also windows behind the B pillars. Good to use the same display for class VI and reverse views. Good with redesigned steering wheel for easy entry/exit.

FH: Seems well adapted due to aerodynamic benefits, which is important for long haul. Also a driver position layout that seems appropriate for longer driving.

6. How well do you think the position of the visual information increases safety /comfort?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

FE: It's a clean layout with less unnecessary information and interfaces, that should increase safety and decrease cognitive workload. But there is a lot of information that the driver wants and needs, so some level of intelligence in showing right info at the right time is needed.

FH: Good to have most information close to line of sight, good solution for head-up information that seems realistic. One drawback with having class II and IV views close to the steering wheel is that the driver's behavior might change towards being

Participant no. 4

Evaluation questions

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				**X**		
Long-haul					**X**	

Comment- Please comment about both concepts:

CD:

- Seems far better than today, but can be still improved on passenger side. Lower windows can be added on both doors.
- HMI panels to be reduced as much as possible. Locate air vent on the main panel (as passenger side)

LH:

- Lower the passenger as much as possible (see RT Magnum)

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul				X		

Comment- Please comment about both concepts:

CD:

- OK

LH:

- Too many screens on HMI panels. CD seems more logical; don't need to look down to see all rear view screens. To be balanced: transparent A pillar vs Screen located like a mirror

3. **According to your area of responsibility, how well does it support your future road-maps?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						X
Long-haul					X	

Comment- Please comment about both concepts:

CD:

- OK

LH:

- OK for cockpit, but not in line for screen location

4. **How cost efficient do you consider these concepts to be?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul			X			

Comment- Please comment about both concepts:

CD:

- Seems lower than today

LH:

- Seems equal than today

5. **How well adapted do you think the concepts are for city distribution / long-haul respectively?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul		X				

Comment- Please comment about both concepts:

CD:

- OK – why not a centered driver (like new electrical bus)?

LH:

- Not convinced by screen locations

6. **How well do you think the position of the visual information increases safety /comfort?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul		X				

Comment- Please comment about both concepts:

CD:

- OK

LH:

- Not convinced by screen locations

Participant no. 5

Evaluation questions

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul				X		

Comment- Please comment about both concepts:

City distribution concept: + Logical and clear improvement. + Good to try some thinking from smaller vehicles as drivers often drive both. - Could the dashboard part that follows the steering wheel be made more symmetric and smaller to obstruct less?

Long haul concept: + Logical regarding choice of layout, technologies and balance to needs.+ Benefits of see through parts thanks to displays. - Reclined A-pillars will actually create more blind-spots. - Rearview displays are placed too low. - Combiner glass HUD could help to reduce blind spots further. - Real benefit of transparent door displays can be questioned, especially on driver side.

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul					X	

Comment- Please comment about both concepts:

City distribution concept: + To have the displays following the steering wheel will secure that much more is visible for all driver sizes. - No really drastic changes like providing a detachable display at the left A-pillar or having a cheap combiner HUD design also for this concept.

Long haul concept: + Wrap around HUD should mean a good improvement. + Symmetrical layout with respect to the driver seems very right for the long-haul application. - There should also be information shown on the transparent A-pillar surfaces!

3. **According to your area of responsibility, how well does it support your future road-maps?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

City distribution concept: + Reducing cost by thinking differently. + Resolving main problems in simple ways. + Good that defroster function is included within the layout. - It would have given more for getting in/out in this concept to remove/reduce the steering column (e.g. by steer-by-wire).

Long haul concept: + The symmetrically arranged rearview displays are key for the concept. + The concept of providing transparent areas is intriguing and could be used even further. The A-pillar displays can also fully be used for providing information thanks to the rearview displays. - The basic layout of the dashboard is too similar to the current. It would have been interesting to see some modularization ideas to provide different levels of functionalities. - The thinking about air vents and storages are missing and should be added. - The concept illustration is not showing the reverse & close-up front view clearly enough.

4. How cost efficient do you consider these concepts to be?

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul			X			

Comment- Please comment about both concepts:

City distribution concept: + Good modular use of displays. + Choice of multifunction controls and SID seems an appropriate and simple solution. - Having dashboard part following steering wheel adds cost. A concept that put primary information / instrument cluster outside the steering wheel could have been even more cost-efficient. – The upper dashboard module could have been made more symmetric with alternate installation of a SID unit on LHS/RHS to a central completely symmetric cluster module.

Long haul concept: + A symmetric cockpit module in front of the driver shows potential. + Use of same displays and symmetrically arranged displays should save cost. - The rest of the dashboard should also have been provided with more symmetry and modular approaches in mind. - Transparent display areas seem expensive. – More needs to be explained to prove the many combiner HUDs are cost-efficient enough – could exactly the same modules be used in different places?

5. How well adapted do you think the concepts are for city distribution / long-haul respectively?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

City distribution concept: + Main issues have been addressed (importance of direct vision, cost-efficient approach, ease of getting in/out). - It would have been nice with yet another cost-cutting approach (e.g. much smaller display following steering wheel or instrument cluster outside steering wheel). - Nomadic devices for delivering or checking goods are also common. The concept should also have addressed how this is solved (e.g. by portable unit attached to the outer side of the dashboard). Long haul concept: + The proposal shows a clear understanding of the priorities among different aspects in long haul (direct vs indirect vision, how to reduce distraction, etc). + Solutions with higher technology level are chosen based on that these trucks can be allowed to cost a bit more.+ There are key approaches that could be used even more (symmetrical driver module, wrap-around HUD, see-through A-pillars). - It would have been great if transparent display areas could also have been combined with 1) showing information and 2) providing entertainment functions (e.g. a large display in the passenger side dashboard that faces the driver seat which could have replaced the door display).

6. How well do you think the position of the visual information increases safety /comfort?

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution						X
Long-haul				X		

Comment- Please comment about both concepts:

City distribution concept: + Having primary and secondary displays that follow the steering wheel should mean big improvements as the relations to the driver stay the same (and could maybe also be used to pick more simple display solutions that cannot be viewed from as many eye point locations). + Having a proper SID forms a good improvement over current Volvo FE. + The new positions for indirect vision views are all safer than the current. - What about door window on the passenger side – does larger side window fully compensate for that, maybe an entire glass door could have been proposed? Long haul concept: + The symmetric cockpit module has good potential, but could be used even further – how will e.g. a low speed maneuvering situation be handled in relation to loading/unloading? + Transparent A-pillars have a good potential, but displays should probably also be used for warnings & other information. + Looking into a differently shaped steering wheel is an important aspect that could also be explained further (e.g. benefits of different spoke angle and how controls can be integrated). - The concept could have been brought even further (a bit like the wilder brainstorming idea with augmented reality on the wrap-around windscreen – which could maybe have utilized an even larger wrap-around HUD for the same purpose). - The touch control area seems to get a bit too far to the right. Maybe smaller rearview displays should be used as they are anyway closer to the driver than on the A-pillars?

Participant no. 6

Evaluation questions

1. **What is your opinion about how vision of the surroundings (direct and indirect vision) is provided with these concepts?**

Ratings – Please add an X for both concepts:

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul					X	

Comment- Please comment about both concepts:

I believe the "add on" on the side can compromise visibility when driving in urban environment. The SID is quite big and most probably too intrusive.

2. **What is your opinion about how the visual in-vehicle information is provided with these concepts?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul					X	

Comment- Please comment about both concepts:

3. **According to your area of responsibility, how well does it support your future road-maps?**

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					x	
Long-haul					x	

Comment- Please comment about both concepts:

4. How cost efficient do you consider these concepts to be?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution			X			
Long-haul					X	

Comment- Please comment about both concepts:

5. How well adapted do you think the concepts are for city distribution / long-haul respectively?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution				X		
Long-haul					X	

Comment- Please comment about both concepts:

6. How well do you think the position of the visual information increases safety /comfort?

*Ratings – Please add an **X** for both concepts:*

Concept	Unsatisfactory	Poor	Fair	Good	Very good	Excellent
City distribution					X	
Long-haul						X

Comment- Please comment about both concepts:

J. REQUIREMENTS LIST

ID	Requirement description (What?)	Value	Regulated	Justification (Why?)
1	**Internal visibility**			
1.1	Primary information shall be located in drivers line of sight	<15° vertically from central field of view		Safety / Comfort
1.2	Secondary information shall be located close to line of sight	<30° vertically from central field of view		Safety / Comfort
1.3	Warning systems shall be located where the driver can detect motions	<170° horisontally		Safety / Comfort
1.4	Head Up Display shall provide the right information when needed	N/A		Safety / Comfort
1.5	Secondary information shall be easy to monitor	Position within the maximum monitoring cone		Safety / Comfort
1.6	Warning information needs to be positioned so it can be detected	Position withiin the maximum detection cone		Safety / Comfort
2	**Direct vision**			
2.1	Information shall not block the direct view	N/A		Safety
2.2	The truck driver shall have visibility all around the truck	No blind spots	X	Safety
2.3	A radius on a ground plot from the driver shall be visible in forward vision for the driver "German Vision Demand"	12 meters		Safety
2.4	A chord of the cround plot circle shall be visible straight ahead inside the A-pillars "German Vision Demand"	9.5 meters		Safety
2.5	The obstruction from fixed installations on the passenger side shall be below maximum allowance angle "German Vision Demand"	7.4 degrees		Safety
2.6	The obstruction from fixed installations on the driver side shall be below maximum allowance angle "German Vision Demand"	9.9 degrees		Safety
2.7	The driver shall be able to see the ground in front of the truck	≥24 degrees from the horizontal line and downwards		Safety
2.8	The driver shall be able to see the ground on the passenger side of the truck	≥14.8 degrees from the horizontal line and downwards		Safety
2.9	The driver shall be able to see the ground on the driver side of the truck	≥48.4 degrees from the horizontal line and downwards		Safety
2.10	The angle between straight-forward to centre of rearview-mirrors shall be below maximum angle	55 degrees		Safety
2.11	Head Up Display shall not reduce direct visibility	N/A		Safety / Comfort
2.12	The steering wheel shall not obstruct the visibility of the instrument cluster	No obstruction		Safety
3	**Indirect vision (Camera Monitor Systems or Mirrors)**			
3.1	Camera monitoring system shall provide the driver with more visibility than mirrors	N/A		Safety / Comfort
3.2	Camera monitoring system shall have high resolution	N/A	X	Safety / Comfort
3.3	Camera monitoring system shall have quick frame rate	<0.5 millisecond	X	Safety
3.4	The required fields of view with minimum magnification and maximum allowed distortion needs to be be provided	N/A	X	Safety
3.5	The front mirror shall provide the driver with front view while driving slowly	Below 15 Kph		Safety
4	**Bad weather conditions**			
4.1	Wipers must cover a sufficient area of the windscreen	≥ 80 %	X	Safety
4.2	Defroster system must cover a sufficient area of the windscreen	Regulated zones	X	Safety
4.3	Defroster system must cover a sufficient area of the side windows	Zones to facilitate seeing mirrors or provide sufficient sideways vision		Safety
5	**Passive safety**			
5.1	Displays shall break in a safe way in case of an accident	Yes	X	Safety
5.2	Displays shall be readable	from driver's eye point of view		Safety / Comfort
5.3	Displays shall have appropriate angle towards the driver	Driver can see the image		Safety / Comfort
5.4	Truck information shall not be visible outside of the truck	None	X	Safety
5.5	Displays shall not reflect in the windows	No reflection	X	Safety / Comfort
5.6	The A-pillars shall be able to withstand crash impact pendulum test	Impact pendulum test	X	Safety
5.7	The edges of the interior components shall not be sharp and have a minimum radii	N/A	X	Safety
6	**Ergonomics**			
6.1	Controls (switches and touch displays) shall be located where the driver can reach them	Maximum reach surface - one finger from the driver position		Safety / Comfort
6.2	The cockpit layout shall provide the driver with calmness	N/A		Safety / Comfort
6.3	The controls shall be intultive	Yes		Safety / Comfort
6.4	The FH layout shall provide the driver with the ability to move easily between the driver seat and the passenger seat	N/A		Comfort
6.5	The interior shall provide sufficient knee clearance	CAD knee clearance requirement surface		Comfort
6.6	Time for finding information shall be minimized	N/A		Comfort
6.7	The amount of simultaneous sensory stimuli shall be minimized	7±2 chunks		Safety / Comfort
6.8	Layout that supports different driver sizes	F05, M50, M97.5		Safety / Comfort
6.9	Controls that are safety critical need to be positioned close enough to the driver	Maximum 500mm sideways from seat centre to control location	X	Safety / Comfort
6.10	The dashboard shall provide cupholder(s)	Yes		Comfort
6.11	The dashboard shall provide storage space(s)	Yes		Comfort