Future Layout of Visual Information in Trucks

Bachelor Thesis in Product Development

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Gothenburg, Sweden, June 2013

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- in collaboration with Volvo Trucks

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Abstract

This report covers the development of a conceptual layout for the visual information in a Volvo truck cab. New technologies enable new ways of providing the truck driver with the visual information needed for driving. This calls for a reconsideration of the current visual information layout and leads to question the current positions of all devices providing visual information, ranging from displays to rearview mirrors.

The new technologies include Head Up Display technology (HUD) that enables projecting visual information directly onto the windows, as well as Camera Monitor Systems (CMS) that can replace the conventional mirrors. These technologies have many advantages, but might also introduce problems like visual distraction and increased cognitive workload for the driver. These aspects were evaluated briefly in this project.

The project was performed with the end user in focus. The concepts were developed based on the properties of the new technologies as well as ergonomics aspects and ideas and inspiration from specialists at Volvo Trucks. Three layout concepts were evaluated in a user study by 16 test drivers in a driving simulator at Volvo Trucks in Gothenburg.

The final layout is based on truck drivers' needs and opinions derived from the user study. This study indicates that it is important for truck drivers that a new layout resembles the one in the current truck cab and that the visual information is provided in logical positions supporting the natural behavior while driving. From an ergonomics point of view it seems to be important that the most frequently used information is presented as close as possible to the driver's line of sight. These are examples of aspects that were taken into consideration when creating the final layout.

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Acronyms

CMS = Camera Monitor System

CO2e = Carbone Dioxide Equivalent

DID = Driver Information Display

ECU = Electrical Control Unit

FCW = Forward Collision Warning

HMI = Human-machine interaction

HUD = Head Up Display

LCS = Lane Change Support

SID = Secondary Information Display

WRC = Wireless Remote Control

1. Introduction

1.2 Background

Volvo Trucks is an international corporation and is the second biggest producer of heavy trucks in the world (Volvo Trucks[1], 2013). The first Volvo truck was built in 1928 in Gothenburg, Sweden and they are now sold and serviced in over 130 countries worldwide. Volvo Trucks is continuously working with quality improvement, safety and to decrease the effect on the environment caused by their products.

Volvo Trucks is affected like so many other companies by the rapid technical progress of today. There are many new technical solutions that can solve issues in critical driving situations in innovative ways. This leads to question whether traditional solutions and layouts should be revised and eventually phased out to pave the way for new concepts.

With the help of new technology the driver may access information that was not available before and also get the possibility to access it in new ways. Volvo Trucks are now looking into the possibility of replacing the traditional rearview mirrors with camera and display systems. To implement this, the whole layout of the driver cabin may be affected and some conventional instruments may have to be moved to new positions. At the same time it is also possible that the traditional solutions for providing visual information can be replaced by new technologies that are becoming mature. Such new technologies are new ways of installing displays as well as Head Up Display (HUD) technologies.

A changed driver interface can also affect the direct vision out from the cab and introduce problems with driver distraction. This is a problematic issue when it comes to repositioning different means of visual information in the cab. Other aspects that also have to be considered are whether there is enough space to implement new information devices and where these should be positioned in relation to each other. Yet another aspect to consider is how easily the drivers get used to new positions of visual information.

1.3 Problem statement

When a driver is provided with visual information about the surroundings of the truck through windows, displays and mirrors, there are some issues involved. The most substantial issue is blind spots (blocked field of view) around the vehicle which cause visibility problems and are a potential danger (Volvo Trucks[2], 2013). The cab of a typical European truck sits on top of the engine (Cab Over Engine type of layout), which means that the driver's position is far from the ground, limiting the close up visibility around the cab. Additionally, there are a number of objects in the cab blocking the driver's visibility out from the cab. *"The rearview mirrors on the side of trucks can for example block a whole passenger car. This is identified as one of the main visibility problems in today's trucks[1]".* Drivers are also supplied with a large amount of information that they need to perceive and interpret without losing focus of the driving task.

To eradicate the problem with the mirrors blocking visibility the mirrors could be replaced by Camera Monitor Systems (CMS). But when doing that it could mean that the whole layout of the visual information in the cab might have to change when new displays will have to fit in the cab. It is therefore necessary to evaluate what solutions for visual information should be used and where they should be positioned.

1.4 Purpose

The purpose of this project is to suggest and evaluate alternative layouts for the positions of visual information in future truck models and suggest preferred relations between the different types of visual information. This will be done based on the positioning of displays for indirect vision rearwards and the close-up areas surrounding the truck.

1.5 Question formulation

The following question formulations states which aspects this thesis work covers:

- What layout for the different types of visual information should be used in trucks?
    - How should different types of visual information be positioned in relation to each other?
    - Are there any advantages of moving visual information from the traditional dashboard to alternative positions?
- What are the visibility advantages of C*MS* in comparison to conventional mirrors?
- What are the preferred positions for camera displays within the cab when implementing CMS?
- Which types of visual information are most suitable for HUD technology?
- Are there any advantages in gathering all visual information in the same place?

[1] *Patrik Blomdahl (Ergonomics Team & Feature Leader, Volvo Trucks, GTT) interviewed by the authors on 18th February 2013*

1.6 Scope / limitations

There are a lot of aspects that need to be considered when changing an existing layout and implementing new technologies. It would not be possible to cover all of it in this thesis work, so some limitations is necessary to narrow down the scope and to make the project viable within the time frame.

1.6.1 Transport segment

Volvo identifies three different transport segments; long-haul, distribution and construction (Volvo Trucks, 2012[3]). The Volvo FE and FL models are designed for the distribution segment, Volvo FM can be used in several segments whereas Volvo FH is designed for long-haul transportation. For the construction segment, Volvo FMX is most commonly used.

This thesis work will only focus on the demanding long-haul segment since this segment includes more high-spec solutions and therefore is best suited for implementing new technologies. Due to this, only the FH model ("front-mounted high cab") will be included.

1.6.1.1 The Volvo FH

The Volvo FH is a truck made for long haul transportation and is specifically built for handling the performance demands of long distance driving (Volvo Trucks[1], 2013). It is fuel efficient, strong and profitable and can also be used for heavy construction work (e.g. to transport machinery for building roads). It comes in a number of variations to suit as many different transport tasks as possible. Engine power vary from 420 to 750 horse powers, gross weight for the vehicle combination vary from 18 to 100 tons and there are three types of cabs; Sleeper cab, Globetrotter and Globetrotter XL (Volvo Trucks[1], 2013). However, these variations do not affect the aspects covered in this thesis work. A new Volvo FH model was released in late 2012 with redesigned rearview mirrors, instrument cluster, and instrument panel etcetera. This is the model used as basis for the studies in this thesis work.

Figure 1.1 Volvo FH (Volvo Trucks[1], 2013)

1.6.2 Operating cycles

- Volvo identifies four different operating cycles for trucks, they are (Volvo Trucks[3], 2012):
- Stop and go: stop and go, low speed, stationary
- Local: many stops, low average speed.
- Regional: mixture of short and long distances between stops, stops are usually clustered.
- Long distance: few stops, high average speed, long distances covered during each working period.

This thesis work will look into long distance driving and maneuvering at lower speeds that may come closer to stop and go driving.

1.6.3 Instrument panel design

Changes needed to the instrument panel when removing different means of visual information will not be taken into consideration.

1.6.4 Design of visual information

This thesis work will not include how the visual information itself should be designed – it will only process the positions of the different means of information.

1.6.5 Night time driving

New displays and other visual information can introduce driver distraction. For example, displays can interfere with the driver's night vision when driving in darkness. Only day time driving will be analyzed in this thesis work.

1.6.6 New technology

New technology will be examined and evaluated on the basis of how it could be implemented and used rather than how it works in detail. The technical functionality is secondary from an ergonomics point of view.

1.6.7 Camera Monitor Systems (CMS)

The possibility to use Camera Monitor Systems to replace the conventional rearview and close up mirrors will be examined in this thesis work. However, the position of the camera, the type of lens used and the techniques for delivering the image to the camera monitor will not be included. This has been evaluated in another thesis work at Volvo that will be used as information to this project. Only the position of the camera displays will be included.

1.6.8 Types of information

A truck driver is provided with several types of information; visual, auditory and haptic. Only visual information and visual distraction will be covered in this thesis work.

1.6.9 Economy

When implementing new technologies the cost might be high and therefore not worth introducing. This is a thesis work on a very conceptual level where cost is not taken into considered.

1.7 Methodology

User studies and experiences are important to consider when generating and evaluating ideas and concepts since this is an analyzing and user based thesis work.

1.7.1 Feasibility study

A substantial amount of background information is a necessary base for any project. The information will be gathered from a number of different sources and will be used to plan and map out the project at an early stage.

1.7.1.1 Literature study

A literature study will be performed to gather state of the art information about trucks, passenger cars and new technologies that could be implemented in this project. The study will be done by reading magazines, books, recent project reports, research and internal documents at Volvo.

1.7.1.2 Questionnaires

Questionnaires will be used to define the scope of the project to get a better understanding of what truck drivers think is important regarding visibility and visual information presented while driving.

1.7.1.3 Benchmarking

Different solutions for placing information displays and instrument cluster parts are implemented by competitors to Volvo as well as in the passenger car industry. Different passenger car models will be analyzed and tested in order to get inspiration, new ideas and to evaluate new solutions.

1.7.2 Generating concepts

This chapter presents the methods used for generating layout concepts for the visual information in the truck cab.

1.7.2.1 Creative idea generation

A creative idea generation session will be performed to promote free thinking and to get radical ideas that might be applicable at a later stage. It will also give a deeper understanding of the subject at hand. This method will be implemented as a classic brainstorming session with post-it notes and mind maps.

1.7.2.2 Workshop

A workshop will be performed with experts at Volvo to make sure the layout concepts include state-of-the-art knowledge and ideas from people that work with ergonomics, driver interface, product design and design engineering. The workshop method will be implemented because it promotes creativity and is a good way of synchronizing ideas from people with different backgrounds.

1.7.2.3 Morphological matrix

With the help of the material from the workshop, a Morphological matrix will be used to generate new concepts for the visual information layout. A Morphological matrix is a good way to generate many significantly different concepts that later can be developed further.

1.8 Choosing concepts for final evaluation

When the concepts have been developed, they will be evaluated and rated against identified criteria with the help of different methods. The three highest ranked concepts will be evaluated again and compared so that one concept can be chosen for further development.

1.8.1 Pugh matrix

A Pugh matrix will be used to initially rate the generated concepts and compare them with today's Volvo FH. It is important to use the current cab as a reference to be able to evaluate how well the new concepts perform in relation to the traditional information layout.

1.8.2 Reference group of experts

A group of experts at Volvo with different skills and experience will be consulted to select three concepts for further development and evaluation. This is a vital part of the concept selection to make sure that aspects like ergonomics, driver interface and visibility are taken into consideration when proceeding with the concept development.

1.9 Evaluating final concepts

The chosen concepts will be evaluated by a group of experienced test drivers and experts in order to analyze their advantages and disadvantages. The test drivers' thoughts are valuable because they have a lot of experience of truck driving and the experts provide expertise within their different fields.

1.9.1 Driving simulator

A driving simulator will be used as a tool for evaluating the final concepts. This method can be used for both objective and subjective evaluations. It is a good tool because it enables simulated truck driving in a controlled environment where the test drivers can evaluate several alternative layouts in a short period of time. However, focus will be on subjective analysis of the concepts in this thesis work and the evaluation is qualitative rather than quantitative. The test drivers' opinions about the different positions and layouts will be collected, as well as their thoughts on the different concepts in general.

1.9.1.1 Creating virtual concepts

By creating CAD-models of the concepts they can be implemented in the virtual driving environment of the simulator. It is important to make sure that the information given in the different concepts corresponds with each other to be able to evaluate them on common terms. Quality is also secured by keeping as good control as possible of positioning and dimensions of the concepts.

1.9.1.2 Interviews

Interviews will be conducted during and after the test drivers are using the driving simulator, as well as after getting to know each concept, in order to collect clear subjective opinions and ratings of the different concepts.

2. Theory

This theory chapter will cover the theory needed to follow the development of the thesis work.

2.1 Truck theory

This chapter includes the necessary theory about the Volvo truck cab.

2.1.1 The Truck Cab

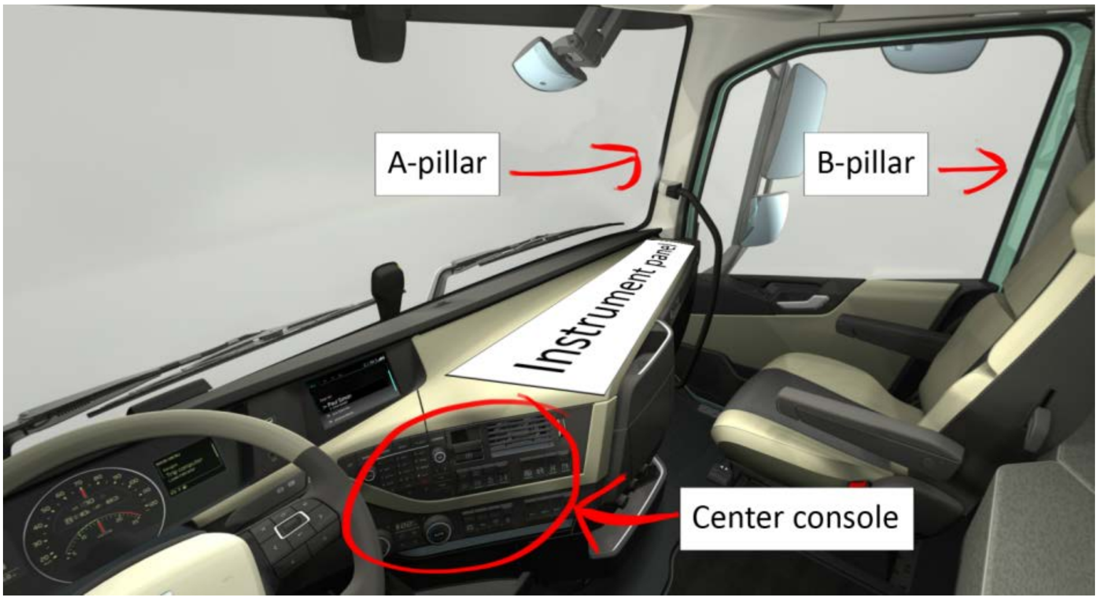

Figure 2.1 Inside the Volvo FH cab

There are a lot of different parts and devices in the cab of the truck. Some of these parts are explained within this chapter in order to support the understanding of the process of this thesis work.

A-pillar
The A-pillars holds the windscreen in place and they are positioned on the left and the right sides of the cab and support the cab roof as seen in figure 2.1.

B-pillar
The B-pillars are located directly behind the doors on each side as seen in figure 2.1. They support the roof and form the border to any rear side window.

Instrument panel
The instrument panel is the engineering module incorporating the instruments and controls as well as many driving related systems and solutions such as, electrical systems and climate system. It stretches between the A-pillars and is a main provider of areas for visual information and controls including the center console as seen in figure 2.1.

Center console
The center console forms a main control area for the various functionality of the truck. Some typical controls found here are the ones for radio and air conditioning as seen in figure 2.1.

2.1.1.1 Visual information in the truck cab

There are different types of visual information that reaches the truck driver. This chapter describes these types as referred to in this thesis work.

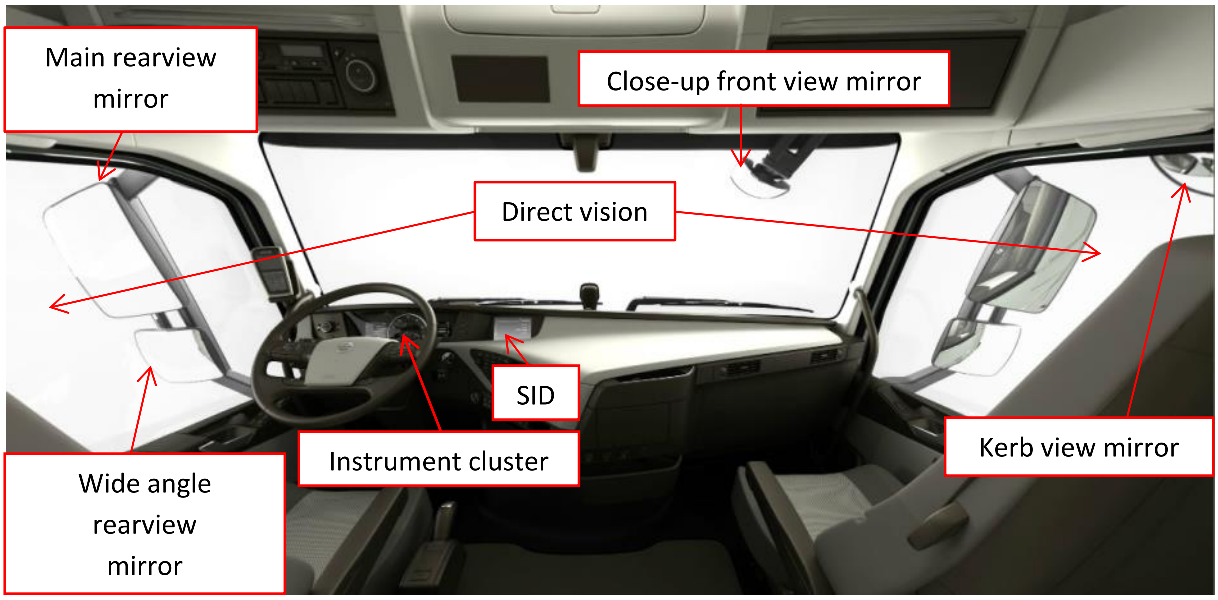

Figure 2.2 Classification of visual information in the Volvo FH truck

Direct vision is the vision out from the vehicle cab through the windows
Windscreen – the windscreen is the primary provider of direct vision forwards
Side windows – the side windows in the doors provide direct vision sideways

Indirect vision

Indirect vision is vision provided indirectly via devices like mirrors or camera monitors:
Rearwards view – shows what is behind the driver at each side of the vehicle as well as behind the vehicle

Main view – covers vision far behind the truck and provides accurate distance judgment
Wide-angle view – covers blind spots closer to the cab and provides a distorted view
Reverse view – covers area behind the vehicle, normally provided as a distorted view from a camera

Close-up front view – shows what is immediately in front of the cab
Kerb view – shows what is immediately beside the cab on the passenger side

Figure 2.3 From left: rearview mirrors, close-up front view mirror and kerb view mirror

Secondary information

Secondary information involves information that is not as important as primary information. This is shown in a Secondary Information Display (SID) often located to the right of the driver.

Secondary Information Display (SID) – integrated in the instrument panel and shows typically information related to navigation, reverse camera, driving times, transport order management, phone and audio systems.

Figure 2.4 Position of the Secondary Information Display (SID)

Driver information (primary information)

Driver information includes vital information about the status of the truck and messages for safe driving. This information is normally shown in an instrument cluster. Typical information types are the speedometer, warning signals, fault messages and fuel levels etc.

Instrument Cluster – included in the instrument panel behind the steering wheel and includes gauges, a Driver Information Display (DID) that involves status indicators, trip information, driver warnings, load indicator and error messages. It also contains gauges, indicators, head light symbols and other tell tales like parking and seat belt indicator.

Figure 2.5 Position of the Instrument Cluster

Warning systems

There are different warning systems alerting the driver to act in critical situations. Two of these provide visual information:

Lane Changing Support (LCS) – The Lane Changing Support system (LCS) alerts the driver of objects in the blind spots on the passenger side of the truck to avoid collision when changing lanes. The warning lamp is placed on the A-pillar (see Figure 2.6)

Forward Collision Warning (FCW) – The Forward Collision Warning system (FCW) warns the driver if there are objects in front of the truck that are getting too close in relation to the current speed of the truck. The driver is warned by a red flashing light in the windscreen (see Figure 2.7).

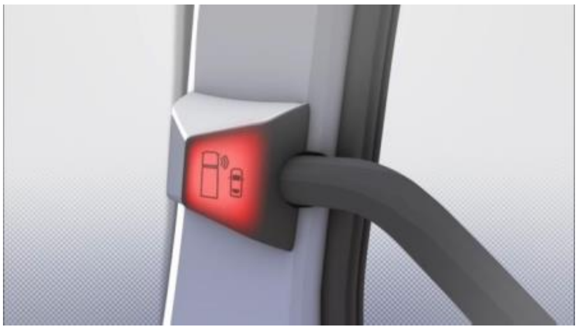

Figure 2.6 Lane Changing Support

Figure 2.7 Forward Collision Warning

2.2 Visibility

The concept of visibility is about what can be seen around a vehicle when sitting inside the cab (Blomdahl, 2012). This is a wide field including several quite different aspects:

- Visibility during the day, at night and in bad weather
- Direct and indirect vision at different speeds
- Use of headlamps and other light sources
- Lack of reflections that can disturb the direct and indirect views
- Light communication with others
- Windscreen wipers ability to keep windows clean
- Defroster systems ability to keep windows free from mist or ice

Of these direct and indirect vision at different speeds are of specific importance for this thesis work. These can be split into the following sub-categories:

- Direct vision
    - Direct vision forwards = Vision through the windscreen being limited both upwards, downwards and sideways by the window boundaries and any fixed installations on the exterior or interior
    - Direct vision sideways = Driver and passenger side through doors and other windows on the cab sides
    - Direct vision rearwards = Vision rearwards from the driver position as supported by any rear window
- Indirect vision
    - Indirect vision rearwards via indirect vision devices like mirrors or cameras
    - Indirect close-up vision via indirect vision devices like mirrors or cameras

2.2.1 Indirect vision in trucks

There are four different types of indirect vision provided in trucks. As seen in Figure 2.8 they are:

Class II - provided by main rearview mirrors
Class IV - provided by wide-angle rearview mirrors
Class V - provided by kerb view proximity indirect vision device (mirror or camera)
Class VI - provided by close-up front indirect vision device (mirror or camera)

NOTE: Class V and Class VI fields of view are only allowed to be provided by Camera Monitor Systems under certain provisions. Class II and Class IV fields of view are not yet allowed to be provided by Camera Monitor Systems, but new standards are being developed listing requirements to be fulfilled if this should be allowed.

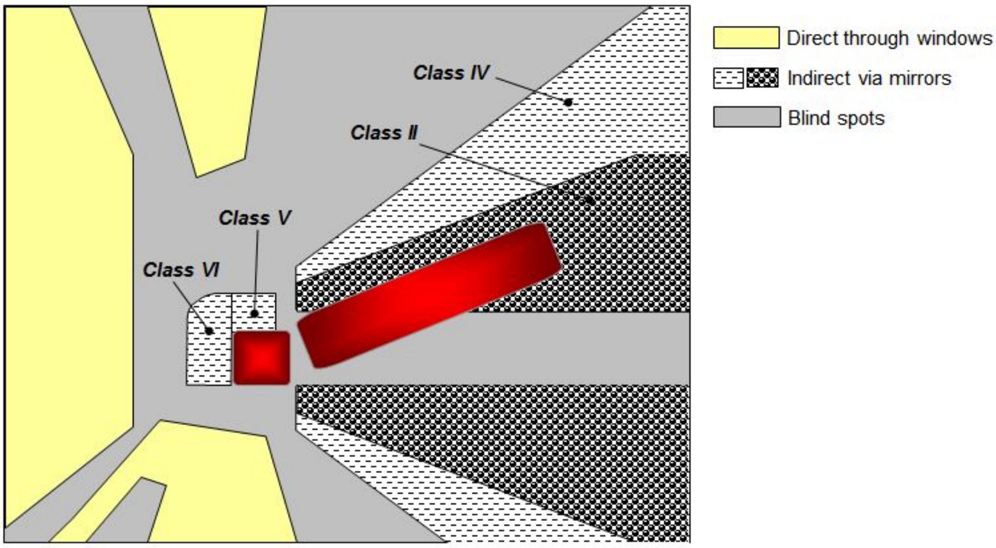

Figure 2.8 Classification of visibility and blind spots in trucks seen from above (Volvo Trucks[2], 2013)

2.2.2 Legal requirements indirect vision devices

The indirect vision in trucks is provided by four different mirrors that are designed to aid the driver in different driving situations (Fronell Fagerström & Gårdlund, 2012). There are strict legal demands on field of vision provided by indirect vision devices. For the indirect vision devices, the United Nations regulation (UNECE, 2010) dictates the minimum requirements for which fields of vision shall be covered with minimum requirements for how these shall be provided. This is the regulation European automotive manufacturers are following (Fronell Fagerström & Gårdlund, 2012).

Class II mirrors

As seen in Figure 2.9 the field of vision requirements by ECE 46-02 for the class II rear-view mirrors.

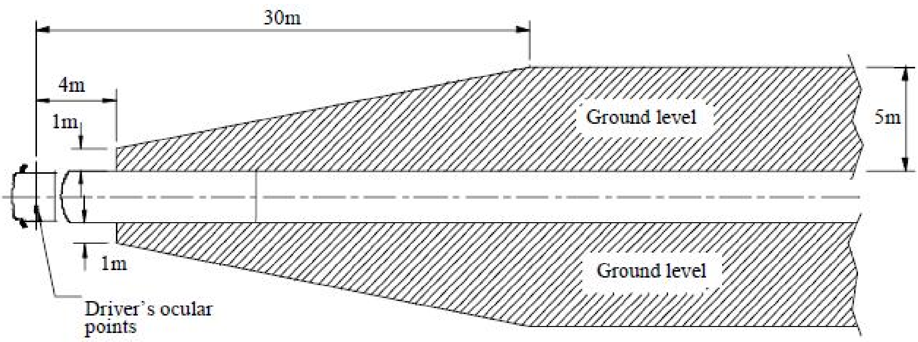

Figure 2.9 Field of vision requirements for Class II mirrors (UNECE, 2010)

Class IV mirrors

As seen in Figure 2.10 the field of vision requirements by ECE 46-02 for the class IV rear-view mirrors.

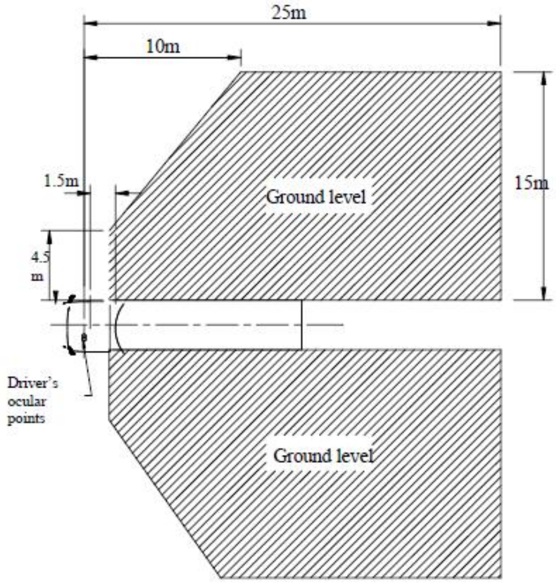

Figure 2.10 Field of vision requirements for Class IV mirrors (UNECE, 2010)

Class V indirect vision devices

As seen in Figure 2.11 the field of vision requirements by ECE 46-02 for the class V rear-view mirrors.

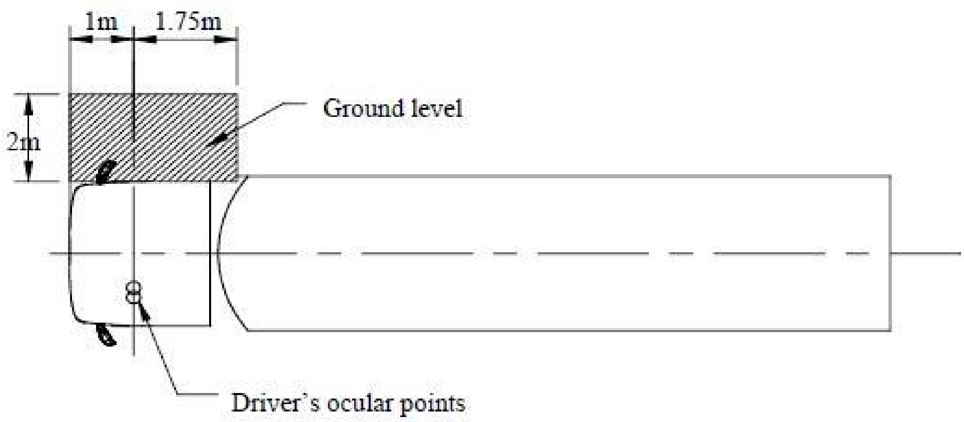

Figure 2.11 Field of vision requirements for Class V indirect vision devices (UNECE, 2010)

Class VI indirect vision devices

As seen in Figure 2.12 the field of vision requirements by ECE 46-02 for the class V rear-view mirrors.

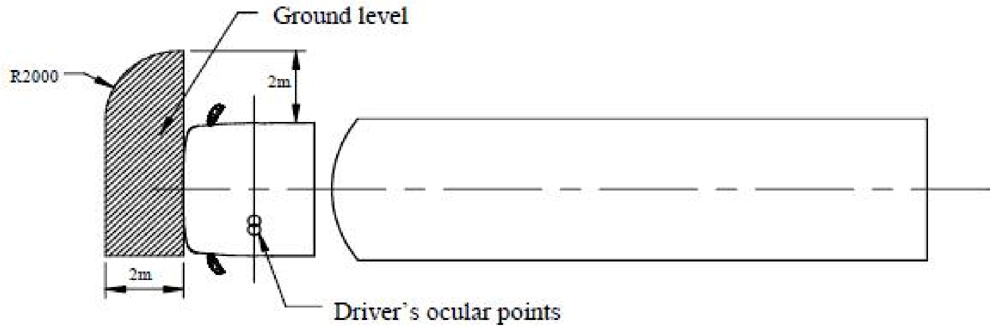

Figure 2.12 Field of vision requirements for Class VI indirect vision devices (UNECE, 2010)

2.3 Camera Monitor Systems (CMS)

A Camera Monitor System consists of a camera, an electrical control unit (ECU) and a monitor that shows the information captured by the camera (Fronell Fagerström & Gårdlund, 2012).

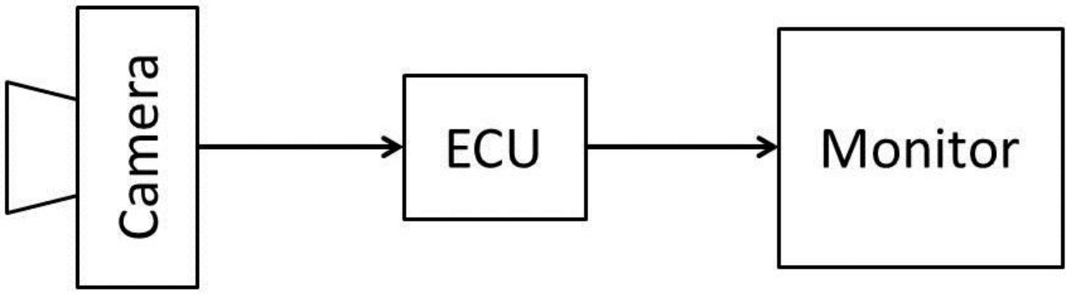

Figure 2.13 Schematic image of how information flows in a CMS (Fronell Fagerström & Gårdlund, 2012).

Cameras are built with many different components and depending on the preferences of the camera lens it is possible to achieve different types of images (Fronell Fagerström & Gårdlund, 2012). Information captured by the camera is received by the ECU which works as a small computer and handles the information received from the camera and forwards it to the monitor that presents the information to the user.

2.4 Head Up Display

Head Up Displays (HUD) is a fairly old technology for displaying information in a location that enables the driver to keep the head up within a vehicle. Originally this way of displaying information was introduced within aircraft. In passenger cars it was first introduced in the -88 Oldsmobile Cutlass Supreme but the technology did not stay (Tretten, 2011). In recent years the HUD technology has started to come back and is implemented in a lot of modern passenger cars, for example the BMW 330 series (BMW[1], 2013).

The HUD technology projects information directly on the windscreen of the vehicle (BMW[2], 2013). Today it is mostly used for showing information like speed, navigation and warnings. The technology today is limited to showing digital texts in one or two colors.

Figure 2.14 Schematic illustration of HUD (Telematic News, 2012)

Figure 2.15 Illustration of the HUD technology (Automotive World, 2012)

2.5 Detecting objects in trucks

The human body has limitations in both the ability to cope with cognitive workload and sensorial aspects like vision and hearing. This chapter will further describe these aspects.

2.5.1 The human eye

The human eye has a peripheral field of vision of approximately 210° but the central field of vision is limited to 2° (d'ydewalle, Parham, & Grooner, 1990). The further away an object is from the eye's foveal vision area, the harder it is for the eye to notice changes in the object. The eye's foveal acuity decreases by a factor of 3 beyond the 15° cone (see Figure 2.15). Within approximately 15° from the central field of vision, eye movements are executed efficiently but there is a border at 30° for the vertical meridian and 35° for the horizontal meridian (Tretten, 2011). There are different limits for detecting objects above and beneath the line of sight. The limit above the line of sight is 50° and below is 70° (Diffrient, Alvin, & Bardagjy, 1981).

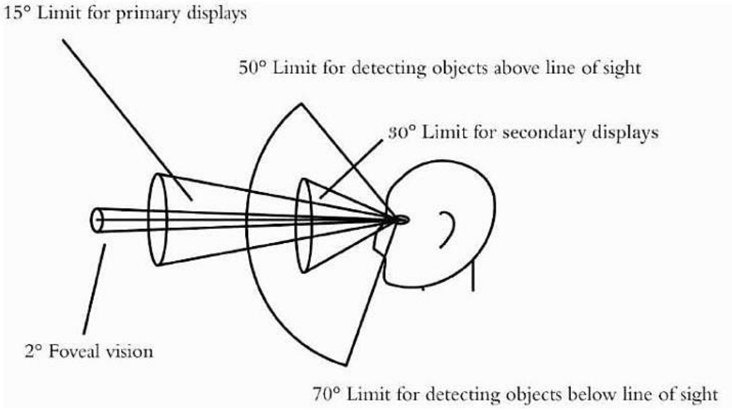

Figure 2.16 Field of foveal vision, central field of vision, and peripheral vision (Tretten, 2011).

2.5.2 Monitoring tasks

When performing monitoring tasks the driver actively moves the eyes to seek information (International Organization for Standardization, 1992). Certain angles are better suited for monitoring while maintaining driver comfort. These angles are specified in Figure 2.16.These aspects of physical vision limitations are important to consider when positioning devices presenting visual information to the driver while maneuvering the vehicle.

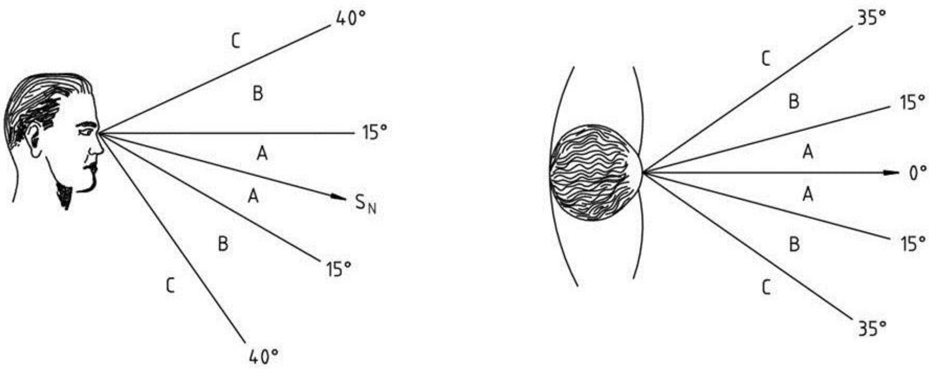

Figure 2.17 Suitable positions for the field of view when monitoring (International Organization for Standardization, 1992)

Level of suitability	Significance
A: Recommended	This zone shall be used wherever possible
B: Acceptable	This zone may be used if the recommended zone cannot be used
C: Not suitable	This zone should not be chosen

Table 1 Suitable grades for zones in figure 2.17

2.5.3 Head movements

When a driver is looking for visual information it is done by moving the eyes and tilting and turning the head (Fronell Fagerström & Gårdlund, 2012). To reduce head movements the visual information should be placed as close as possible to the line of sight. This will also minimize the time necessary for the driver to assimilate the information.

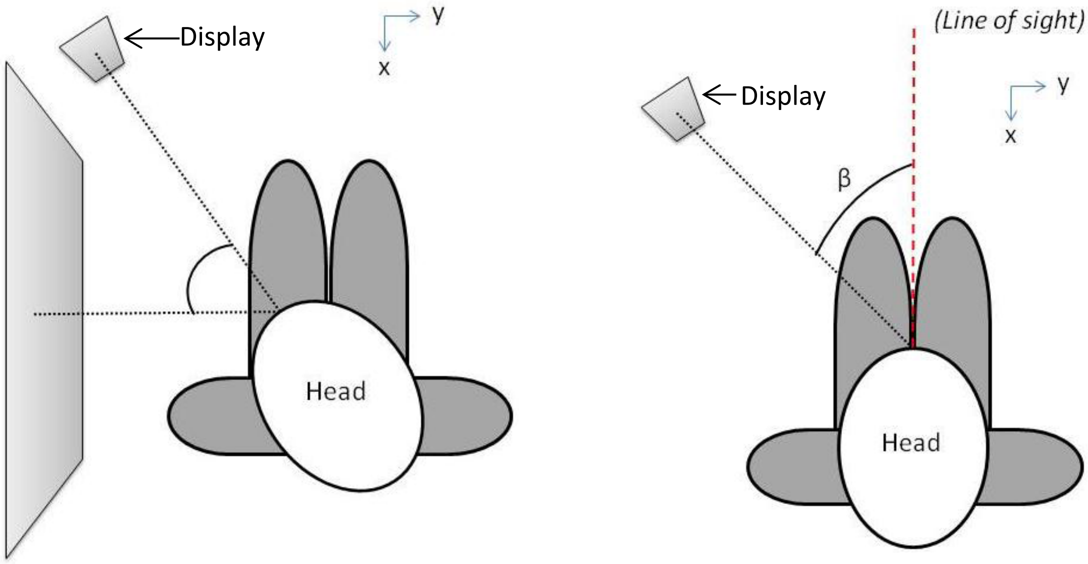

Figure 2.18 Illustration on how the driver has to move the head between direct and indirect vision (Fronell Fagerström & Gårdlund, 2012)

As illustrated in Figure 2.17, the line of sight varies depending on what viewing direction is most useful in different driving situations.

2.5.4 Visual cognitive workload

The definition of cognition is *"a term referring to the mental processes involved in gaining knowledge and comprehension. These processes include thinking, knowing, remembering, judging, and problem-solving. These are higher-level functions of the brain and encompass language, imagination, perception, and planning."* (Cherry, 2013).

In modern trucks the driver receives a lot of different visual information from systems in the vehicle. This is pushing the driver's ability to take on cognitive workload and can distract the driver in different ways. To determine exactly how much mental workload a driver can handle is very complex and will not be studied in detail, but will be taken into consideration in the project.

2.6 Driver distraction

Driver distraction is part of a broader category called driver inattention (Young, Regen, & Hammer, Driver Distraction; A review of literature, 2003). It can be divided into four different categories that will be further explained in the following chapters (ROSPA, 2007):

2.6.1 Visual distraction

Visual distraction is divided into three different types of distractions (Ito, Atsumi, Uno, & Akamatsu, 2001). The first is identified as when the driver's visual field is blocked by objects, for example stickers on the windscreen that can prevent the driver from identifying objects in the road environment. The second type of visual distraction happens when the driver is focusing on another type of visual information such as radio or navigation. The third type is loss of visual attentiveness which means that the driver is looking in the right direction but does not recognize the hazardous road environment.

2.6.2 Auditory distraction

Auditory distraction occurs when a driver focuses on sounds or auditory information instead of the road while driving (Young, Regan, & Hammer, 2003). Typical distractions are using a mobile phone, listening to the radio and having a conversation with a passenger.

2.6.3 Biomechanical (Physical) Distraction

Biomechanical distraction occurs when a physical task is being performed that is not related to driving, for example reaching for something or holding a cup of coffee (ROSPA, 2007). As a result of this the driver may remove one or both hands from the steering wheel instead of focusing on the physical tasks required to drive safely.

2.6.4 Cognitive distraction

Cognitive distraction occurs when a driver starts thinking about something that is not related to driving (ROSPA, 2007). Studies of the driver's eye fixations while performing cognitive tasks show that drivers spend less time scanning the road environment; instead the eyes are fixed on staring ahead than usual. This means that drivers that get cognitively distracted will spend less time checking mirrors or looking around the vehicle for hazards.

2.7 M50 eye-point

The M50 eye-point corresponds to the eye location of the medium-size 50th percentile male truck driver. When speaking about one single point it is the monocular eye-point derived from picking the mid-point between the two eye locations corresponding to binocular vision. This eye point is commonly used for evaluating direct vision because it corresponds to the average driver (Fronell Fagerström & Gårdlund, 2012). When doing concept evaluations in this project, the M50 eye-point is used as a representation of the distribution of eye points.

Figure 2.19 M50 truck driver (male driver of 50th percentile in size)

2.8 Advantages with CMS

By eliminating the rearview mirrors some advantages have been identified. Some of them will be described further in this chapter, there are also other advantages, but those go beyond the scope of this project.

2.8.1 Environmental benefits

By eliminating the rearview mirrors the aerodynamic properties for the truck are improved. With that outset a brief Life Cycle Analysis (LCA) was performed. The results of this analysis will be presented in this chapter (Höcke & Danielsson, 2013).

When driving a Volvo FH without rearview mirrors, the drag is reduced and therefore also the fuel consumption. Volvo Trucks has performed wind tunnel tests and came to the conclusion that the Volvo FH without mirrors will lower its fuel consumption by 1.3%. But when installing cameras on the trucks chassis it is estimated to increase the fuel consumption by 0.3% which means that the fuel consumption would decrease by a total of about 1%[2].

An LCA analysis on both the rearview mirrors and the new CMS was carried out to compare if there are any other advantages by replacing the mirrors with cameras and displays when looking at the whole lifecycle of the product. These additional advantages concern e.g. how much material is used to build mirrors and CMS respectively. The result of that study was that the CMS would use about 24g CO2e/100 km and the mirrors about 13g CO2e/100 km. This means that the CMS has a bigger environmental impact. This is because the active cameras use energy when they are being used but the mirrors are almost passive, although they use some electricity for heating and electrical adjustment. This use of electricity is very small compared to the electricity used by the CMS and has been neglected.

But as mentioned before the mirrors contribute to 1.3% extra fuel consumption which means that even though they are passive when using them they cause an extra 1088g CO2e/100 km which gives the rearview mirrors a total of 1088 + 13= 1102g CO2e/100 km.

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[2] *Linus Hjelm (Aerodynamicist, Volvo Trucks, GTT) intervjuad av författaren den 25 februari 2013*

To compare the two solutions a study was done on how big impact they have per 100 km driven with the truck when looking on the trucks total life cycle. A truck's total life cycle is estimated to 1 000 000 km and it releases 83700g CO2e/100 km because of fuel consumption based on the total life cycle.

When driving a truck with the mirrors, the fuel consumption does not change and the total CO2e/100 km for the truck is therefore: 13 + 83700 = 83713g CO2e/100 km. When driving without the mirrors there is an estimated saving of 1% of the fuel consumption. This means that a truck with CMS has 99% of the mirror equipped truck's CO2 emissions, resulting in 0, 99*83700 = 82863 g CO2e/100 km. The cameras themselves contribute with 24g CO2e/100 km which means that the total is: 24 +82863 = 82887 g CO2e/100 km.

That gives a total saving of 83713 - 82887= 825g CO2e/100 km when using CMS and based on the total exhausts for a truck based on it driving 1 000 000 km is 8260 kg CO2e. This equals a saving of about 3100 liters of diesel during the truck's life cycle. When implementing CMS it is also possible to replace the close-up front view mirror and the kerb view mirror. This is thought to further reduce the CO2 emissions but has not been looked in to in this thesis work.

2.8.2 Visual benefits

As mentioned in chapter 1.3 Problem statementthe mirrors block a lot of the direct vision. By removing them the direct vision should therefore improve. A previous thesis work on Volvo estimated how much direct vision the rearview mirrors blocks and came to the result that they cover about 8% of the total direct vision (Fronell Fagerström & Gårdlund, 2012). This means that if the displays are placed in a way that they do not block any direct vision there is a chance of improving the direct vision by 8%.

It is also possible to remove the close-up front view mirror and the kerb view mirror; this has not been looked into but is thought to contribute with more direct vision as well.

2.9 Conclusion of theory

As explained there are many aspects to consider when determining where to position visual information inside the cab of the truck. Due to physical limitations of the human body, information should be presented close to the actual line of sight to reduce distractions from head movements and within the 15° cone described in chapter 2.5.1 The human eye. Drivers also get visually distracted by information if it takes too much attention or if it is in the line of sight and thereby blocking vision. This contradicts the fact that information should be placed near the line of sight to reduce distractions from head movement, since putting the information too close to the line of sight might disturb the direct vision for the driver. This needs to be taken into consideration when evaluating concepts in this thesis work.

There are many types of visual information in a truck's cab and some of them are regulated by laws. Both direct and indirect vision need to follow strict regulation demands. This has also been taken into consideration when implementing new solutions for providing visual information to the driver.

3. Procedure

This chapter describes how the thesis work was performed.

3.1 Initial questionnaire

To help define the project scope an initial questionnaire was sent to 10 of Volvo's internal truck drivers (see Appendix 1). It was sent to a test driver leader at Volvo's test track in Hällered and was distributed among test drivers. The questionnaire contained 8 open-ended questions for the drivers to answer with their own comments. The questions covered different aspects of visual information in the Volvo FH today such as the positioning, importance, preferred type, how easily understandable it is and whether it is considered helping with the driving tasks.

3.2 Benchmarking

Benchmarking was implemented to get practical experience of some of the new technologies for visual information and was performed by trying two different passenger cars.

3.2.1 Head up Display

BMW is one of the car manufacturers that are pioneering in Head up Display (HUD) technology in passenger cars[3]. The BMW 330 Diesel Touring M-Sport was used for the benchmarking and was tested for 2 hours on urban and extra urban roads (see Figure 3.1). The information that can be shown in the HUD includes current speed, maximum allowed speed, turn-by-turn navigation information and distance to the next turn or roundabout. The position of the HUD information can be changed vertically to suit different driver lengths and the brightness of the projected information can be adjusted to suit different light conditions. The HUD was in a light blue color and automatically changed colour to orange in dark environments such as garages and tunnels.

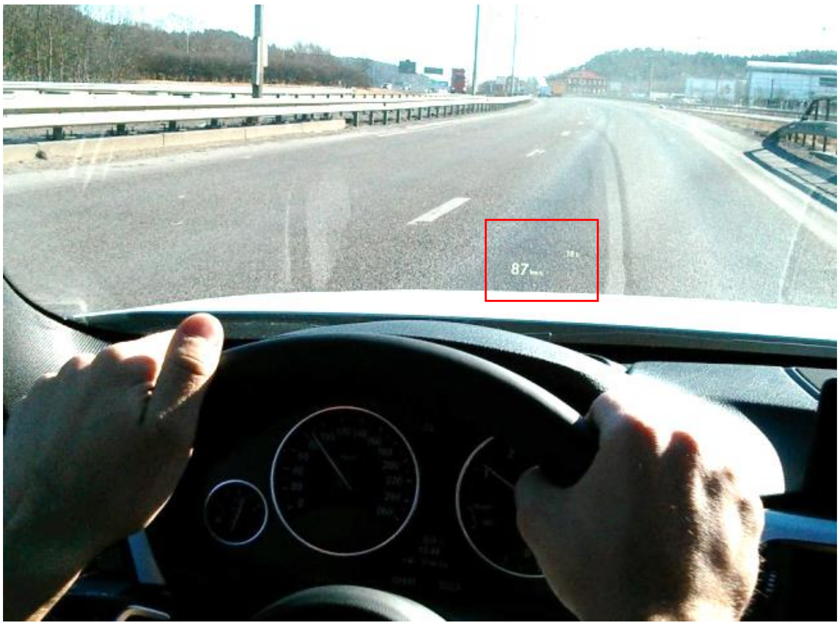


Figure 3.1 BMW 330 Diesel Touring M-Sport's Head up Display

[3] *Patrik Blomdahl (Ergonomics Team & Feature Leader, Volvo Trucks, GTT) interviewed by the authors, 18 February 2013*

3.2.2 Alternative instrument cluster

Nissan Leaf is one example where an additional instrument cluster is positioned above the steering wheel. This layout was briefly tested at a car dealer. The information shown in the additional cluster above the steering wheel is shown there exclusively and includes current speed, clock, outside temperature, warning symbols and engine load.

Figure 3.2 Nissan Leaf's instrument cluster

3.2.3 Camera Monitor System (CMS)

The Nissan Leaf has a center stack display which works both as a navigation device, climate control, an entertainment unit and a rearview camera monitor when reversing. The reverse aid shows the area behind the vehicle and estimates the reverse path depending on steering wheel angle as well as the distance to nearby objects.

Figure 3.3 Camera Monitor System within Nissan Leaf

3.3 Initial idea generation about visual information

An initial idea generation was performed to start getting ideas about different technologies, functions and new positions for visual information in the truck cab. It involved brainstorming with post-it notes and mind maps on different subjects defined by the research questions. The subjects were: driver information, indirect vision, and direct vision. The ideas were generated with open minds and without any criticism.

3.4 Workshop about visual information

A workshop was conducted at Volvo's office in Lundby, Gothenburg to get ideas for functions, solutions and different positions for the visual information in the truck cab. A total of eight people attended the workshop, which took three hours to finish. The attendees all work at Volvo Trucks and have different backgrounds and experience:

1 Design engineer
2 HMI specialists
2 Ergonomics specialists
1 Product design specialist
2 Industrial design engineering master students (doing HMI thesis work)

At arrival the participants were briefed with necessary information for performing the workshop. They were divided into two groups, each group with a different aspect to focus on. To initially get to know each other better and to initiate the creative thinking process, a tower building contest was conducted. The participants were asked to build a tower as high as possible in 15 minutes with only A4-sheets and tape.

Figure 3.4 planning the tower building

Then the two groups were divided into different rooms where an idea generation session took place. Each group had a theme to focus on when generating ideas, either maximum safety or high tech solutions. With the help of a pen and post it notes they were asked to write down as many ideas as possible in three minutes on different subjects that they were given. The following subjects were used:

- Direct vision
- Indirect vision
- Vehicle information (such as current speed, fuel level and engine temperature)
- Secondary information (such as navigation, audio system and climate controls)

Figure 3.5 Writing ideas on post-it notes

After each subject the ideas were presented and categorized among the group members until all four subjects were completed.

Next the participants were asked to discuss the ideas that they had come up with and combine them in different ways and try to form concepts. Each group was given a few A1 sheets with a picture of the inside of a Volvo FH cab, with all current instruments and displays blurred to promote thinking in new ways. They were also given sheets of paper with different conventional instruments such as speedometer, radio, navigation unit, warning symbols etc. to cut out. With help of this material the participants illustrated and visualized their ideas in the truck cab environment and formed a few concepts.

3.4.1 Documenting the workshop

The workshop generated a lot of information and ideas on alternative layouts and different ways to use new technology. All the ideas and functions from the post-it notes and the A1 sheets (see Figure 4.2) were compiled in Excel where they were categorized after type of solution. The results from the two groups were put in separate Excel sheets. The ideas that were considered out of line of the project scope, and therefore not applicable, were put aside. The remaining functions and ideas were rated based on the two criteria “Feasibility” and “Relevance for thesis”. The functions and solutions with the highest rating were then selected for further development.

3.4.1.1 Matrix of functions

The functions and solutions from the workshop with the highest ratings were organized and categorized in a function matrix in order to see what concept solutions that could be generated from the workshop results (see Table 4.1). Based on these ideas the process of generating complete concepts could be initiated.

3.5 Concept generation

After choosing a number of solutions from each group to move on with, they were combined in a single Excel sheet for detailed concept generation.

3.5.1 Morphological matrix

A morphological matrix was created with the five identified categories from the workshop of visual information on the Y-axis; “Direct vision”, “Indirect vision”, “Vehicle information”, “Secondary information” and “Driver support”. Each category has subcategories and each subcategory has a number of corresponding solutions from the workshop along the X-axis. The solutions were then combined in different ways creating seven different concepts (see Appendix 2). This way of generating concepts ensures that each concept has a solution for each of the visual information subcategories. It also makes it easy to vary the solutions between the generated concepts (see Appendix 3).

3.6 Choosing final concepts to evaluate

The seven concepts were reduced to three significantly different concepts to make sure that the concept evaluations would give clear results. These three concepts were chosen using two different methods; a Pugh matrix and a group of experts:

3.6.1 Pugh matrix

In the Pugh matrix, the seven concepts were compared with the new Volvo FH model from 2012 as reference. The following parameters were used for the brief evaluation. The different features are aspects that concern ergonomics and the scope parameters are aspects that are important for Volvo to include.

Features – ergonomics aspects (what the driver experiences)

Direct vision
Positioning of indirect visiblity
Cognitive workload
Distance from line of sight
Adaptability

Scope – project aspects (important aspects for Volvo)

Right solution for transport segment
Scalability
Feasibility – cost
Feasibility - introduction time
Feasilbilty – reliability

The concepts were rated between -5 and 5, with the steps -5, -3, -1, 0, 1, 3 and 5, where grades above 0 means an improvement compared with the reference, and grades below 0 means a degradation. Each aspect was weighed between 1 and 5, with 5 being very significant. This was a rough estimation to do a first evaluation of the concepts. It was not used to exclude any of the concepts entirely. The result is presented in chapter 4.5.1.

3.6.2 Group of experts

With the Pugh matrix as a base a group of experts at Volvo were chosen to further evaluate the concepts and to exclude and combine them into three final concepts, as a complement to the previous evaluation. A total of five people attended the meeting; two ergonomics specialists, one product planner, one electrical devices specialist and one driver interface specialist. The seven concepts were presented and described both using text and visualizations and where then discussed and evaluated subjectively within the group. To make a selection, all participants got 10 points each to distribute freely between the concepts. Four concepts received a majority of the points, and two of them were combined into one concept, resulting in three final concepts for further development (see Figure 4.14).

3.7 Preparing final concepts for driving simulator

The three final layout concepts were evaluated in a driving simulator by a number of drivers and experts. This chapter describes the process of preparing the concepts for the virtual environment in the simulator.

3.7.1 CAD design

The concepts had to be created digitally to enable evaluation in the driving simulator. This was done by building CAD models in CATIA V5 according to the concept specifications. The sizes of the displays were derived from an earlier thesis work at Volvo that looked into the possibilities of camera-monitor systems (Fronell Fagerström & Gårdlund, 2012). The following sizes were specified:
Right main rear view (class II): 150x270 mm
Right wide-angle rear view (class IV): 130x140 mm

The displays on the left hand side are closer to the driver, which allows smaller display sizes. These sizes were estimated based on measurements in the truck CAD model to:
Left main rear view (class II): 125x177 mm (10 inches, 16x9)
Left wide-angle rear view (class IV): 76x101 mm (5 inches, 4x3)

The Secondary Information Display (see chapter 2.6.3) used in the current FH model is 7 inches. The same size is used for all displays showing secondary information like navigation and radio in two of the three final concepts. In the third concept, all information is placed in a big display to the right of the steering wheel. It covers most of the instrument panel and the monitor size that best correspond to these dimensions is 23 inches.

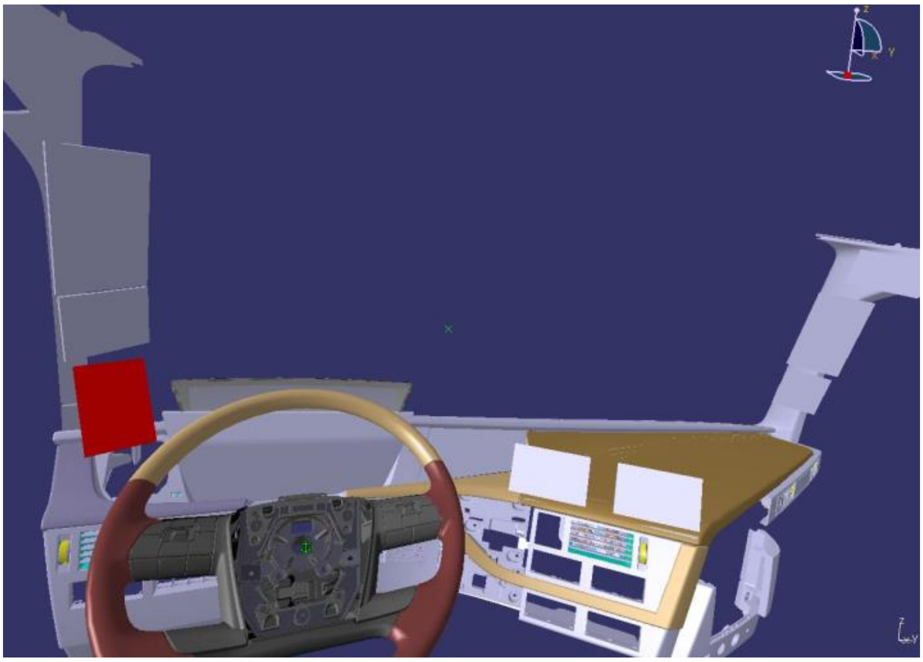


Figure 3.6 Building concepts in CATIA V5

3.7.2 Referencing in the virtual environment

To make sure that the driving simulator resembles real driving as much possible, the simulator viewpoints were referenced to the M50 eye point that is identified by Volvo (see chapter 2.1.2). The M50 eye point was used because it represents the average driver (50 percentile), which means that most drivers should find this eye point position natural. The M50 eye point as well as the M50 heel point that Volvo uses were used to reference the virtual environment with the physical environment so that the physical seat, steering wheel and pedals are in the correct position in relation to the simulator.

3.8 Evaluating final concepts

After preparing the concepts for the virtual environment they were evaluated in a driving simulator with 14 experienced truck drivers and 4 product specialists. The evaluations were carried out during two weeks and the process is described further in this chapter.

3.8.1 Driving simulator

The driving simulator that was used for the concept evaluations has been used in previous evaluations at Volvo and is adapted for maneuvering at low speeds with trucks. It is provided by Oryx Simulations in Umeå who also helped to implement the three final concepts into the simulator environment according to detailed specifications provided by the thesis workers. Oryx had a technician on site at Volvo a few days before the start of the evaluations to make sure everything worked properly.

The simulator consists of three 46 inch LCD displays, an adjustable steering wheel, an adjustable seat, and accelerator and brake pedals. It contains a head tracking system with a sensor above the driver´s head that tracks the head movements in X and Y directions and the environment moves according to the head movements. This functionality is included to give the driver a more realistic feeling of the simulation since he or she can behave more like in real truck, for example lean forwards to get a better view of the trailer through the rearview mirrors.

Figure 3.7 Driving Simulator

3.8.1.1 Driving Environments

The driving environments that were used were designed by Oryx Simulations to put the driver in a number of common traffic situations. The environments are based on two common types of driving for the Volvo FH; long distance driving and maneuvering at lower speeds. Both enviroments are free from moving objects like other traffic and pedestrians and they were both used to evaluate each concept.

Environment 1: Long Distance Driving – country road driving

This environment consists of a long, slowly turning country road containing two crosses with 90 degree turns and both up and down hill driving, as well as straight stretches without slopes. Each driver drove the same stretch on the country road, which took around four minutes. This environment was used since it is a typical environment for long distance driving (Figure 3.8). Typical for long distance driving is also that drivers are less active and need to keep focus further away, i.e. the behavior of monitoring the surroundings become quite specific.

Figure 3.8 The country road environment

Environment 2: Maneuvering at lower speeds

The maneuvering environment consists of a large range yard with a connecting road system where the test driver follows arrow directions on the road, maneuvers between orange cones, and finally reverses the vehicle between two other trucks and backs up towards a loading dock (Figure 3.9). The track took about five minutes for the test persons to finish. This is a common environment for a truck driver to operate, and the yard contains several sharp turns and narrow sections. The environment was chosen both to represent driving in dense city environments and low speed maneuvering to reach the right spot for loading or unloading goods. In the corresponding driving situations, drivers are more active and need to look for information in different directions.

Figure 3.9 The Maneuvering environment

3.8.2 Participants

To gather enough information to get reliable results a total of 16 people participated in the evaluation, whereof a majority were professional truck drivers working at Volvo's test track in Hällered. The other participants work in different parts of the product development process at Volvo Trucks, but have truck driver licenses and experience from driving trucks. Most participants have different backgrounds and were chosen to get opinions on the concepts from a range of different perspectives. The following people participated:

12 experienced truck drivers (9 male, 3 female)
1 Ergonomics expert (male)
2 Product managers (male)
1 Range requirement manager (male)

Before the actual simulator evaluations were initiated, a pilot evaluation was performed to test the questionnaire and the driving environment and to estimate the amount of time needed. The pilot evaluation was done with a HMI specialist with experience from simulator evaluations.

3.8.3 Video recording

A video camera was placed on a tripod behind the driver to record the simulator tests and to document the drivers' behavior during the evaluations. This was done to make sure that everything was documented in case information would get lost.

3.8.4 Questionnaire

A questionnaire was assembled to let the test persons subjectively evaluate the concepts. It contained a few questions about personal data such as name, length, age and driving experience. It also contained 11 questions for each concept about the positions of the different means of visual information, the first impression and general opinion about the concepts, as well as a few summarizing questions. All questions are open-ended and the participants were expected to answer with a number between 1 and 5 and motivate their ratings. The five-graded scale is commonly used for similar evaluations at Volvo Trucks. The grade 1 equals poor, while 5 equals excellent (See appendix 4).

3.8.5 The simulator evaluation

The test drivers were first briefed about the purpose of the thesis work and how the evaluation would be carried out. They were then shown how the simulator works and they got to do some test driving to get acquainted with it.

The evaluation started with letting the participants drive today's Volvo FH with the conventional rearview mirrors that they are used to. This was done both to let the drivers get a feel for the simulator and to be able to use the current FH layout as a reference to the new layout concepts.

The test persons then tried each of the concepts in both the country road environment and in the truck yard environment. The concepts were evaluated in a controlled varied order to avoid the same concepts always being the first one to be evaluated. This ensures the fairness of the evaluations since it is natural to compare the following concepts with the one evaluated first.

While driving, the participants were asked the first few questions about their first impression of the new layout concept. After each concept, including the FH reference cab, they were asked a number of specific questions about the positions of rearview displays, instrument cluster, secondary information etc. The same evaluation questions were asked about each concept to enable a fair evaluation. All questions (See Appendix 4) were objective and where asked in the same way to all the drivers to secure that all drivers evaluated the concepts in the same way. After all the concepts had been evaluated the drivers were asked about their general opinion of the concepts and gave each of them a total score. A question about their opinion about the truck simulator was also included.

3.8.6 Analyzing evaluation results

When all simulator evaluations were completed, the results were organized and analyzed. The ratings in the questionnaire were summarized and an average score was calculated for each question, with the trucks drivers' scores separated from the experts'. The comments were analyzed and grouped, and the corresponding ones were merged into more general comments to make the analyzing process more comprehensible. The solitary comments were ignored at this point and only the recurring comments were treated further.

For each question in the questionnaire, the average scores for the different layout concept, including the reference FH cab, were compiled in bar charts for comparison. The comments were put next to the scores since an average score is more telling if underpinned by comments (see chapter 5.1). The standard deviation was also taken into consideration by analyzing the scores to see whether the drivers had similar or different opinions on the different aspects and how many drivers had evading opinions and why.

3.8.7 Creating final concept

Some of the questions concerned the positioning of specific devices for visual information, for example the instrument cluster and the rearview camera monitors. To form a final concept, these positions were chosen according to the highest average scores. This means that the final concept is a combination between the three final concepts, with the best parts taken from each concept. Theoretical rules about perception and the human eye were also taken into consideration when creating the final concept.

4. First results

This chapter contains the results and conclusions from the questionnaires, workshops and concept generation sessions. These results lead to the design and specifications of the three final information layout concepts evaluated in the truck simulator. The evaluation results are presented in chapter 5.

4.1 Results of initial questionnaire

The questionnaire with questions about different aspects of visual information in the current FH cab was distributed to 10 truck drivers at Volvo's test track in Hällered. 5 questionnaires were answered, and the conclusions reached from this initial survey are listed below.

- Reverse camera monitors are placed too far from the rear view mirrors.
- Warning lamps and flashing symbols should be placed close to the line of sight.
- Reverse camera should be standard in trucks.
- Speedometer right in front of the driver is good, but the instrument cluster is placed too low.
- The windscreen should be extended downwards for better close up visibility forwards.
- The steering wheel is too bulky and covers parts of the instrument cluster when turning.
- Cameras aimed in more directions than backwards would be good since the vision sideways through mirrors sometimes is very limited.

A conclusion of these results is that there seems to be room for improvement and a wish for moving some of the instruments and displays, such as the reverse camera monitor and the instrument cluster. The steering wheel is thought to be bulky and covers instruments, and more cameras should be implemented. This is a small survey with only 5 participants, which is not enough for definite conclusions, but the opinions gave a hint about some problematic areas and helped defining the scope of the thesis work further.

4.2 Results of idea generation

The initial idea generation session resulted in many ideas concerning a range of different areas. Brainstorming is a good method for creative thinking and was used to gather all functions and solutions from the literature study and benchmarking and to get as many new and radical ideas as possible on paper. The ideas were written down in different mind maps depending on subject. This way of starting the thinking processes around the subject of visual information presentation was a good preparation for the workshop. Some of the ideas extracted from this session are listed below.

- Dynamic visual information that is shown only when and where it is needed
- Show information on demand
- New layout should resemble the current FH cab to not confuse drivers
- Information projected on the windscreen (Head up Display)
- Instrument cluster closer to the line of sight
- See-through A-pillars
- See-through panels underneath the steering wheel

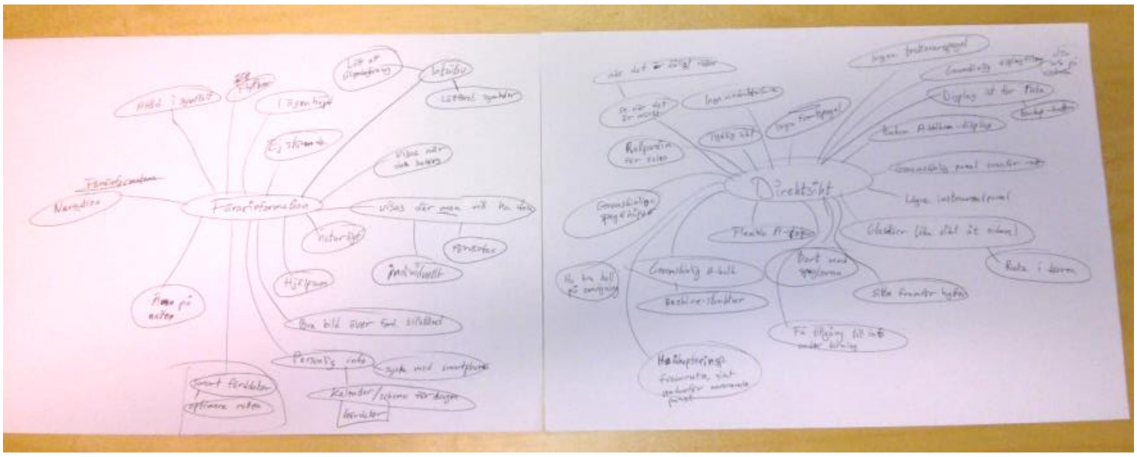


Figure 4.1 Mind maps from the idea generation (in Swedish)

4.3 Results of workshop

The workshop described in chapter 3.4 resulted in many ideas for repositioning the visual information in the truck cab and solutions for implementing new technology. The ideas written on post-it notes were organized and categorized in an Excel sheet. The following general categories were identified:

- Solutions for the A-pillars
- Redesigned instrument panel
- Minimize information
- Alternative information in information cluster
- Solutions for the windows
- Bird's Eye view
- Combined use of displays
- Solutions for the steering wheel
- Camera Monitor Systems (CMS)
- Head Up Displays (HUD)

For a more detailed list of all the ideas see Appendix 2 Workshop on layout for visual information.

The workshop also resulted in three conceptual cab layouts on the A1 cab interior pictures that the participants were given (Figure 4.2, Figure 4.3 and Figure 4.4).

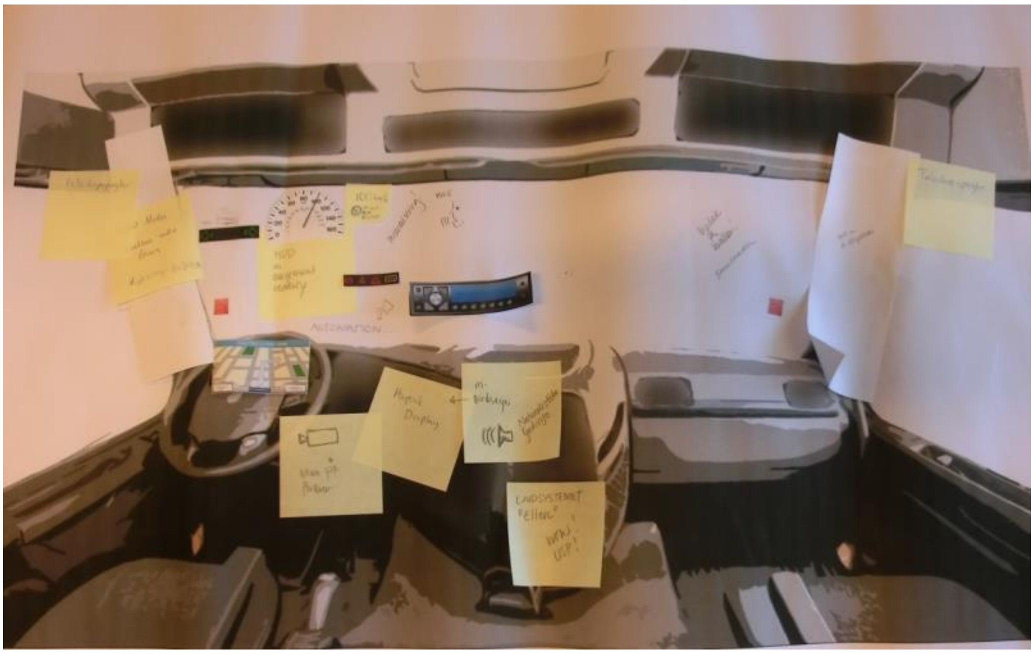


Figure 4.2 Workshop concept 1 (text in Swedish)

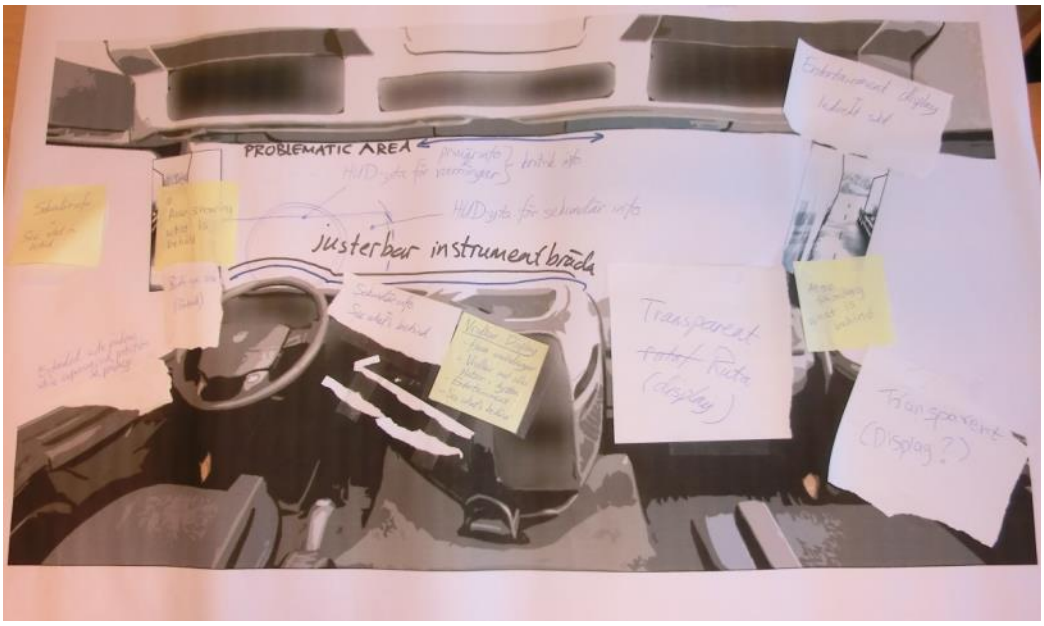


Figure 4.3 Workshop concept 2 (text in Swedish)

Figure 4.4 Workshop concept 3 (text in Swedish)

After the workshop the categories and the ideas from the workshop concepts (see Figure 4.2, 4.3 & 4.4) were then entered into a Concept matrix (see table 4.1) that was used to try to identify a number of concepts with different focus and aim. The following concept ideas were identified:

- Minimalistic Concept
- Maximized visibility
- Safety Concept
- Economic Concept
- Maximum information in HUD concept
- Information in steering wheel
- Maximized indirect vision

Concepts -->	Minimalistic Concept	Maximized visibility	Safety Concept	Economic Concept	Max info in hud concept	Info in steering wheel	Maximized Indirect vision
Solutions / Categories							
A-pillar							
Transparent		X	X				
Display showing what is behind		X	X				
Use to show information	X						
Instrument panel							
Whole panel is a display							X
Minimize							
Minimize information	X			X		X	
Information on demand	X			X		X	
Information through sounds	X						
Information cluster							
Navigation help in cluster	X		X	X		X	
Mirrors							
Adjustable size according to usage		X	X				X
Transparent mirror housing		X	X				
Windows							
Extend front windscreen downwards	X	X	X				
Windows below instrument panel		X					
Windows beneath door handle		X					
Bird eye view							
Implement Bird's Eye view		X	X				X
Co-use displays				X		X	
Driver info shown on A-pillar display	X			X			
Navigation for forwards driving, rear view when reversing	X			X			
Nomadic Devices	X			X		X	X

Steering wheel							
Info (indicators/speed) on steering wheel						X	
Smaller steering wheel (enables new cluster positions)	X	X		X			X
Cluster above / beside steering wheel			X				
CMS (no lack of indirect visionfrom dirt/snow etc.)							
Cameras that cover all hidden areas		X	X				X
Camera views shown on displays inside cab		X					X
Swop between camera view and what is behind A-pillar/panel	X	X	X				
Show reverse view behind driver (natural to look behind when reversing? Ask drivers)							X
Displays in the middle of cab				X			
HUD							
Project (relevant) vehicle information in HUD	X			X	X		
Show current speed limit			X		X		
Display on top of instrument panel (LCD HUD)					X		
Navigation help in HUD	X		X		X		
Warnings in HUD			X		X		

Table 4.1 Matrix of functions

4.4 Results of concept generation

To further specify the concepts and make sure that each concept contained a complete set of visual information, 12 different means of visual information were defined. These were positioned differently in each concept, which is specified in detail in this chapter.

1. Left main rear view
2. Left wide angle rear view
3. Right main rear view
4. Right wide angle rear view
5. Kerb (pavement) view
6. Close-up front view
7. Instrument cluster
8. Bird's Eye view
9. Secondary Information
10. Driver Information
11. Warning symbols
12. Navigation / radio / entertainment

As a result of the workshop an idea of having a bird's eye view was implemented. The idea is to position cameras on the roof of the truck's cab and trailer to capture the surroundings of the truck. These camera images could then in theory be combined to show in one display what is currently in the truck's surroundings from above. This combined view is thought to be a good tool for maneuvering with trucks.

With the help of the functions identified in the workshop a Morphological Matrix was created to generate 7 concepts (See Appendix 2) that are described further in this chapter.

A. Minimalistic concept

This concept is designed to minimize the cognitive workload on the driver. Information should be shown only when it is needed. Camera Monitor Systems (CMS) are used instead of rearview mirrors for indirect vision rearwards. The CMS displays are positioned on the A-pillars, close to the current mirror positions, to resemble the traditional FH cab layout. The kerb view is solved by adding an additional window on the lower part of the passenger door. The close-up front view is solved by a lowered instrument panel and extended windscreen downwards. Navigation information is given to the driver verbally to reduce the visual information, but is also shown in a multi-use display to the right of the steering wheel. This display is also used for entertainment and secondary information. Driver information is shown when needed in the same display as the left rearward view (left A-pillar). Gauges are placed on the steering wheel and warnings are projected in the windscreen. The size of the steering wheel might be reduced to give more room for the information around it on the surrounding dashboard panels.

Figure 4.5 Minimalistic concept

B. Optimized direct vision concept

This concept is designed to increase the direct vision as much as possible. The windscreen and the side windows are extended downwards and the instrument panel is lowered. Windows are added on the right hand side below the instrument panel as well as on the lower parts of both doors to increase visibility for blind spots. Thereby no mirrors/displays are needed for front and kerb views. The A-pillars are transparent (alt. displays that show what is behind the A-pillars). The main and wide angle mirrors are replaced with camera monitors to further increase the direct vision by removing unnecessary obstructions. A big monitor for rearward vision is placed behind the driver to resemble what is seen when looking over the shoulder and to minimize the inevitable obstruction of direct vision. Secondary information, driver information and gauges are placed above the center stack and indicators, symbols, current speed limit and critical information (warnings) are projected in the windscreen. The lane changing support lamps are placed on the A-pillars like in the current FH cab. Infotainment is placed on the steering wheel and navigation information is shown in the instrument cluster position (behind the steering wheel).

Figure 4.6 Optimized direct vision concept

C. Optimized indirect vision concept

In this concept, focus is on indirect vision. Displays on the A-pillars show what is behind to eliminate the blind spots caused by the A-pillars and a display on the passenger door covers the blind spot caused by the door structure (to provide the kerb view). Displays for rearwards vision are placed on each side of the steering wheel, making it easy for the driver to keep track of what is behind and beside the truck with limited head movements. A display for close-up front view is placed on top of the center stack (camera pointing forwards rather than down on the ground). As a complement to the different views, a bird's eye view is shown in a top center stack position together with entertainment and navigation information. Gauges, indicators and symbols are placed above the steering wheel (as seen in the benchmarking of Nissan Leaf in chapter 3.2.2 Alternative instrument cluster) while SID and DID information is placed beside the steering wheel. Lane changing support lamps are placed below the displays on the A-pillars and other critical information, including forward collision warning, is projected onto the windscreen (HUD).

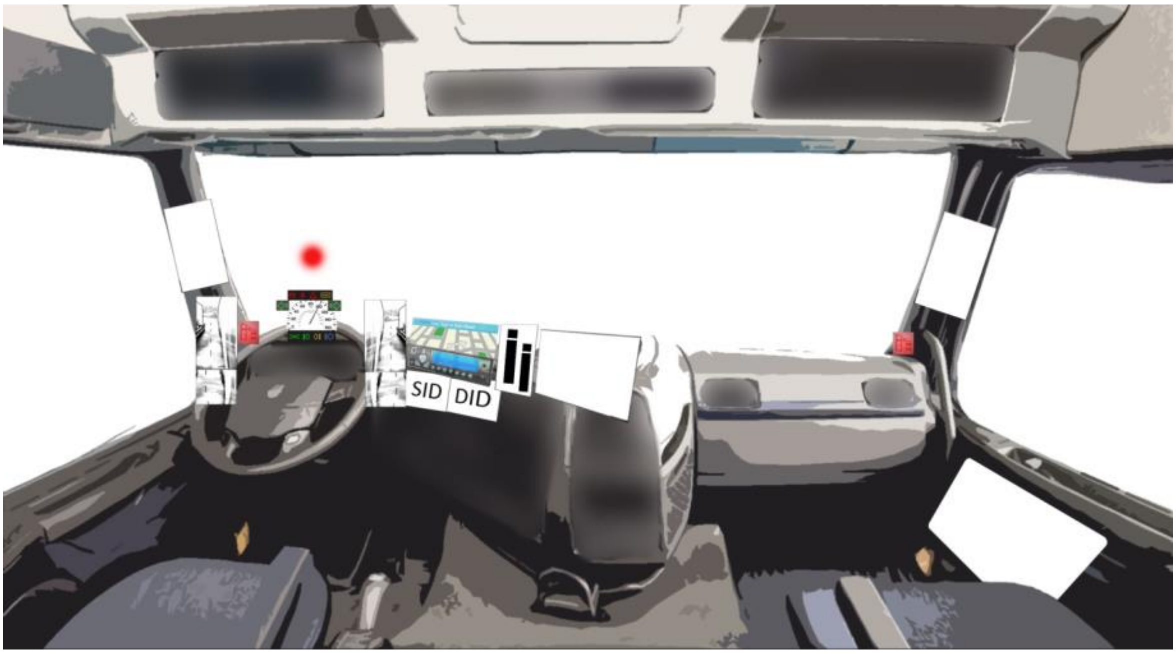


Figure 4.7 Optimized indirect vision concept

D. Dynamic/personalized concept

This is a futuristic concept where the layout of visual information is highly customizable. The windscreen is covered with a transparent display film that can show information where the driver wants. The instrument panel closest to the driver has room for nomadic devices that can show what the driver chooses. There are displays on the A-pillars that either can be used to show certain information, show what is behind the A-pillar or work as CMS displays. On the doors there are additional windows below the handles and all camera views including rearwards, close-up front, kerb and bird’s eye views can be shown in the cluster of nomadic devices on the center stack. Gauges, SID and DID information, entertainment, navigation and symbols as well as critical information and warnings can be shown either in the windscreen display film or on either of the displays on the dashboard.

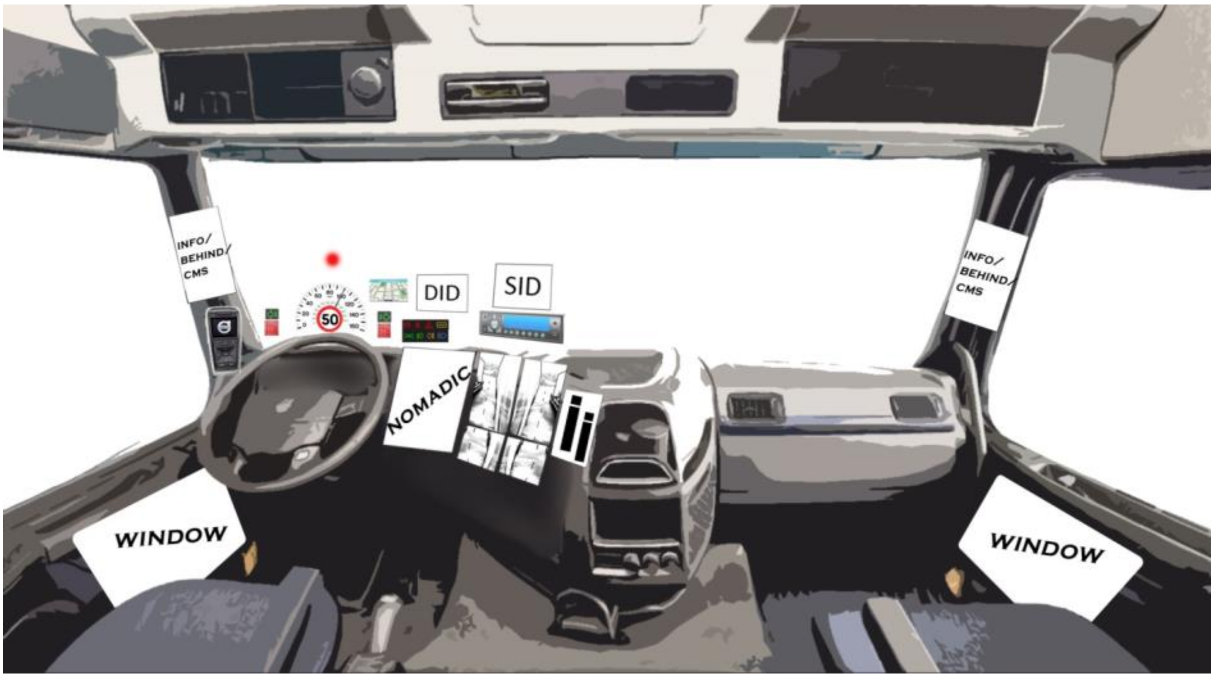


Figure 4.8 Dynamic/personalized concept

E. Head up concept

This concept takes advantage of projection technology to show information to the driver directly in the field of vision (head up). It maximizes the head up information to try to find a good amount of information to show in the field of vision and the idea is to show the right information at the right time. The windscreen is extended downwards to maximize direct vision forwards and the side windows are also extended downwards. The instrument panel is adjustable and follows the steering wheel setting. Displays are placed on the A-pillars and are used both to show what is behind the A-pillar when needed and to show rearwards camera views when needed. The camera view for close-up forward vision is shown on an adjustable display placed in a high-up center stack position when driving below 25 km/h. When driving faster than 25 km/h forwards, this display can also be used to show navigation information or alternatively entertainment information. When reversing, it can show a reverse camera view as well. The kerb view is shown in a display above the right A-pillar, where entertainment also can be shown. On the windscreen, primary driver/vehicle information is shown within a 15 degree cone from the line of sight and secondary information is shown within a 30 degree cone (as seen in chapter 2.5.1 The human eye). On the low part of the left A-pillar is the Wireless Remote Control (WRC) and to the right of the steering wheel is a display for Bird's Eye view.

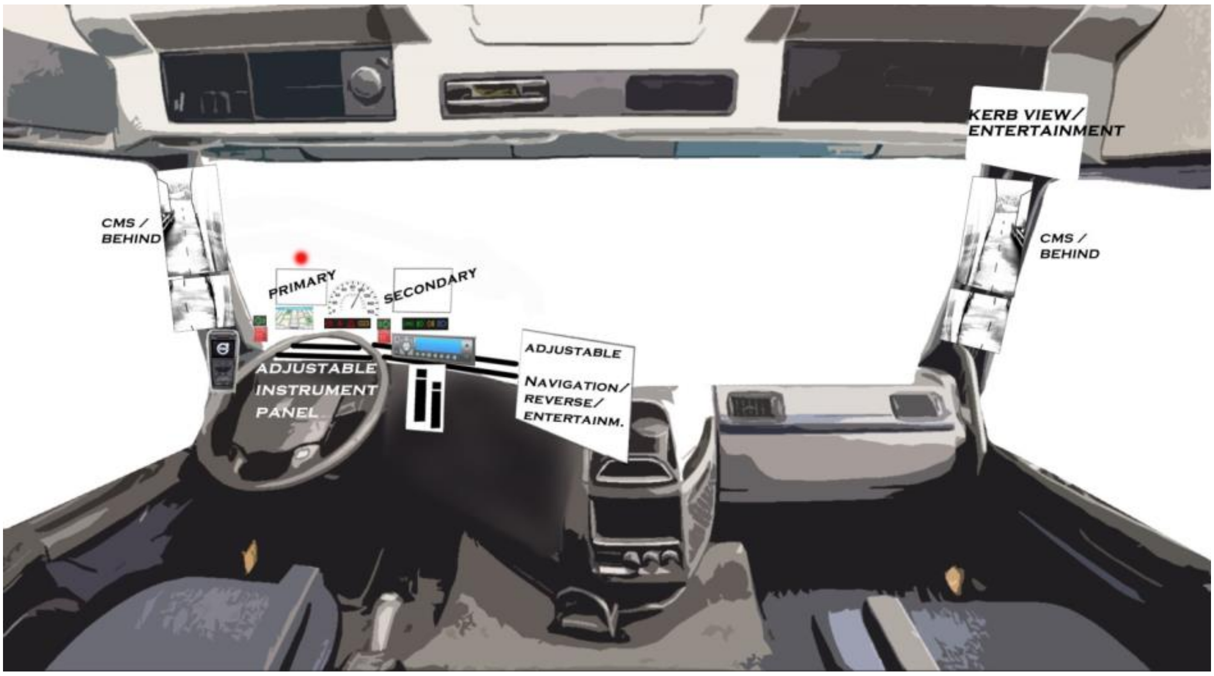


Figure 4.9 Head up concept

F. Economic concept

Low cost is in focus in this concept. A display on the left A-pillar is used to show driver information while the rest of the information like secondary and driver information, navigation, entertainment and all CMS views are placed in a display cluster on the center stack to keep cost down. The WRC is placed at the lower part of the left A-pillar to be easily accessible. The forward collision warning is projected in the windscreen and the lane changing support lamps are placed at the same position as in the current FH.

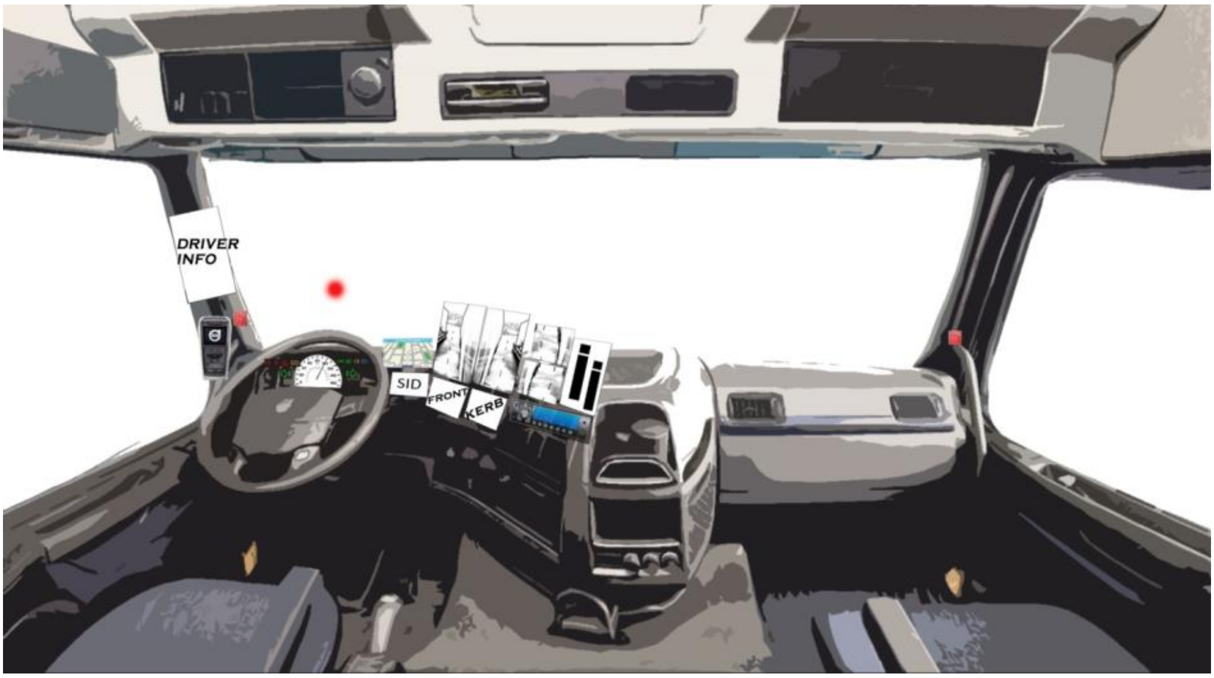


Figure 4.10 Economic concept

G. High tech concept

This concept is a combination of concept D (dynamic) and E (head up) but the positions are defined and not customizable. The dashboard consists of a big display and on the A-pillars there are displays connected to a camera that films what is behind the A-pillars and show that in the displays to make it a see-through display. The same technology is implemented in the passenger door. Rearwards camera views are shown at a mid-top windscreen position and the close-up front view is shown beside the rearward views. The display on the passenger door works as kerb view and to the right of the steering wheel is an Bird's Eye view display. Gauges (minimum info) are shown in the instrument cluster behind the steering wheel while driver information is projected on the windscreen (HUD) together with driver information, warnings and navigation. Entertainment and secondary information is shown on the dashboard display and the WRC is placed to the left of the steering wheel.

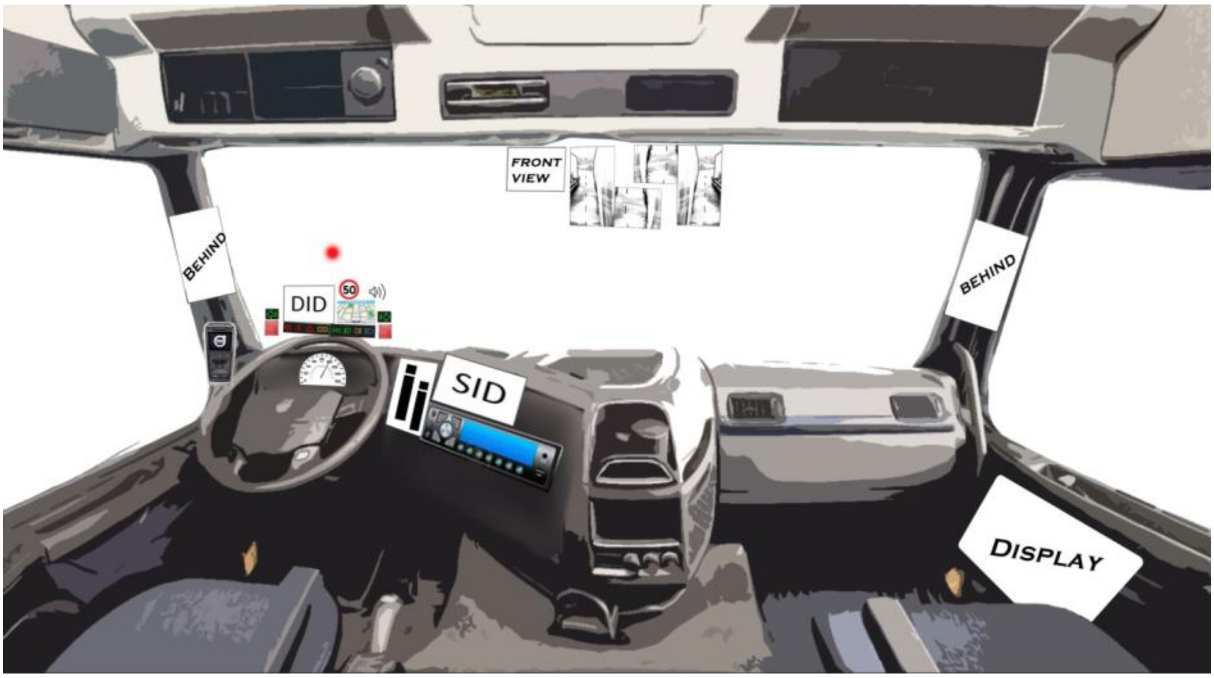


Figure 4.11 High tech concept

4.5 Evaluating first seven concepts

4.5.1 Pugh matrix

All seven concepts were compared with the most recent FH truck model by a number of parameters specified by Volvo as seen in Table 4.2 Pugh Matrix. The maximum total score was 185 and the minimum score was -185. Most of the concepts scored below 0 on many of the project aspects since they were assumed to be more expensive, have a longer introduction time and be less reliable than the current Volvo FH. The scalability aspect was excluded since it was too difficult to estimate.

Concept A – “Minimalistic” received a score of 23 for the ergonomics aspects in total and was assumed to have an advantage from most aspects compared with the current FH truck cab, and should not be too difficult for the driver to adapt to thanks to a similar positioning of the rear view displays (on the A-pillars). The concept scored 1 on the project aspects thanks to low cost, short introduction time and because it is assumed to be a good solution for the long haul transport segment. The concept scored a total of 24 points.

Concept B – “Optimized direct vision” scored -25 on the ergonomics aspects in total since it was assumed to be difficult to adapt to because of the positioning of the rear view displays behind the driver, although the direct vision was believed to be significantly increased compared to the current FH model. Regarding the project aspects, the concept scored -37 due to high cost and that it probably is a worse solution for the long haul transport segment than the current model because of the display position. The concept scored a total of -62 points.

Concept C – “Optimized indirect vision” received the highest score of 45 on the ergonomics aspects in total due to the position of indirect vision displays close to the line of sight and increased direct vision. Regarding the project aspects the concept got a score of -13, much due to several changes of the cab layout. The total score of 32 was the highest of all seven concepts.

Concept D – “Dynamic” received -13 points on the ergonomics aspects because of the center placed rear view mirrors. It scored -45 on the project aspects due to advanced technology and high costs. The total score of -58 was among the lowest.

Concept E – “Head up” scored 15 points on the ergonomics aspects, since the information is projected on the windscreen and therefore is close to the line of sight, making the information easy to assemble. The concept got the second highest score of -7 on the project aspects due to a promising solution for the long haul transport segment. The total score was 8 for this concept.

Concept F – “Economic” received -13 on the ergonomics aspects with low scores for adaptability and positioning of the rear view displays. Also the distance from the line of sight is bigger than for the current FH truck model. The score for the project aspects was -17 and the total score was -30.

Concept G – “High tech” scored -19 on the ergonomics aspects and received low scores for positioning of indirect vision displays, adaptability and distance from line of sight. Regarding project aspects, the concept received -53 point, the lowest score of all concepts, with low values for cost, solution and reliability. The total score was also the lowest of all, -72 points.

Concept evaluation - Pugh matrix

Rating compared to the reference model: -5, -3, -1, 0, 1, 3, 5
-5 worst, 0 same as ref, 5 best

		Weight (1 - 5)	Reference: New FH	Concept A: "Minimalistic"	Concept B: "Optimized direct vis."	Concept C: "Optimized indirect vis."	Concept D: "Dynamic"	Concept E: "Head up"	Concept F: "Economic"	Concept G: "High tech"
Features	Direct visibility	5	0	3	5	3	3	3	3	3
	Positioning of indirect visiblity	4	0	1	-5	3	-3	1	-3	-3
	Cognitive workload	4	0	1	0	3	-1	-1	-1	-1
	Distance from line of sight	3	0	1	-5	5	-1	1	-1	-3
	Adaptability	3	0	-1	-5	-3	-3	-1	-3	-3
	Subtotal		0	23	-25	45	-13	15	-13	-19
Scope	Right solution for transport segment	4	0	3	-3	3	-1	3	-1	-3
	Scalability	3	0							
	Feasibility - cost	4	0	-1	-3	-1	-5	-3	0	-5
	Feasibility - introduction time	3	0	-1	-3	-3	-3	-1	-3	-3
	Feasilbilty - reliability	4	0	-1	-1	-3	-3	-1	-1	-3
	Subtotal		0	1	-37	-13	-45	-7	-17	-53
	Total			24	-62	32	-58	8	-30	-72

Table 4.2 Pugh Matrix

4.5.2 Group of experts

The group of five experts (see chapter 3.6.2) with experience from different fields of development discussed the seven concepts and modified and combined them into three final concepts. These three concepts are described further in the next chapter, but are here presented with the corresponding rating from the group.

Concept F – "Economic" received 3 points of the total 50 points, which was enough to be chosen as one of the final concepts. It was slightly modified by moving all information to the big center stack display and the name was changed to "Combined integrated display" to describe the purpose of the concept.

Figure 4.12 Combined Integrated Display Concept

Concept A – "Minimalistic" was popular among the experts and was given 22 of the total 50 points. It was kept almost as it was, but the position of the speedometer on the steering wheel was questioned by the ergonomics experts. Also the window in the passenger door was questioned, since it will be covered if driving with a passenger. Because of its resemblance with the conventional Volvo FH the concept was renamed "Minimalistic Tradition".

Figure 4.13 Minimalistic Tradition concept

Concept E – "Dynamic" and concept G – "High tech" were combined into one concept called "Head up on windows" and received 25 of the 50 points together. The head up solution was popular among the experts and they had a lot of comments on these concepts. Different positions for the displays were discussed and finally the group agreed on placing the right rear view displays at the center of the top of the windscreen and the left rear view displays to the left of the driver, one on the left A-pillar and one projected on the left side window.

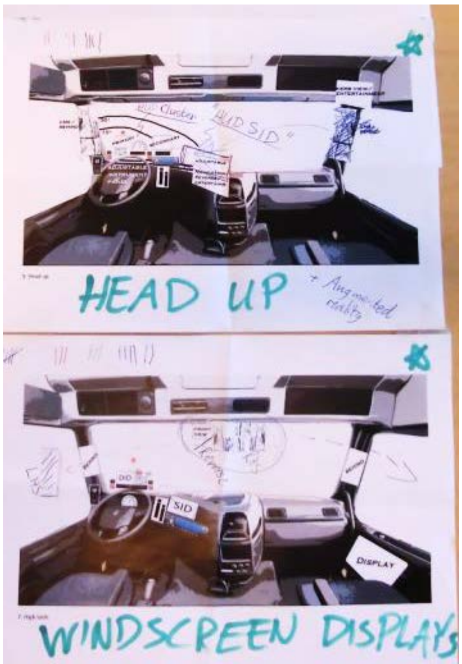


Figure 4.14 Head up on all windows concept

4.5.3 Modification of concepts

All concepts were modified so that they included the same corresponding visual information functions. It is also important to compare the concepts under the same conditions to make the simulator evaluations reliable and to make sure the drivers evaluate the layouts rather than a varied design of the different devices. The warning systems (Lane Changing Support and Forward Collision Warning) were excluded since they are not within the scope of the thesis work. The other warning symbols, indicators and the Wireless Remote Control were also excluded for the same reason but the status lamps were kept to remind the drives of the conventional Volvo FH.

4.5.3.1 First final concept – "Combined Integrated Display"

The layout of the information in the concept "Combined integrated display" was modified and enhanced with help from experts at Volvo. The visual information was rearranged to enable fitting all necessary information within the display area in an intuitive way. Some touch controls were placed closest to the driver and the rearward views on each side of the middle of the display, creating a "visual center" with all necessary camera views together in a symmetrical fashion. The size of the display was set to 23 inches, since that was the closest standard monitor size that was as big as possible without being covered by the steering wheel or blocking additional direct vision out from the truck cab.

4.5.3.2 Second final concept – "Minimalistic Tradition"

The different means of visual information were rearranged according to feedback from experts at Volvo as well as inspiration from passenger cars like Nissan Leaf. The current instrument cluster design was restored, but placed above the steering wheel to make it easier for the driver to assimilate the information while driving. Additional driver information was placed in two 7 inch monitors to the right of the steering wheel instead of spread out in the cab, to get a more minimalistic concept. The kerb view display was moved from the passenger door to the top of the right A-pillar to avoid it being obstructed of any occupant using the passenger seat.

4.5.3.3 Third final concept – "Head Up on All Windows"

Instead of arranging the primary and secondary information within 15 degree and 30 degree cones, the instrument cluster from the current FH truck was used, since the importance of different information is outside the thesis work scope and it would be a clear benefit if the test persons directly could recognize what was provided in this new position. The information that was placed in the instrument panel at first was moved so that all information is projected onto the windscreen. This was done to examine how much information that can be projected onto the windscreen without disturbing the driver too much.

4.6 Final concepts for evaluation

The three modified final concepts ready for simulator evaluation are described further in this project. The following concept specifications were sent to Oryx Simulations for them to be able to implement the concepts in the virtual truck cab environment.

Final concept 1: "Combined Integrated Display"

The aim with this concept is to keep cost at a low level by combining all necessary information in one large display placed to the right of the steering wheel. The concept has both cost- and environmental advantages since one large display is cheaper and more environmentally friendly than many small ones thanks to use of less materials and components. Since there is a lot of information to be shown within the display area, some information is only shown when needed. This is also to reduce the cognitive workload on the driver by reducing the amount of visual information given to him/her while driving. One part of the display works as controls thanks to touch display functionality.

The display is divided into a number of different areas, all showing different information. What and when information is shown in the different areas is specified in Table 4.3.

Area	Function	What is shown	When is it shown
A1	Touch screen with switches for controlling different truck functions	Different digital switches	Always
A2	Touch screen with switches for controlling different truck functions	Different digital switches	Always
B1	Class II rear view	Left main rear view	Always
B2	Class IV rear view	Left wide angle rear view	Always
C0	Bird's eye view (all-around) / Navigation	Bird's Eye view showing objects hidden in blind spots / GPS information for navigation	Bird's Eye view when driving forwards slower than 15 km/h and when reversing / Navigation when driving forwards faster than 15 km/h
C1	Driver/driver information	Gauges like speedometer Minimized navigation info Audio/radio information Climate controls and information	Always
C2	Secondary driver information	Secondary Information Display	Always
C3	Class V view	Kerb view	Always
D1	Class II rear view	Right main rear view	Always
D2	Class IV rear view	Right wide angle rear view	Always
E	Symbols	Warning symbols and different control lamps	Always

Table 4.3 Combined Integrated Display specification

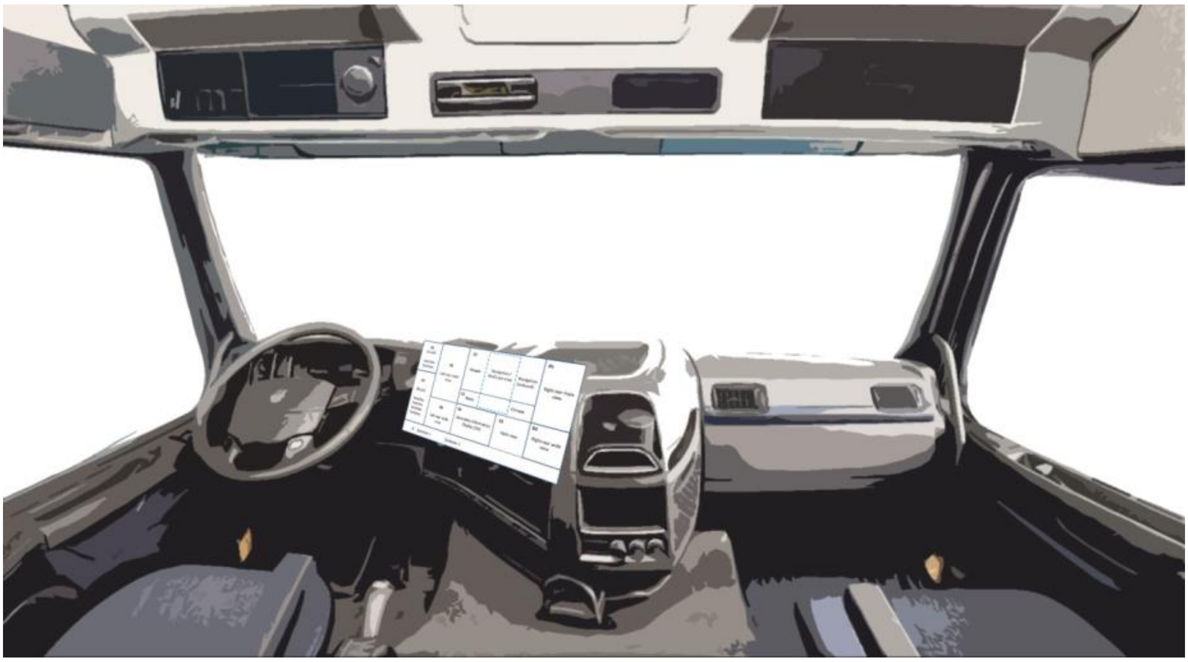


Figure 4.15 Combined Integrated Display finalized concept

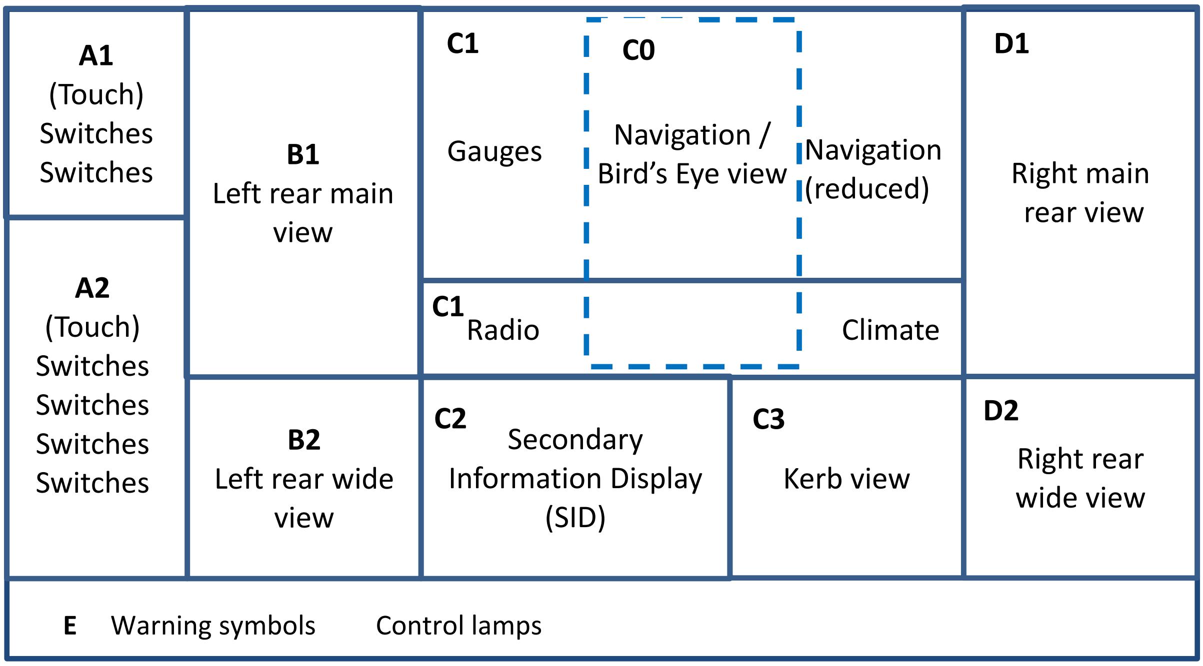


Figure 4.16 Combined Integrated Display specification

Final concept 2: "Minimalistic Tradition"

This concept is designed to minimize the cognitive workload on the driver and only show information when relevant. The main and wide angle rear views are placed on the A-pillars, making the layout resemble the traditional FH cab layout. The instrument cluster is placed above the steering wheel in an integrated plastic panel. This is thought to make the information easier to assimilate than when placed behind the steering wheel like in the current FH cab. Which information is shown where and when is specified in Table 4.4 below.

Area	Function	What is shown	When is it shown
A	Class II rear view	Left and right main rear views	Always
B	Class IV rear view	Left and right wide angle rear views	Always
C	Bird's Eye view	Bird's Eye view showing objects hidden in blind spots	Up to 15 km/h forwards and always when reversing
D	Class V view	Kerb view	Always
E	Instrument cluster	Same instrument cluster as current FH truck model	Always
F	Navigation	GPS information for navigation	Always
G	Class VI view / Secondary driver information	Close-up front view / Secondary Information Display	Front view up to 15 km/h forwards / SID from 15 km/h and when reversing

Table 4.4 Minimalistic Tradition specification

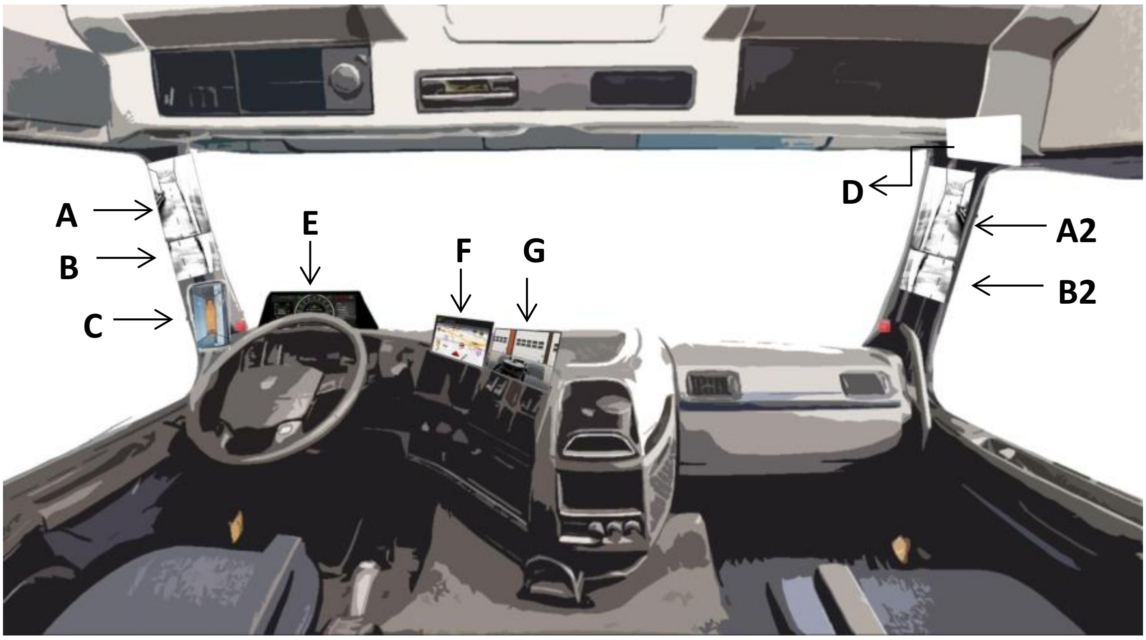


Figure 4.17 Minimalistic Tradition finalized concept

Final concept 3: "Head Up on All Windows"

In this concept, projection technology is used to show certain information "head up" in the windscreen. A modified instrument cluster is projected in the windscreen, right above the steering wheel, with the primary information (such as navigation help, current speed and speed limit, critical information, warnings and alerts) closest to the line of sight. The secondary information (driver- and trip information, driver information etc.) is projected around the primary information.

Area	Function	Which information?	When?
A1/A2	Class II rear view	Left and right main rear views	Always (A2 = projected, A1 = display)
B1/B2	Class IV rear view	Left and right wide angle rear views	Always (projected)
C	Class VI view	Front view	Up to 15 km/h forwards Switched of otherwise
D	Class V view	Kerb view	Always (projected)
E	Instrument cluster	Same instrument cluster as current FH truck model	Always (projected)
F	Navigation	GPS information for navigation	Always (projected)
G	Bird's Eye view / Secondary Information Display (SID)	Bird's Eye view showing objects hidden in blind spots / Secondary driver information	Bird's Eye view up to 15 km/h forwards and when reversing/ SID from 15 km/h forwards
H	See-through display	Showing what is behind A-pillars	Always

Table 4.5 Head Up on All Windows specifications

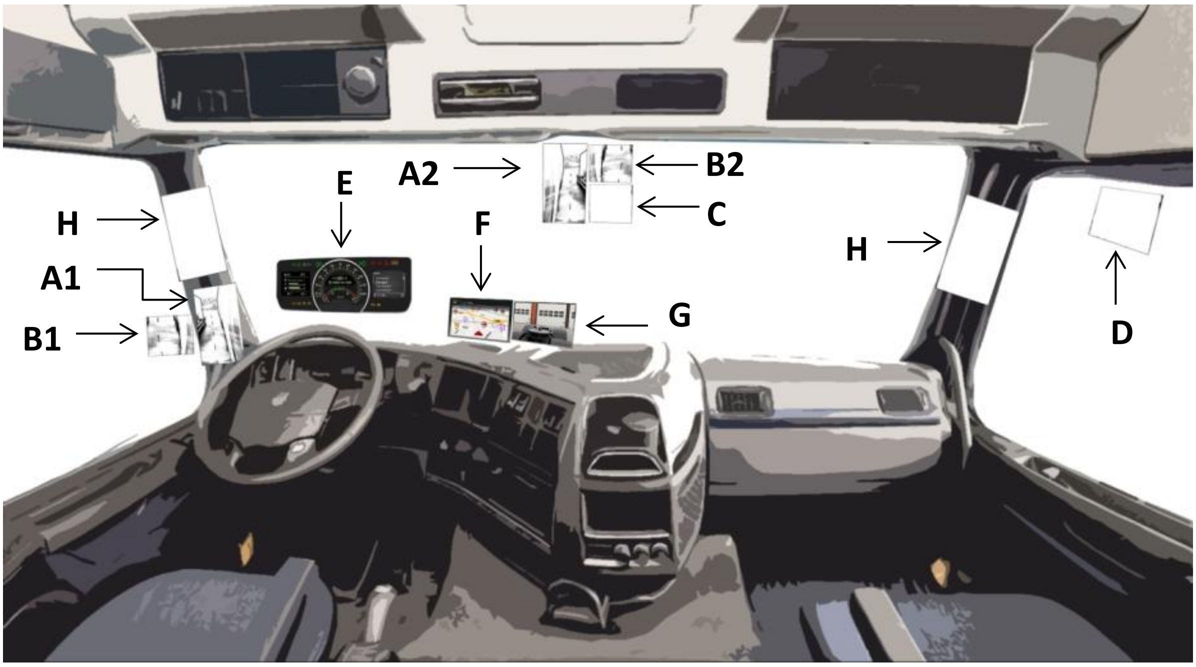


Figure 4.18 Head Up on All Windows finalized concept

4.7 Final concepts in the driving simulator

The following pictures are screenshots showing how the concepts look in the simulator environment. The first picture shows the current FH cab (the reference layout). In concept 1 – "Combined Integrated Display", all visual information is shown on a 23 inch computer monitor mounted below screen 2 and 3 (see figure 4.21 & 4.22 Driving simulator). The same 23 inch monitor is used to show the two displays to the right of the steering wheel in concept 2 – "Minimalistic Tradition". This was done due to technical limitations in the simulator.

Figure 4.19 Current FH layout (reference)

Figure 4.20 Combined Integrated Display

Figure 4.21 The 23 inch monitor information in Combined integrated display

Figure 4.22 Combined Integrated Display in the simulator

Figure 4.23 Minimalistic Tradition

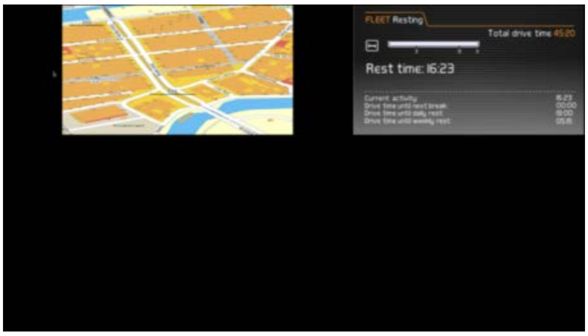


Figure 4.254 The 23 inch monitor information in Minimalistic Tradition

Figure 4.245 Minimalistic Tradition in the simulator

Figure 4.26 Head Up on All Windows

Figure 4.27 Head Up On All Windows in the simulator

5. Final result

The simulator evaluations resulted in average scores with corresponding comments for all questions in the questionnaire. The significant and relevant results are presented in this chapter. For more specific information and tables with significant comments, see Appendix 4 Evaluation results

5.1 Simulator evaluation results

The simulator evaluation resulted in a lot of data which was processed and compiled. The average scores given by the participants were calculated and are presented together with the corresponding comments for each question. To summarize the comments they have been generalized to get an understanding of how many drivers have similar opinions on the questions and concepts. This is presented with the generalized comment followed by a number, for example 3/12, which means that 3 out of 12 drivers share this opinion about the question (see Appendix 4). When three drivers or more have the same opinion about something it has been considered to be significant and representative for the test group. The rest of the comments are not included in the report. Every average score is also provided with the corresponding standard deviation to see how much the individual answers varied compared to the average score. When the standard deviation are considered high they are colored yellow and when they are considered very high they are colored red in the tables below.

The results of the experts and the drivers have been separated to see if and how their opinions differ. The group of experts consists of 4 persons, which is considered not enough to give reliable statistics. Because of that, the experts' scores and comments are used as advisory information to complement the results of the drivers. This is done in a notion that the experts are well educated in their areas of expertise, and they have some driving experience and general understanding, so their comments are therefore considered valuable anyway.

Initially in this chapter the positions for the four different types of visual information were analyzed. After that the possibility to use and assimilate the visual information in different traffic environments and driving situations were analyzed.

5.1.1 Direct vision

The participants were asked the question *"What do you think about the possibility to see through the windows in this concept?"* in order to get opinions about the direct vision in the different concepts. The results are presented below.

Drivers' results

Concept	Avg.	Std. dev.
Reference	3,91	0,76
Concept 1	4,50	0,65
Concept 2	4,42	0,49
Concept 3	3,33	1,03

Table 5.1 Drivers' average scores and standard deviation

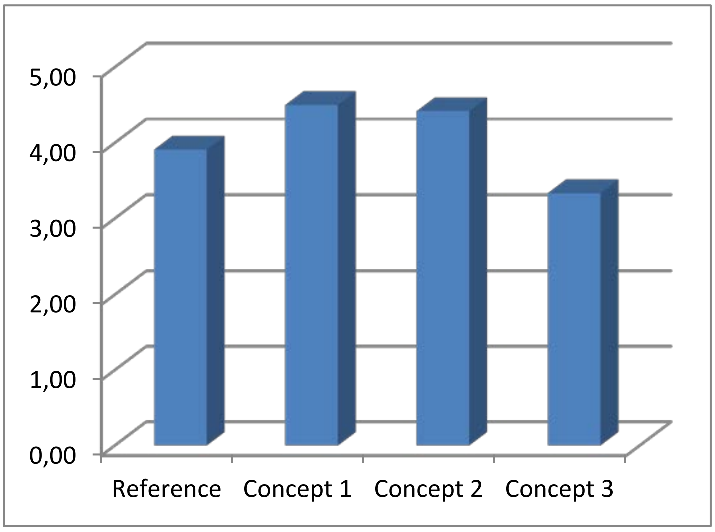


Chart 5.1 Drivers' average scores on direct vision

Concept 1 and 2 received approximately the same average score by the drivers. In concept 1 all of the drivers commented that the direct vision could not get any better since there is nothing disturbing it. The same goes for concept 2 though some drivers did not like the position of the instrument cluster because it obstructed some direct vision forwards. Some drivers also pointed out that their score was based on the premise that the new rearview devices will not cover more direct vision than the A-pillars do. In concept 3 many of the drivers thought the projected information disturbed the direct vision but the see-through displays on the A-pillars enhanced the direct vision. These different opinions led to a high standard deviation.

Both concept 1 and 2 received a higher average score than the reference which points to that the direct vision seems to improve when the rear view mirrors are removed, if no new information is positioned in the windows.

Experts' results

Concept	Avg.	Std. dev.
Reference	4,00	0,43
Concept 1	4,75	0,43
Concept 2	4,5	0,50
Concept 3	4,25	0,43

Table 5.2 Experts' average scores and standard deviation

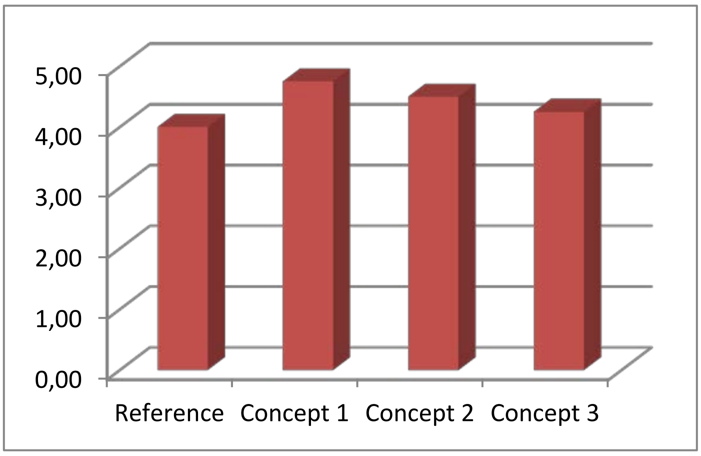


Chart 5.2 Experts' average scores on direct vision

The three concepts received roughly the same score by the experts, with concept 1 scoring the highest.

The reference received the lowest score with a low standard deviation. The experts agree that the direct vision is good but there is room for improvements.

Concept 1 got the highest score with a low standard deviation. The experts agreed on that nothing disturbs the direct vision in this concept.

Concept 2 scored the second highest score with a low standard deviation. The general opinion was that the direct vision was just as good as concept 1 but the instrument cluster disturbed it a little.

Concept 3 got the second lowest score with a low standard deviation. In this concept the SID and navigation display seemed to be disturbing the direct vision somewhat.

Both the experts and the drivers seem to see an increase in direct vision when removing the mirrors and using the new positions for rearview devices in all the concepts. In concept 1 and 2 the direct vision seems to be best.

5.1.2 Indirect vision

The participants were next asked the question *"What do you think about the layout for the indirect vision in this concept?"* to find out their thoughts on the positions of the rear view devices (mirrors or rear view camera monitors) in the different concepts. The results are presented below.

Drivers' results

Concept	Avg.	Std. dev.
Reference	4,08	1,35
Concept 1	2,58	1,32
Concept 2	4,25	0,60
Concept 3	2,64	1,23

Table 5.3 Drivers' average scores and standard deviation

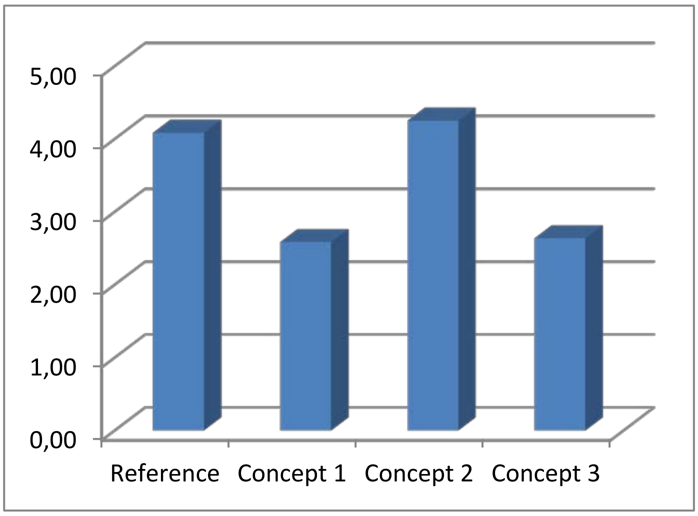


Chart 5.3 Drivers' average scores on indirect vision

The reference and concept 2 received the highest scores on this question, while concept 1 and 3 received approximately the same low scores. The drivers' opinions were scattered, resulting in high standard deviations for the reference and concept 1 and 3.

The reference received the second highest score with a high standard deviation. It was generally liked but some drivers did not share that opinion and that is why the standard deviation is so high. Most drivers liked the layout because it feels logic and natural and that the mirror housing is slim.

Half of the participating drivers thought the rear view display positions in concept 1 were dangerous because they have to take their eyes off the road to see them, but they liked that the camera views were gathered. Some drivers did not like the concept at all which probably led to the high standard deviation.

Concept 2 received the highest score with a low standard deviation and was generally liked by the drivers. Most drivers thought that the position was logical without disturbing the direct vision much. They also thought that this position would be easy to get used to.

Concept 3 received the second lowest average score and most drivers noted that the indirect vision displays felt scattered and hard to find because they were not symmetrically distributed. Generally the drivers' opinions on the layout of indirect vision in this concept were very scattered. Some drivers appreciated the positions because they were close to the line of sight but most drivers criticized that they obstructed too much direct vision, which contradicts the other drivers' opinions.

Generally it seems like it is important to place the rear view devices in a symmetrical way and on positions that the drivers are used to. It is also important that the layout is logical, with the right rear view to the right and the left rear view to the left.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,50	0,50
Concept 1	2,00	0,71
Concept 2	4,50	0,50
Concept 3	2,75	0,83

Table 5.4 Experts' average scores and standard deviation

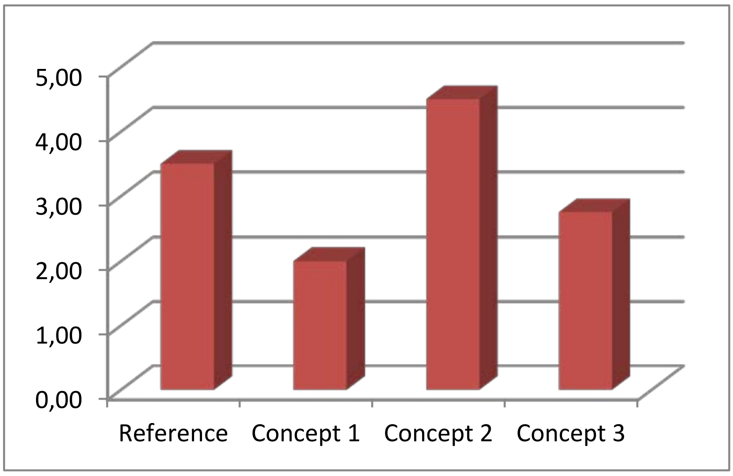


Chart 5.4 Experts' average scores on indirect vision

The experts' results are similar to the drivers', with concept 2 as the highest rated and the reference following, and concept 1 and 3 significantly lower. The reference got the second highest score with a low standard deviation. Generally the experts liked it because it feels logic and natural.

Concept 1 scored lowest with a fairly low standard deviation. The experts agreed on that it feels dangerous too look down to the right for indirect vision because it is too far away from the line of sight. They also said that it does not feel logical to look to the right to get information about what is behind the truck on the left hand side.

Concept 2 scored highest with a low standard deviation. In this concept the experts were generally positive about the positions because it feels natural and logical to have them on the corresponding sides.

Concept 3 got the second lowest score with a fairly low standard deviation. Most experts thought that the asymmetry makes it harder to find the information and that it is not logical to have the right hand side rearview vision device in the middle of the windscreen.

5.1.3 Driver information

To find out what the participants thought about the driver information (instrument cluster) they were asked the question *"What do you think about the positioning of the driver information (such as the instrument cluster)?"*.

Drivers' results

Concept	Avg.	Std. dev.
Reference	3,67	0,75
Concept 1	2,36	1,23
Concept 2	2,58	0,95
Concept 3	2,67	1,25

Table 5.5 Drivers' average scores and standard deviation

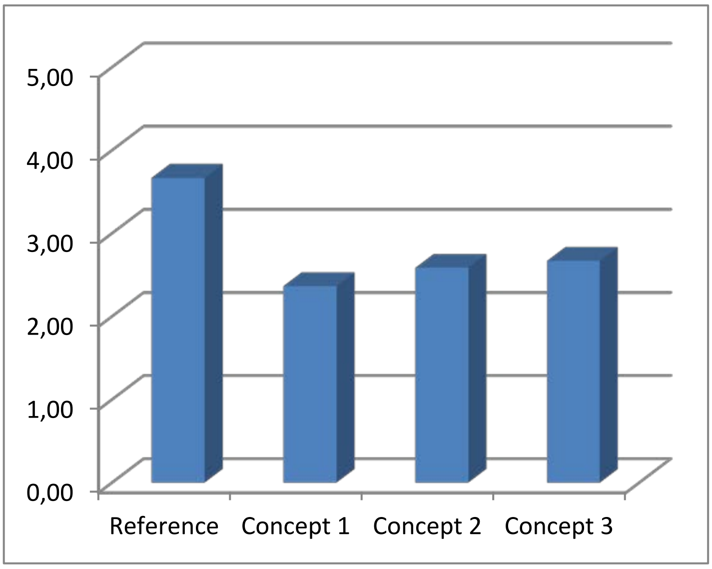


Chart 5.5 Drivers' average scores on driver information

On this question, the reference scored higher than the three concepts, which received similar average scores. The position of the instrument cluster in the reference seems to be quite good, but the steering wheel hides some of the cluster information for some drivers when driving the Volvo FH in reality.

Concept 1 got the lowest score with a high standard deviation. The driver information layout in concept 1 differs from the instrument cluster layout in the other concepts. Some drivers mentioned that the information is less scattered than in the reference, but more cluttered. Regarding the position more than half of the drivers mentioned that it felt dangerous to look down to the right to get the driver information because they lost focus on the road. The high standard deviation is thought to be because the position is generally disliked but some of them still liked the fact that the information is gathered. This means that the drivers both liked and disliked different parts of the concepts and considered it to be difficult to give a fair score.

Concept 2 received the second lowest score and a fairly high standard deviation. Regarding the position of the instrument cluster in concept 2, many drivers were worried that it would disturb too much direct vision forwards.

The drivers' opinions were scattered, resulting in a high standard deviation. Some of them liked the transparent Head up Display because they could see the information clearly regardless of their position. Other drivers mentioned that it disturbed the direct vision forwards. They prioritize the direct vision, and not all that information is needed right in the line of sight.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,75	0,43
Concept 1	2,25	0,83
Concept 2	3,00	1,00
Concept 3	3,75	1,09

Table 5.6 Experts' average scores and standard deviation

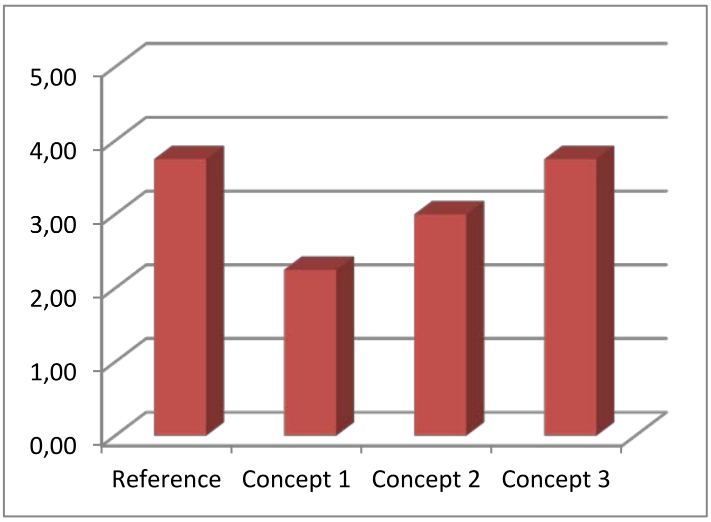


Chart 5.6 Experts' average scores on driver information

The experts' average scores were similar to the drivers' for the reference and concept 1, but higher for the other two concepts. The experts liked the position of the instrument cluster in the reference because it is easy to find. As for the drivers, they disliked the position of the driver information in concept 1 and mentioned that the important information is too small and too far from the line of sight. The cluster position in concept 2 was disliked by the experts too, because it disturbed some direct vision. Concept 3 was rated as high as the reference. The experts seems to be more welcoming to the Head up technology than the drivers, and some experts mentioned that they like the cluster information in the line of sight, while others were afraid that it would disturb the direct vision too much.

A general opinion about the instrument cluster position seems to be that information should be placed as far up as possible without disturbing the direct vision. This is to provide the driver with the information in a safer way due to a smaller distance from the line of sight. Some information could be projected in the windscreen, but further down than in concept 3 and not the whole instrument cluster.

5.1.4 Secondary information

The participants were asked the question *"What do you think about the positioning of the secondary information such as the navigation?"* in order to get opinions about the secondary information in the different concepts. The results are presented below.

Drivers' results

Concept	Avg.	Std. dev.
Reference	3,50	0,65
Concept 1	2,83	1,14
Concept 2	3,83	0,55
Concept 3	3,25	1,09

Table 5.7 Drivers' average scores and standard deviation

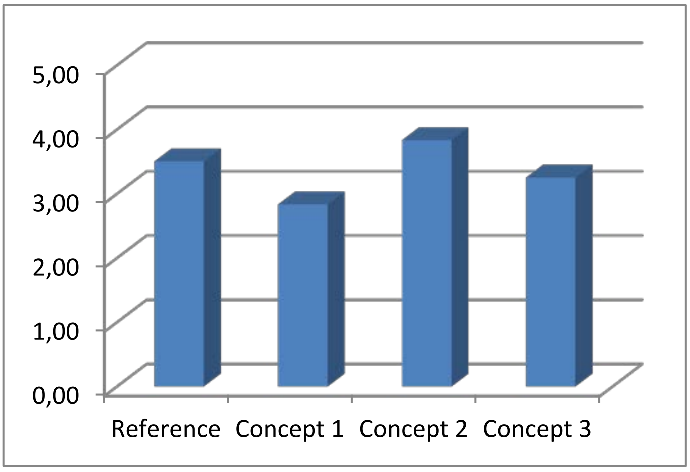


Chart 5.7 Drivers' average scores on Secondary information

The reference scored second highest with a low standard deviation. Most drivers liked the position because it is easy to find when they need it. But some drivers commented that they use it to store keys and other things, which compromises the function of the SID.

Concept 1 scored the lowest and has a fairly high standard deviation which points towards very different opinions among the drivers. The actual scores differ a lot among the drivers because they have different opinions on the positions in this concept. Almost half of the drivers thought the position was okay because it is similar to the FH and also because it is not so important for driving. But some of the drivers also thought the SID was hard to find in the big display.

Concept 2 scored highest when it comes to the position of the secondary information with a low standard deviation which means that the drivers seem to have similar opinions. Almost all the drivers liked the position because they do not have to move their head and it does not disturb the direct vision.

Concept 3 scored second lowest with a high standard deviation. The standard deviation is high because one driver gave it score 1 and another driver gave it a 5. The rest of the scores were between 2 and 4, which means that the average score was around 3 and the standard deviation of 0.77 when excluding the highest and the lowest scores. Most drivers liked the position because it is close to the line of sight without disturbing the direct vision. Only two drivers did not like the position.

Concept 2 has both highest average score and lowest standard deviation but is not significantly better than the reference and concept 3. This is thought to be because the position of the SID being very similar in those concepts. A conclusion that can be made is that the drivers prefer the SID close to the original position because it promotes natural behavior, but they want it to sit higher and closer to them but not projected on the windscreen.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,00	0,71
Concept 1	2,50	0,87
Concept 2	3,00	0,71
Concept 3	3,50	1,50

Table 5.8 Experts' average scores and standard deviation

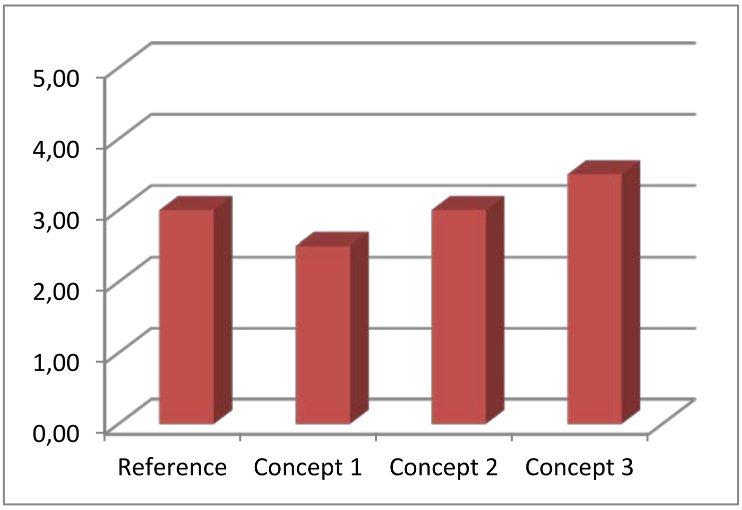


Chart 5.8 Experts' average scores on secondary information

The reference and concept 2 scored the same average of 3 with the same standard deviation. Most of the experts think that the SID in the reference is too far away but like the position in concept 2 because it is easy to find. Based on the comments the experts prefer concept 2.

Concept 1 received the lowest score and fairly low standard deviation which means that the experts had similar opinions about the grade for the concept. In general the experts did not like it and criticized different aspects regarding the positions but did not agree on the same aspects to criticize.

Concept 3 received the highest score but with a high standard deviation. The standard deviation is so high because two experts scored a 4, one a 5 and one scored 1. This means that all experts but one agreed that they liked this position for the SID very much. This person said that the SID was obstructing the direct vision. Generally they like the position because it is close to the line of sight but it is not important enough to take that much direct vision.

The experts do not agree on concept 3 but they have similar opinions on the reference and concept 2. As a result of that concept 2 and the reference are considered to be more representative for the experts. That result is similar to the one of the drivers where they preferred concept 2 and the reference, this because the position of the SID in the FH is good but the position in concept 2 is preferred.

A conclusion on that is that the position of the SID in Concept 2 is the one that is most preferred among the drivers and experts because it is similar to the FH but closer to the line of sight.

5.1.5 Possibility to take in visual information during country road driving

The participants were asked the question *"What do you think about the possibility to take in different visual information that you need during country road driving in this concept?"* in order to get opinions about the possibility to assimilate visual information during country road driving in the different concepts. The results are presented below.

Drivers' results

Concept	Avg.	Std. dev.
Reference	4,17	0,55
Concept 1	2,50	1,26
Concept 2	3,64	0,77
Concept 3	3,00	1,29

Table 5.9 Drivers' average scores and standard deviation

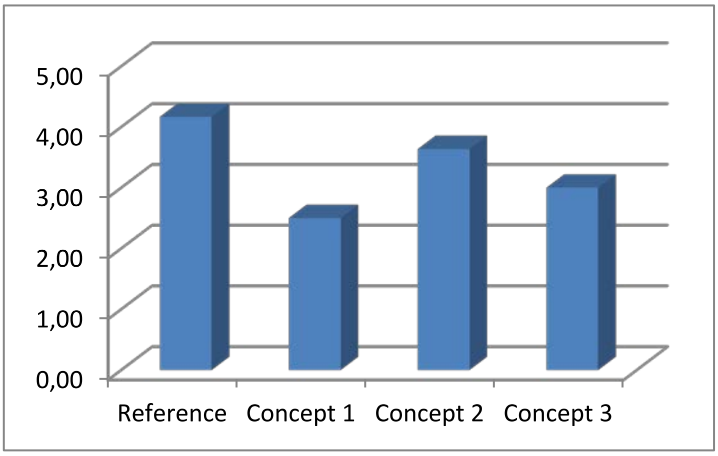


Chart 5.9 Drivers' average scores on possibility to assimilate visual information – driving on country roads

The reference received the highest score with the lowest standard deviation. Most drivers thought it was easy to assimilate the information because they are used to the layout. Many drivers' opinions were also that they really like the rearview mirrors. Even though they disturb the direct vision they are so small and thin on the new FH that it is not a problem.

Concept 1 had the lowest score and a high standard deviation. The scores were very scattered because the drivers seem to not really agree on their opinions about the possibility to assimilate visual information. Most drivers shared the opinion that it feels dangerous to look down to the right while driving because they felt that they lost attention of the road environment. Many drivers also thought that it was easy to get an overall view of the truck surroundings in this concept.

Concept 2 had the second highest score and a fairly low standard deviation. Most drivers thought it was easy to assimilate visual information because it is similar to the FH and that the direct vision is increased with the new layout.

Concept 3 got the second lowest score with a high standard deviation. The scores for this concept were also very scattered and the drivers seem to disagree on what they think about the concept. Many drivers liked that the information was gathered and also appreciated the position of the instrument cluster and the ability to see through it. Many drivers thought there were too much information and thought it was not logical to have the rear view devices positioned asymmetrically. Many drivers also commented that they did not like the positions of the right rear view devices because they lost the direct vision through the passenger window when they looked in the middle of the windscreen.

The reference received the highest scores in this context but the comments on Concept 2 that had the second highest score said that they liked it because it resembles the Volvo FH and that they also got more direct vision. A conclusion of that is that it seems to be important that the information is positioned in a way that supports natural behavior and resembles the Volvo FH.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,50	0,50
Concept 1	2,67	1,25
Concept 2	4,75	0,43
Concept 3	4,00	1,00

Table 5.10 Experts' average scores and standard deviation

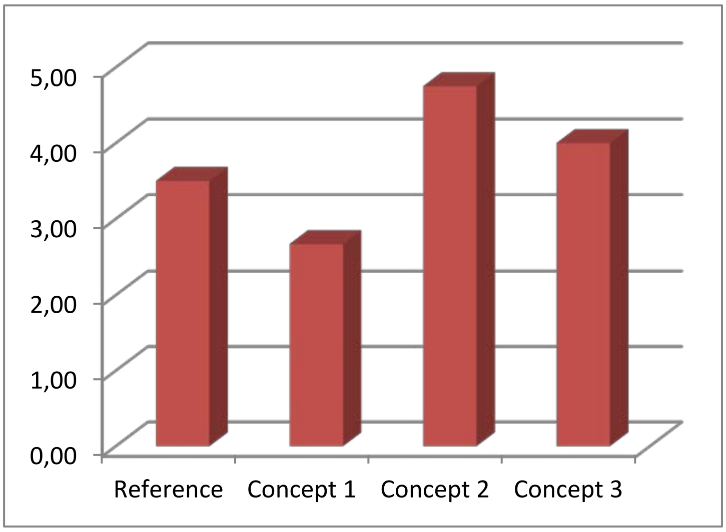


Chart 5.10 Experts' average scores on possibility to assimilate visual information – driving on country roads

The reference had the second lowest score among the experts with a low standard deviation. They seem to think it is fairly easy to assimilate the information and mention that they really like the mirrors on the FH.

Concept 1 got the lowest score with a high standard deviation because of very different opinions on the concept. They disagree on a lot of things in the comments but generally they criticize the concept because they think it is hard to take in the information from this position.

Concept 2 received the highest score and lowest standard deviation. They think it feels easy and natural because it resembles the Volvo FH which makes it easy to know where to look for information.

Concept 3 has the second highest score and a fairly high standard deviation because two experts like it and grade it high and two experts are more restrictive. Generally they like it and think it is easy to assimilate information because they did not have to move their head that much.

Concept 2 was graded highest by both experts and drivers and that seems to be because it feels natural and logical because the information is found in the natural directions (right rearview to the right and left rearview to the left). A conclusion of this is that when driving on a country road, resemblance to what the drivers are used to makes it easier to assimilate the visual information. This because it is important for the drivers to look to the logical positions in the natural directions.

5.1.6 Possibility to assimilate visual information during maneuvering at low speeds

The participants were asked the question *"What do you think about the possibility to assimilate different visual information that you need for maneuvering at low speeds?"* in order to get opinions about the possibility to assimilate visual information during country maneuvering at low speeds in the different concepts. The results are presented below.

Drivers' results

Concept	Avg.	Std. dev.
Reference	3,73	0,45
Concept 1	2,91	1,00
Concept 2	4,18	0,39
Concept 3	3,00	1,21

Table 5.11 Drivers' average scores and standard deviation

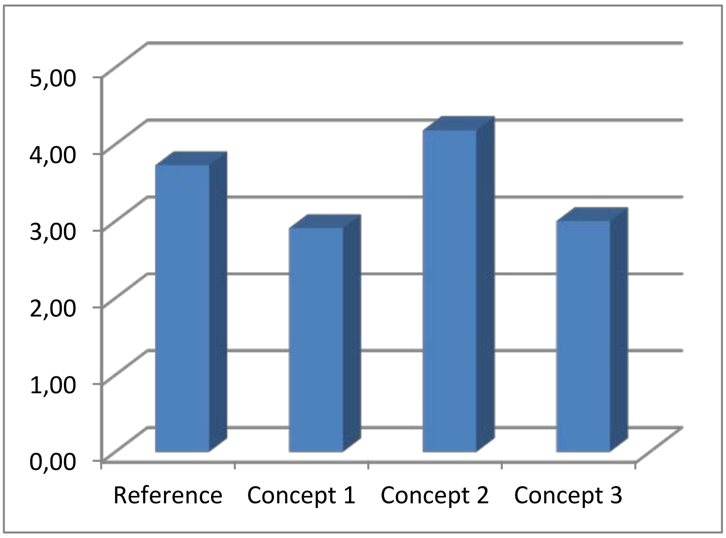


Chart 5.11 Drivers' average scores on possibility to assimilate visual information – maneuvering at lower speeds

The reference received the second highest score with a low standard deviation. Many of the drivers say that they mostly use the mirrors when maneuvering at low speeds and that they give a good view of the truck's surroundings. Some drivers mention that they like that the mirror housings are slim and have a big gap between them which offers more direct vision.

Concept 1 got the lowest score with a high standard deviation due to many different opinions about the concept. Many drivers say that they find the information but the position of the display does not feel logical because it makes it hard to drive in this environment because they have to look away from the road too much. Some drivers also mention that they are not used to the position but it is good that the information is gathered.

Concept 2 received the highest score and lowest standard deviation. Most drivers think it is easy and logical to assimilate the information because the positions feel natural and close to the driver in this concept. Some also mention that the position of the Bird's Eye view is preferable and that the device helps a lot.

Concept 3 got the second lowest score and a high standard deviation. The scores were very scattered which points towards that the drivers have different opinions on the concept. Many drivers thought it felt illogical and hard to find the information. Some mentioned that they really like the Bird's Eye view and that it helped to see through the A-pillars.

Concept 2 had the highest score of all the concepts and seems to be the one the drivers prefer. A conclusion of this is that it seems that when maneuvering at low speeds it is important to use natural and logical positions to quickly find the right information, and that see-through displays seem to be a good aid for narrow environments and maneuvering.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,75	0,43
Concept 1	2,75	0,43
Concept 2	4,50	0,87
Concept 3	3,25	0,43

Table 5.12 Experts' average scores and standard deviation

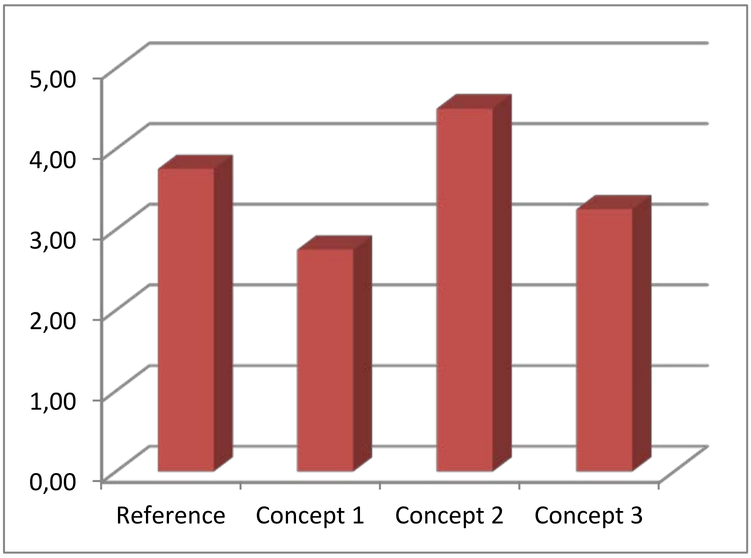


Chart 5.12 Experts' average scores on possibility to assimilate visual information – maneuvering at lower speeds

The reference received the second highest score with a low standard deviation. Generally the experts like the way to assimilate visual information and especially the mirrors that they think are very good for this kind of driving.

Concept 1 got the lowest score with a low standard deviation. The experts criticize the concept and do not think it feels good to find the information in the middle and that it distracts the driving.

Concept 2 received the highest score with a fairly low standard deviation. Generally they like the concept and mentions that it feels natural and logical to assimilate the information in this concept.

Concept 3 received the second lowest score with a low standard deviation. Most experts are critical towards the concept and some mention that the SID and cluster distracts them and that it would be hard to get used to the new positions.

Both the experts and the drivers preferred concept 2 because it feels logical and natural to assimilate information when maneuvering at low speeds. This strengthens the conclusion that it is important to resemble the Volvo FH layout to make it easier and more natural to assimilate information, especially the rearview device positions since they are frequently used when maneuvering.

5.1.7 Relations between visual information

The participants were asked the question *"What do you think about the relation between the different kinds of visual information?"* in order to get opinions about the relations between visual information in the different concepts. The results are presented below.

Drivers' results

Concept	Avg.	Std. dev.
Reference	3,75	0,72
Concept 1	2,33	1,03
Concept 2	3,83	0,55
Concept 3	2,83	0,99

Table 5.13 Drivers' average scores and standard deviation

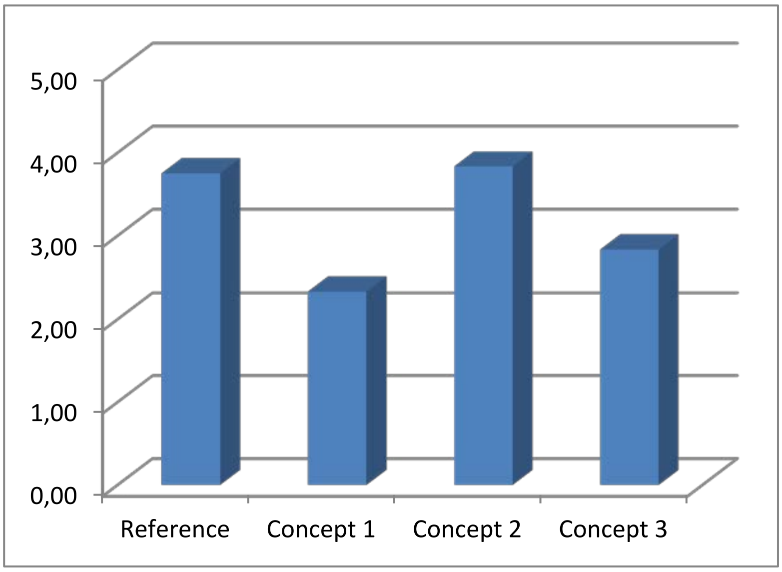


Chart 5.13 Drivers' average scores on relations between visual information

The reference received the second highest score with a low standard deviation closely followed by Concept 2. Most of the drivers think it is a logical relation between the different means of visual information and it is what they are used to.

Concept 1 scored the lowest with a fairly high standard deviation. The scores were generally low but with a few drivers liking the concept more than the other participants. Many drivers think that it is hard to find the information needed in the display because it is cluttered and they mentioned that they had to concentrate to find it, which made they lose focus of the road.

Concept 2 scored highest with a low standard deviation. Most of the drivers think the relations are logical because it looks like what they are used to. Some drivers mentioned that they did not like the position of the instrument cluster though.

Concept 3 scored second lowest with a fairly high standard deviation. Most scores were between 1 and 3, except two scores that were higher which explains the standard deviation. Generally they agree on their opinion of the grade of the concept. Most drivers think the information is too scattered and they do not like the asymmetrical positions and horizontal relations of the rearview devices. Some drivers also think there is too much information in one place.

A conclusion of this is that concept 2 seems to get a high average score because the relations are logical and similar to the reference FH, which the drivers prefer as much as concept 2.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,50	0,87
Concept 1	3,00	0,82
Concept 2	4,25	0,43
Concept 3	3,50	0,87

Table 5.14 Experts' average scores and standard deviation

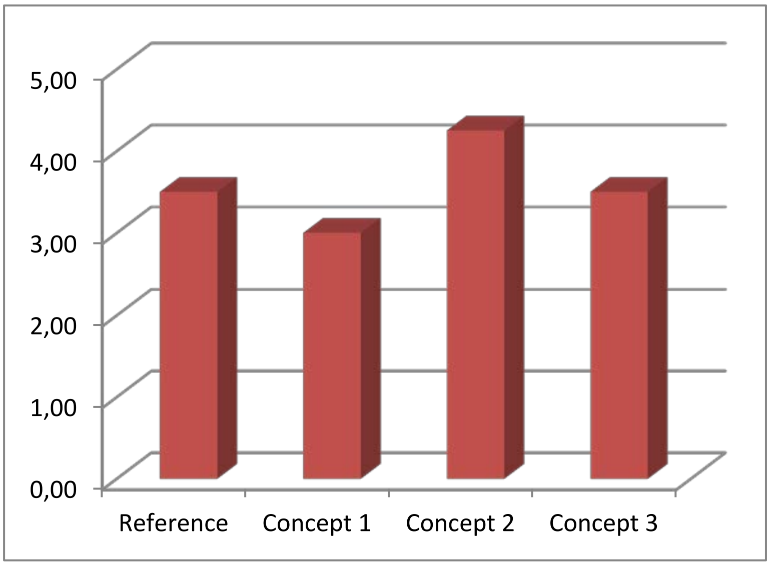


Chart 5.14 Experts' average scores on relations between visual information

The reference and concept 3 received the second highest scores with fairly low standard deviation. The experts think that the relations in the reference feels good and logical but they like concept 3 because they do not have to turn their head so much to get the information.

Concept 1 scored lowest with a fairly low standard deviation. The comments differ a lot on this concept but most experts think that less prioritized information takes too much space in the display.

Concept 2 scores highest with the lowest standard deviation. Generally the experts feel that the relations are logical and that they find it where they expect it to be.

These results are very similar to the drivers' where they also preferred concept 2. Both experts and drivers seem to prefer it because the relations are similar to the Volvo FH. A conclusion that can be made is that it seems to be important for the participants to have similar relations between the different types of visual information to make it logical for them, which promotes safe driving and natural behavior.

5.1.8 Total score

After all concepts had been tried in both environments, the participants were asked *"What is your total score for the concepts now that you have tried them all?"* to get their general opinions about the different concepts in relation to the reference.

Drivers' results

Concept	Avg.	Std. dev.
Reference	3,33	0,75
Concept 1	2,25	1,01
Concept 2	3,83	0,37
Concept 3	2,69	1,20

Table 5.15 Drivers' average scores and standard deviation

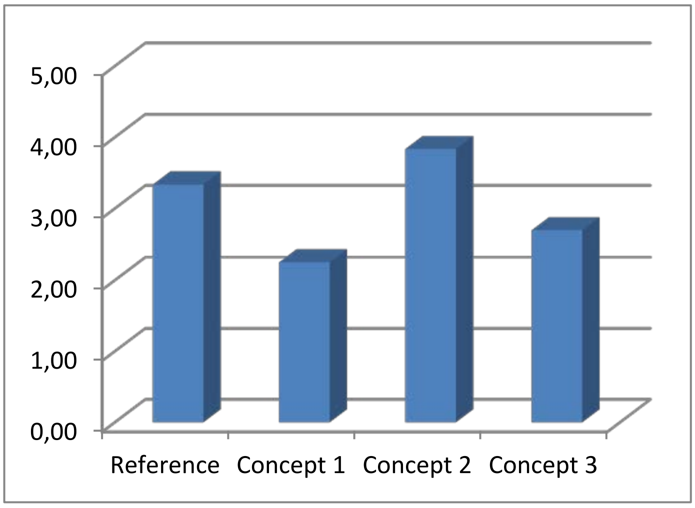


Chart 5.15 Drivers' average total score for the concepts

After having tried all concepts, the drivers' final opinions were rather clear. Concept 2 received the highest average score, followed by the reference, concept 3 and then concept 1 with the lowest overall score.

The direct vision and the positions of the rear view mirrors were mentioned as advantages in the current FH cab (reference), but some drivers thought that the rear view mirrors disturbs the direct vision too much. 3 out of 12 drivers spontaneously said that they like concept 2 better, when asked about the reference.

Some drivers thought Concept 1 was dangerous to drive with because it makes the driver focus too much on a display placed towards the middle of the truck cab instead of on the road. Further, they thought the information in the display was messy and cluttered, while 2 out of 12 drivers mentioned that it is good to have all information gathered in one place. These deviating opinions are thought to cause the high standard deviation.

Most drivers agreed on that concept 2 is good because it resembles today's FH cab and that the positions of the rear view camera displays are logical. 5 out of 12 spontaneously said that this is their favorite concept and 10 of 12 gave it the score 4. However, some drivers disliked the position of the instrument cluster since it disturbed the direct vision a bit.

The opinions about concept 3 differed a bit, resulting in a high standard deviation for the average total score. 4 of 12 drivers liked the position of the instrument cluster, while 3 of 12 disliked it for disturbing the direct vision. Many drivers seemed to agree on that the layout of the visual information felt scattered and that some of the Head up Displays disturbed the direct vision. The asymmetry of the rear view camera display layout was generally disliked. The see-through displays on the A-pillars were spontaneously mentioned by some participants as a good aid for minimizing blind spots, especially during maneuvering at low speeds.

Experts' results

Concept	Avg.	Std. dev.
Reference	3,25	0,83
Concept 1	1,50	0,50
Concept 2	4,50	0,50
Concept 3	3,00	0,71

Table 5.16 Drivers' average scores and standard deviation

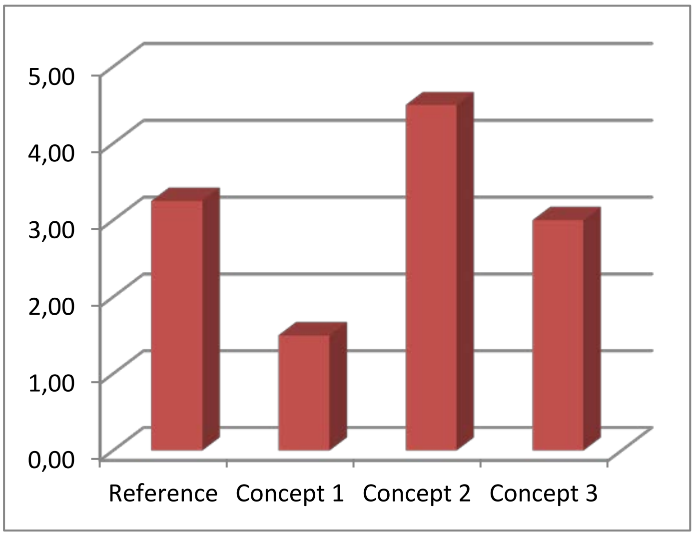


Chart 5.16 Experts' average total score for the concepts

The experts' opinions correspond with the drivers' comments and scores. Concept 2 was the most popular, followed by the reference, concept 3 and then concept 1. They confirm the drivers' thoughts about concept 1 being dangerous because it makes it easy to lose contact with the road environment. They also seemed to think that it feels wrong to look for the left rear view information in a display placed to the right of the steering wheel. All experts liked concept 2, two of them gave it score 4 and the other two gave it score 5. The experts' opinions were scattered regarding concept 3, with some thinking there is too much information in the line of sight and that the rear view camera displays should be placed symmetrically, while some thought it would be okay with some adjustments.

5.2 Conclusions of simulator evaluation results

Based on the results in the simulator evaluation some conclusion on how to position different types of visual information will be made in the following chapter. This will be done by looking into the results and complementing them with theoretical aspects.

Direct vision:

Among both drivers and experts the concepts got higher average scores than the Volvo FH with one exception for concept 3 where the drivers rated it the lowest. This point towards that removing the rearview, kerb view and front view mirrors seems to give a better direct vision, both for country road driving and when maneuvering. Projecting information on the windscreen is not appreciated from a direct vision point-of-view and seems to disturb the direct vision. This should be considered when designing new layouts for visual information in trucks to obtain as good direct vision as possible.

Indirect vision:

Both drivers and experts agree that concept 2 was best regarding the indirect vision and neither ones liked concept 1 or 3. Both groups also identified that they prefer to have a layout that resembles the Volvo FH because it makes it more natural and logical for them. This seems to be because the driver receives complementing peripheral direct vision through window areas close to the rearview mirrors when they are placed like in the Volvo FH and concept 2, which is important for safe driving.

The drivers did not like the fact that the rearview devices in concept 3 were placed asymmetrically which seems to indicate that they should be positioned vertically symmetrical. The positions in concept 2 for indirect vision devices are closer to the driver's line of sight which reduces head movements and minimizes the time to assimilate the information as described in chapter 2.5.3 Head movements.

The bird's eye view should be positioned to the left like in concept 2 according to a report on Volvo Trucks (Borre & Larsson, 2012) From an ergonomics point of view it should be positioned within a 15° cone but not further away than 30° from the central field of vision so that eye movements can be executed efficiently as described in chapter 2.5.1 The human eye if possible. The Bird's Eye view was shown when reversing and when driving forwards up to 25 km/h. This seems to be appreciated by the drivers and they agreed on that it is a good aid when maneuvering at low speeds but is not needed when driving fast.

The position of the kerb view device was appreciated because it was placed logically and close to what it is showing in the display. Drivers also mentioned that they perceived it to be closer to them which also decreases head movements and minimizes the time to assimilate the information. From an ergonomics point of view it should not be positioned higher than 50° from the central field of vision since that is the limit for detecting objects above line of sight and preferably within the 30° cone if possible.

The see-through displays placed on the A-pillars in concept 3 was appreciated and was mentioned by 8 participants as an advantage, especially when driving at low speeds. This because they reduce the blind spot issue by showing what is behind the A-pillars, which is a recognized problem in urban areas where there is a lot happening around the truck cab.

All these aspects should be considered when designing new layouts for indirect vision.

Driver information:
The experts preferred the position of the driver information in concept 3 and the Volvo FH and the drivers preferred the position in the current Volvo FH. Both drivers and experts could not agree on whether the instrument cluster should be projected on the windscreen or not. It seems that they like to have it close to the line of sight, but they prioritize the direct vision so it should not be in the middle of the line of sight. Generally they thought there was too much information displayed and that only some information should be in the HUD.

To minimize eye and head movements the instrument cluster should be positioned within 15° but not further than 30° from the central field of vision vertically and horizontally as described in chapter 2.5.1 The human eye. That contradicts the fact that the closer to the line of sight an object is the more it disturbs the direct vision as described in chapter 2.6.1 Visual distraction. That makes the possibility to project information on the windscreen a good alternative since you can see the information with maintained direct vision because you see through the projected information.

The simulator evaluation showed that the participants disagree on the projected instrument cluster. A conclusion of that is that it seems to be important to keep the conventional position for the instrument cluster but some of the driver information can also be projected in a HUD with the possibility to turn it on and off. That way the driver can choose to have the information there if the driver feels that it enhances his driving experience. As of that it seems that both the HUD and the conventional instrument cluster and its position should be integrated in a new layout for the driver information.

Secondary information:
Both the drivers and the experts preferred the position of the SID in concept 2, but concept 1 and the reference were not significantly less preferred because the positions in the concepts are very similar to the one in the Volvo FH. They seem to prefer concept 2 because the SID is positioned higher and closer to the line of sight, though the experts like it projected the drivers do not want it projected. But since the drivers represent a bigger group of participants their opinions are chosen. That seems to point towards that the SID position should resemble the conventional one, but be moved closer to the line of sight vertically.

Theoretically the SID should sit as close to the line of sight as possible both vertically and horizontally for safety reasons, as described in chapter 2.5.1 The human eye. The result of the evaluation points towards the same as long as the information is not projected. A conclusion of this is that the SID should be positioned similar to concept 2 and not be projected.

Ability to assimilate visual information:
Both drivers and experts agree that the positions in concept 2 are the ones that make it easiest to assimilate information in both country road driving and maneuvering at low speeds. It seems that it is very important for drivers to find the information in positions that they are used to in order to make it easy to assimilate information in both driving situations. Concept 2 resembles the Volvo FH's positions and made the drivers behave naturally during the simulator evaluations and they did not have a problem finding the right information, which is important for safe driving. This points towards that regardless of the environment the driver is driving in it is important to get the information from positions that feels logical to more easily take in the information. This should be considered when designing a new layout of the visual information in trucks.

Relation between types of information:
Both drivers and experts share the opinion that concept 2 had the best relations between the different types of visual information. It seems to be important that the relations feel logical and they seem to be apprehended more logical when they resemble the Volvo FH that the drivers are used to. But it also seems to be important that the indirect visual information is close to the corresponding direct vision so that drivers see both the indirect vision and the direct vision peripherally. This should be considered when designing new layouts for visual information in trucks.

Total scores:
When prompted with the question about what they think about the concepts after having tried them all, drivers expressed a little different opinions in some cases but were fairly consequential. Concept 2 was the concept they preferred for the same reasons stated in the earlier questions. This points towards that concept 2 might be a good base to start with when designing new layouts for visual information.

5.3 Description of final visual information layout

Since the positions for each information type were evaluated individually, the final concept is a combination of these visual information positions. It is basically concept 2 – "Minimalistic tradition" with ideas from concept 3 – "Head up on all windows".

5.3.1 Direct vision

The direct vision is enhanced by replacing the traditional rear view, kerb view and front view mirrors with a camera-monitor system (CMS).

5.3.2 Indirect vision

The rear view mirrors are replaced with cameras pointed backwards to correspond with what is seen in today's mirrors. The rear view camera monitors are positioned on the A-pillars, with the main view above the wide-angle view (see Figure 5.2). When needed, the driver can activate a see-through functionality with a button on the steering wheel (see Figure 5.3). When activated, the main rearview displays turn to see-through displays like in concept 3 and show a camera view of what is on the other side of the A-pillars. This can be used when driving in urban areas, in roundabouts or when maneuvering in narrow environments. The wide-angle rearview displays still give indirect vision rearwards, which is assumed to be enough since the functionality is supposed to mostly be used in critical situations where visibility forwards is more important. The see-through functionality can quickly be switched to the normal main rear view.

The kerb view camera shows the same view as the traditional kerb view mirror. The camera view is not mirrored, resulting in a flipped view compared to the view seen in the conventional kerb view mirror. The 7 inch display is placed on the right A-pillar, above the right main rear view display.

The front view mirror is replaced with the bird's eye view which is shown on a 7 inch display placed on the left A-pillar, below the left wide-angle rear view. This view also replaces the reverse camera view since it shows the whole area around the vehicle. The display is automatically turned on when activating the reverse gear and when driving forwards up to 25 km/h. It has additional functions described further in chapter 4.6.

5.3.3 Driver information

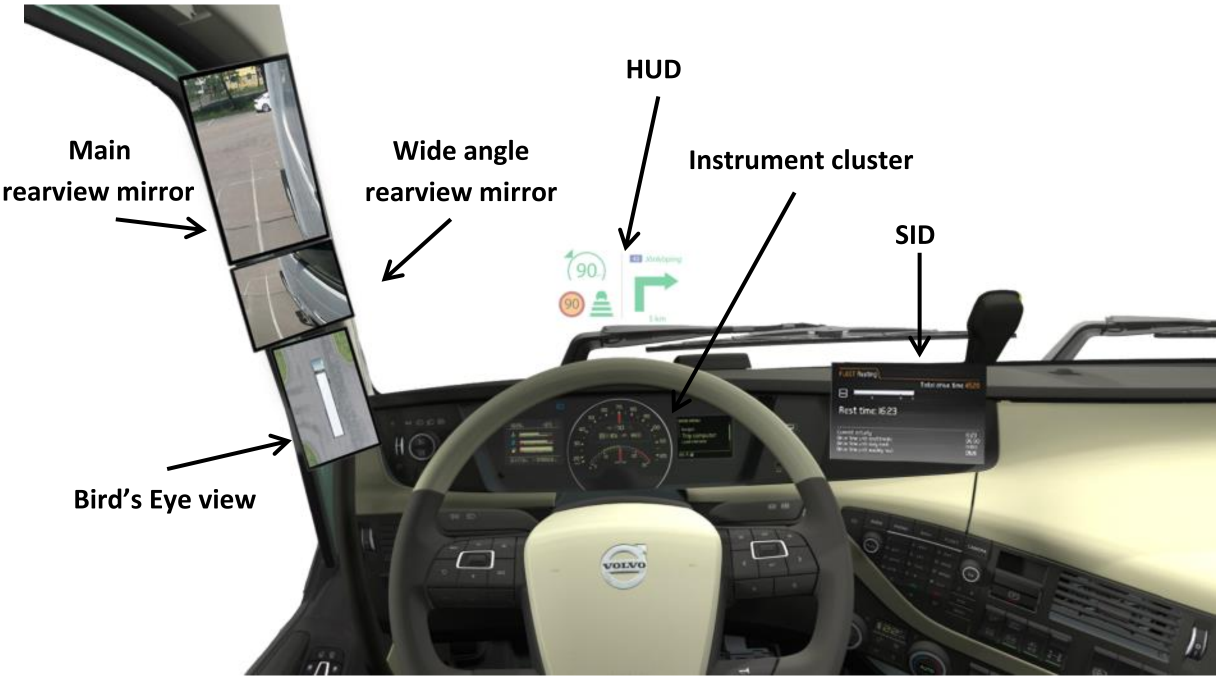
The driver information is shown in the traditional instrument cluster, with the most important information also projected on the windscreen in a Head up Display (HUD) as seen in Figur 5.2

5.3.4 Secondary information

The secondary information display (SID) is placed a bit higher than in the current FH cab, as high up as possible without disturbing the direct vision through the windscreen. This is illustrated in Figure 5.2. This display is used in the same way as the current SID, with driving status, truck status and navigation information but is slightly bigger in this concept to be able to fit more information.

Other secondary information is shown in the 7 inch multi-purpose display on the left A-pillar, below the left wide-angle rearview display. When not showing the Bird's Eye view, this display can be used for interacting with other drivers and friends and family through social networks. It is removable and can be used as a wireless remote control (WRC) and as a delivery system for keeping track of the coming deliveries and to get signatures from customers for example.

Figure 5.1 Final concept on country road



Figur 5.2 Final concept specification

Figure 5.3 Final concept with see-through

5.4 Suggestions for extra features

During the process of this thesis work many ideas have been identified but not all of them have been implemented. In this chapter some extra features that have been identified during the project will be presented for further development in the future. These functions has not been researched or evaluated.

Diameter of the steering wheel

The diameter of the steering wheel could be decreased as well as the size of the instrument cluster. This gives more space around the steering wheel so that other information could be placed there. This also allows a bigger size for the SID. In Figure 5.4 the steering wheel is 85 % of the original size, with the original steering wheel marked with red crosses for comparison.

Moving the instrument cluster relative to the steering wheel

When changing the position of the steering wheel the instrument cluster position is static. This could cause the steering wheel to conceal parts of the instrument cluster. To eradicate that problem the instrument cluster could move together with the steering wheel. This means that when changing the angle of the steering wheel the whole cluster would move the same angle to always stay in a preferred position (see Figure 5.4 and Figure 5.5).

Figure 5.4 Smaller steering wheel and bigger SID

Figure 5.5 Tilted steering wheel forwards with the instrument cluster following the steering wheel position

6. Discussion

There are a few things that might have had an effect on the results presented in the previous chapter. These aspects are discussed in this chapter.

6.1 Simulator limitations

The simulator has some limitations that might have affected the results of the concept evaluations. First of all, the three 46 inch monitors that the virtual truck cab is displayed on have a limited range downwards. This means that almost the whole instrument panel is hidden for the driver, which may contribute to an unrealistic feeling of the simulator.

Another limitation is the limited speed estimation which is caused by the graphics engine in the simulator, as well as the lack of moving objects and a working speedometer. The driver had no clues about what speed they were driving, and many drivers underestimated the speed. Some drivers even drove off the road when coming too fast into a turn. This could also have affected the results since it makes the simulator feel less realistic and made some people dizzy.

The seat and steering wheel adjustments were limited. The seat had no height adjustment and the length adjustment range is shorter than in the Volvo FH. The steering wheel had no telescope adjustment and could only be tilted. This may have caused some test persons to sit unnaturally, with could have had an effect on the results. Further, there was no resistance in either the pedals or the steering wheel, which some test drivers found notable. There was also a graphics problem with the Head up concept, which made two of the displays flicker. This might have caused some of the negative comments on this concept.

The bird's eye view in the simulator shows more than an all-around camera system would do in reality. This is because a real system would include cameras on the truck's trailer while the simulator shows a view from the "sky" right above the truck. This might have caused the test persons to score this aid higher than they would score a real bird's eye view system.

6.2 Concept differences

It was important to make all concepts feel equal, so that none of the concepts felt more "worked at" and would make for an unfair comparison. This was meant to be done by assuring that all concepts included the same means of visual information, just moved to different locations. This was achieved for concept 2 and 3, but concept 1 – "Combined integrated display" had different driver information than the other ones. This was because the whole instrument cluster could not fit in the 23 inch display. In concept 3 – "Head up on windows", the whole instrument cluster was "projected" on the windscreen because of this reason, which would not have been done in reality. This might have led to lower scores for the head up concept. Concept 3 included a see-through display on the A-pillars that was not included in the other two concepts.

6.3 Evaluation results

The participants' age, length and driving experience are things that might have affected their opinions. The shortest test persons mentioned that the steering wheel covered the instrument cluster in concept 2 – "Minimalistic tradition", which could have been because the head tracking unit was locked at the M50 distance in Z direction. The oldest test persons gave the lowest average score on concept 3 – "Head up on windows", which could mean that the age affects how open drivers are to new technologies.

6.4 Risk factors with CMS

Mirrors are static passive devices that always mirror what is behind them. If a mirror is broken they will still mirror the surroundings whether it is in one piece or a thousand pieces. This means that if the mirrors are for example cracked and stays in the mirror housing during the driving the driver can still see what is in the mirror even if it is not as good as when it is not broken.

A risk factor of using CMS is that if the camera breaks down the image in the monitor will disappear and everything would turn black which is potentially dangerous. There is also a risk that the monitor will malfunction which would cause the same outcome. Another thing is that the cameras have a much smaller area that they capture the rear view with and are therefore more affected by soiling. For example when water splashes up on the mirrors and only a little bit of the total mirror area is concealed the same amount of water would most likely cover a great part of the camera lens and therefore conceal most of the rear view. These are identified problems that are being worked with but they are crucial to find solutions for before implementing Camera Monitor Systems.

6.5 Difficulties

During the project, there were some difficulties that had to be dealt with in order to be able to proceed.

6.5.1 Scope

In the beginning of the project, the scope was to be defined in order to know in what direction to proceed. Since the project is intended for a master thesis work of 30 ECTS, the scope had to be narrowed somewhat to suit the 15 ECTS timeframe. The most difficult aspect was to decide on which types of visual information to focus on, and how thoroughly they were to be analyzed since visual information layout is a very complex subject.

6.5.2 Virtual models

There were some difficulties with importing the concept CAD models into the simulator software. This was done by Oryx Simulations in Umeå and there was a problem regarding what file formats were supported which made it necessary to send very large files that had to be converted. This was not accounted for and delayed the simulator evaluation with almost two weeks.

6.6 Further development

Some things that were excluded in this thesis work need to be examined further. Since this project only evaluated three different conceptual layouts, there might be a need for evaluation of more positions. Another thing that needs to be examined is the exact sizes of the different displays, since this was outside the thesis work scope, as well as the design of the Head up Display information.

Further, a similar evaluation could be done for other transport segments and other truck models than the Volvo FH. Also, aspects like night-time driving, new dashboard design and economy should be taken into consideration when developing the final concept further.

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8. Appendices

Appendix 1

Frågeformulär – layout av ”visuell information”

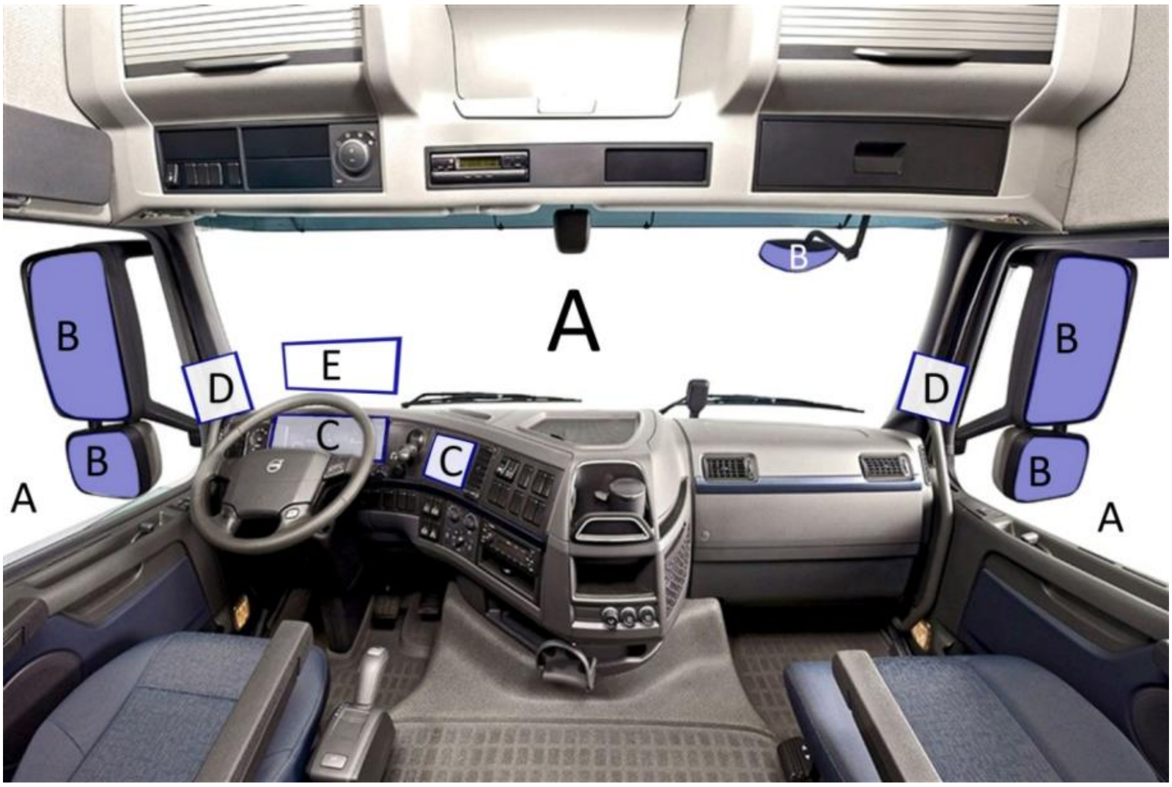
Bakgrund

Vi gör ett examensarbete om hur "visuell information " kan arrangeras på ett bättre sätt än idag. Med "visuell information " menar vi alla typer av visuell information som föraren behöver för att köra fordonet. De beskrivs nedan och är illustrerade på bilden med motsvarande bokstäver.

- sikt för att se omgivningen genom fönsteröppningar **(A)**
- sikthjälpmedel som speglar **(B)**
- information om fordonet via instrument och displayer **(C)**
- synliga varningar som rör fordonet eller omgivningen runt fordonet **(C), (D), (E)**
- Information som projiceras direkt på rutan **(E)**

Det kommer många nya tekniska funktioner och lösningar, och detta gör att det kan vara läge att tänka nytt kring hur "visuell information " arrangeras totalt sett runt förarplatsen.

Svara så utförligt som möjligt på nedanstående frågor. Ta dessutom gärna chansen att ifrågasätta befintliga lösningar genom att jämföra med andra lösningar som ni känner till (hos personbilar, etc.).



Generella frågor

1. Vad anser du om den visuella information av olika slag (enligt bakgrunden ovan) som lastbilsförare får idag under körning?
(vad fungerar bra, vad fungerar mindre bra)

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2. Vilken visuell information (enligt bakgrunden ovan) är speciellt viktig vid olika körsituationer?
(Nämn olika typer av information tillsammans med tillhörande körsituationer som du känner till.)

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Olika typer av visuell information

3.

a) Hur upplever du placeringen av visuell information som är direkt kopplad till körningen i en lastbil idag? (såsom fordonsvarningar, hastighetsmätare, m.m.)

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b) Hur upplever du placeringen av ytterligare visuell information i en lastbil idag? (såsom radiodisplayer, navigation, orderhantering, styrning av påbyggnationer, etc.)

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c) Hur upplever du storleken hos och antalet fönsteröppningar hos en lastbil idag? (så att de motsvarar vad som behövs i olika körsituationer)

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d) Hur upplever du placeringen av speglar och kameradisplayer i en lastbil idag?

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e) Hur upplever du placeringen av visuella säkerhetsvarningar i en lastbil idag?
(såsom varning att du ligger för nära framförvarande fordon eller planerar att byta fil samtidigt som en bil ligger i filen intill)

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Specifika körsituationer

4. Är det någon visuell information som känns överflödig, i så fall vilken och i vilka körsituationer?

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5. Är det någon visuell information som saknas, i så fall vilken och i vilka körsituationer?

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6. Finns det någon visuell information som är svår att förstå i olika körsituationer?
(Nämn vilken information, på vilket sätt och i vilken körsituation)

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7. Finns det någon visuell information som är svår att ta del av i olika körsituationer?
(T.ex. att informationen döljs, är svår att se, inte sitter i synfältet etc.)

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8. Är det något annat du vill tillägga?

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Tack för din medverkan!

Appendix 2 Workshop on layout for visual information

Group 1 - safety					
Direct vision	Feasibility	Relevance for thesis	**Indirect vision**	Feasibility	Relevance for thesis
Move structures			**Birds eye view**		
Move rear-view mirrors	4	5	Customizable Bird's Eye view system	4	4
Move functions that can be moved to where they are not blocking vision	3	5	Goods terminals with cameras that cover the whole terminal and transfer images to vehicles	2	2
Transparency			**Augmented reality**		
Additional window under instrument panel on passenger side	2	2	Enhance/highlight borders, signs and obstructions	4	4
Transparent doors	2	2	Motion detecting sensors activate displays showing hidden objects	3	3
Rear side windows	3	2	**Camera monitor system (CMS)**		
Transparent A-pillars	2	4	Camera mounted on rear of cab	5	5
			Cameras cover all hidden areas	5	5
			CMS with adaptive eye tracking system	3	5
			Co-use camera displays that don't need to show view at all times	5	5
			Show what is behind		
			Displays showing what is behind (A-pillars, panels)	4	5
			Rear camera view projected behind driver	4	5
			Camera displays that can swop between rear view and vision behind display	4	5

Vehicle information	Feasibility	Relevance for thesis	**Secondary information**	Feasibility	Relevance for thesis
Explanatory			**Alternative senses**		
Use pictogram that shows information where it belongs	4	3	Haptic displays	3	2
Speedometer that shows how little time you save when driving fast	5	3	Voice (controlled?) GPS	4	3
Show current speed limit	5	4	Smaller displays, more voice control		
Individualization			**Nomadic devices**		
Individualized appearance (digital/analogue)	3	2	iPad with Volvo apps	4	3
Individualized position (movable cluster)	3	2			
			Cognitive workloads		
Show information when needed			Easier to contact family, friends, colleagues	4	1
Show fuel meter when reaching critical level	4	4			
Show speed info when speed limit changes	4	4	**Navigation**		
			Driver related secondary info (maps, add-ons etc) showed where needed (tweakable HUD)	2	3
Position			Navigation help in HUD	4	5
Information cluster that follows the driver's movements/position	2	2	Navigation in information cluster	5	5
Smaller steering wheel enables new cluster positions (smaller sizes has been tested)	4	4			
Cluster above / beside steering wheel	4	5	**Volvo should not develop SID**		
Head-up display					
Show critical/relevant information in HUD	4	5			
Display on top of instrument panel	5	5			
(Transparent?) display on windscreen	3	4			

Group 2 High Tech					
	Feasibility	Relevance for thesis	**Indirect vision**	Feasibility	Relevance for thesis
Direct vision					
			Display		
Move driver	3	2	Displays integrated in the windscreen	3	4
Sit above the cargo	2	3	The interiorpanel is a display for rearview and much more	3	4
Chair that you can slide from side to side			**Rearview mirrors**		
Transparency	1	3	Half transparent rearview mirrors that reflects what is needed	2	4
Opakt glas	2	4	Rearviewmirrors that are seen when needed	2	5
See through a-pillar	2	3	**Random**		
Transparent doors/roof			Windsheild all the way to the floor	4	4
Projected view	2	3	Sitting backwards	2	4
Replace glass with big display + camera			All around view	4	5
Argumented reality	1	1			
Se through doors with glasses on	**1**	1			
Help with nightvision					

Vehicle information	**Feasibility**	**Relevance for thesis**	**Secondary information**	**Feasibility**	**Relevance for thesis**
Minimize			**Personalize**		
Eliminate screens, show on demand	2	3	Sync information through waze to know where to avoid traffic stockings	2	2
Only show the info that is deviant	5	4	More entertainment like videogames and so on	4	1
Only show the info when it's needed	5	4	Sync your computer with your truck	3	1
No symbols			**GPS**		
Vocie communication	2	3	Redcable	5	2
Receive warnings as an ambient light in the cab	4	3	**On demand**		
Personal settings			Navigation info when it's needed for example in a turn	5	2
Personalized settings saved in the car key	2	1	Show radio and navigation on windscreen when needed	5	2
Solutions of today					
Information in the steering wheel	5	5			
Information through your mobile device	4	3			
Project information on the windsheild	5	5			
Optimize according to task					
1 Thing at a time related to the task the driver is doing	5	4			
Categorize the information according to the driving situation	5	4			

Appendix 3 Morphological Matrix

Concept 1 Minimalistic

Category	Solution / Position					
Direct vision						
Windscreen	Extend windscreen downwards	Windscreen = display				
A-pillars	Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel	Transparent	Panel = display	Windows below panel	Lower on passenger side	Lower on driver side	
Mirrors	Transparent housing	Remove and use CMS				
Doors	Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Indirect vision						
Rearwards	Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)	
Close-up front	Direct vision (lower instrument panel)	CMS (display on mid-top windscreen)	CMS (display top center stack)			
Kerb view	CMS (display on mid-top side window)	CMS (display on passenger door)	CMS (display top center stack)	Additional window in door		
Bird’s Eye view	Birds eye view (cameras on roof)					
Vehicle information						
Gauges	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	
SID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
DID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Indicators, symbols etc.	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices

Secondary information						
Infotainment	On steering wheel	Beside smaller steering wheel	In LCD HUD (top central)	Above/beside steering wheel		Nomadic devices
Navigation	Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support						
WRC (wireless remote)	On A-pillar					
FCW (forward collision)	In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)			
LCS (lane change)	In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)			
Speed limit	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)			

Concept 2 Optimized Direct vision

Direct vision							
Windscreen		Extend windscreen downwards	Windscreen = display				
A-pillars		Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel		Transparent	Panel = display	Windows below panel	Lower on passenger side		
Mirrors		Transparent housing	Remove and use CMS				
Doors		Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Indirect vision								
Rearwards		Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)		
Close-up front		Direct vision (lower instrument panel)	CMS (display on mid-top windscreen)	CMS (display top center stack)				
Kerb view		CMS (display on mid-top side window)	CMS (display on passenger door)	CMS (display top center stack)	Additional window in door			
Bird's Eye view		Birds eye view (cameras on roof)						
Vehicle information								
Gauges		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)		
SID information		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices	
DID information		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-	Nomadic devices	

						use)	
Indicators, symbols etc.		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Secondary information							
Infotainment		On steering wheel	Both sides of smaller steering wheel	In LCD HUD (top central)			Nomadic devices
Navigation		Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support							
WRC (wireless remote)		On A-pillar					
FCW (forward collision)		In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)			
LCS (lane change)		In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)			
Speed limit		In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)			

Concept 3 Optimized Indirect vision

Direct vision							
Windscreen		Extend windscreen downwards	Windscreen = display				
A-pillars		Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel		Transparent	Panel = display	Windows below panel	Lower on passenger side		
Mirrors		Transparent housing	Remove and use CMS				
Doors		Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Indirect vision							
Rearwards		Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)	
Close-up front		Direct vision (lower instrument panel)	CMS (display on mid-top windscreen)	CMS (display top center stack)			
Kerb view		CMS (display on mid-top side window)	CMS (display on passenger door)	CMS (display top center stack)	Additional window in door		
Bird's Eye view		Birds eye view (cameras on roof)					
Vehicle information							
Gauges		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	
SID information		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
DID information		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Indicators, symbols etc.		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices

Secondary information							
Infotainment		On steering wheel	Both sides of smaller steering wheel	In LCD HUD (top central)			Nomadic devices
Navigation		Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support							
WRC (wireless remote)		On A-pillar					
FCW (forward collision)		In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)			
LCS (lane change)		In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)			
Speed limit		In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)			

Concept 4 Dynamic personalized

Direct vision						
Windscreen	Extend windscreen downwards	Windscreen = display				
A-pillars	Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel	Transparent	Panel = display	Windows below panel	Lower on passenger side		
Mirrors	Transparent housing	Remove and use CMS				
Doors	Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Rearwards	Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)	
Close-up front	Direct vision (lower instrument panel)	CMS (display on mid-top windscreen)	CMS (display top center stack)			
Kerb view	CMS (display on mid-top side window)	CMS (display on passenger door)	CMS (display top center stack)	Additional window in door		
Bird's Eye view	Birds eye view (cameras on roof)					
Vehicle information						
Gauges	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
SID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
DID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Indicators, symbols etc.	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices

Secondary information						
Infotainment	On steering wheel	Both sides of smaller steering wheel	In LCD HUD (top central)			Nomadic devices
Navigation	Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support						
WRC (wireless remote)	On A-pillar					
FCW (forward collision)	In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)	Windscreen/instrument panel (customized)		
LCS (lane change)	In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)	Windscreen/instrument panel (customized)		
Speed limit	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Windscreen/instrument panel (customized)		

Concept 5 Head Up

Direct vision							
Windscreen		Extend windscreen downwards	Windscreen = display				
A-pillars		Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel		Transparent	Panel = display	Windows below panel	Lower on passenger side	Lower on driver side	Adjustable
Mirrors		Transparent housing	Remove and use CMS				
Doors		Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Indirect vision							
Rearwards		Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)	CMS (displays on top windscreen)
Close-up front		Direct vision (lower instrument panel)	CMS (display on mid-top windscreen)	CMS (display top center stack)			
Kerb view		CMS (display on mid-top side window)	CMS (display on passenger door)	CMS (display top center stack)	Additional window in door		
Bird's Eye view		Birds eye view (cameras on roof)					
Vehicle information							
Gauges		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	
SID information		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
DID information		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Indicators, symbols etc.		In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices

Secondary information							
Infotainment		On steering wheel	Both sides of smaller steering wheel	In LCD HUD (top central)			Nomadic devices
Navigation		Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support							
WRC (wireless remote)		On A-pillar					
FCW (forward collision)		In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)			
LCS (lane change)		In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)			
Speed limit		In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)			

Concept 6 Economic CMS

Direct vision						
Windscreen	Extend windscreen downwards	Windscreen = display				
A-pillars	Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel	Transparent	Panel = display	Windows below panel	Lower on passenger side		
Mirrors	Transparent housing	Remove and use CMS				
Doors	Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Indirect vision						
Rearwards	Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)	
Close-up front	Direct vision (lower instrument panel)	CMS (display on mid-top windscreen)	CMS (display top center stack)			
Kerb view	CMS)	CMS	CMS	Window in door		
Bird's Eye view	Birds eye view (cameras on roof)					
Vehicle information						
Gauges	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	
SID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
DID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Indicators, symbols etc.	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices

Secondary information						
Infotainment	On steering wheel	Both sides of smaller steering wheel	In LCD HUD (top central)			Nomadic devices
Navigation	Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support						
WRC (wireless remote)	On A-pillar					
FCW (forward collision)	In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)			
LCS (lane change)	In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)			
Speed limit	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)			

Concept 7 High Tech

Direct vision						
Windscreen	Extend windscreen downwards	Windscreen = display				
A-pillars	Transparent	Displays show what is behind pillar	Use to show information	CMS displays on pillars		
Instrument panel	Transparent	Panel = display	Windows below panel	Lower on passenger side		
Mirrors	Transparent housing	Remove and use CMS				
Doors	Additional windows beneath handle	Extend side windows downwards	Display on passenger door showing hidden area			

Indirect vision						
Rearwards	Mirrors with adjustable size	CMS (display/projected behind driver)	CMS (displays on A-pillars)	CMS (displays on each side of steering wheel)	CMS (all displays in center)	CMS (mid-top windscreen)
Close-up front	Direct vision (lower instrument panel)	CMS (mid-top windscreen)	CMS (display top center stack)			
Kerb view	CMS (display on mid-top side window)	CMS (display on passenger door)	CMS (display top center stack)	Additional window in door		
Bird's Eye view	Bird's eye view (cameras on roof)					
Vehicle information						
Gauges	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Instrument cluster
SID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
DID information	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices
Indicators, symbols etc.	In projected HUD (on windscreen)	In LCD HUD (top central)	On steering wheel	Above/beside steering wheel	On A-pillar display (co-use)	Nomadic devices

Secondary information						
Infotainment	On steering wheel	Both sides of smaller steering wheel	In LCD HUD (top central)			Nomadic devices
Navigation	Instrument cluster (behind steering wheel)	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)	Vocal information	Nomadic devices
Driver support						
WRC (wireless remote)	On A-pillar					
FCW (forward collision)	In projected HUD (on windscreen)	On steering wheel	On A-pillar display (co-use)			
LCS (lane change)	In projected HUD (on windscreen)	Lamps on A-pillars	On A-pillar display (co-use)			
Speed limit	In projected HUD (on windscreen)	In LCD HUD (top central)	On A-pillar display (co-use)			

Appendix 4 Evaluation results

1. What is your first impression when driving this concept in a country road environment?			
Drivers	**Avg:**	**Std. Dev.**	**Comments:**
Reference	3,80	0,75	
			-I really like it, this truck is made for country road driving 8/12
Concept 1	2,33	0,85	
			- I am not used to look down to the right for information and it makes me lose focus on the road which feels dangerous 11/12
			- The driver information is to messy and small, it's hard to see it 3/12
Concept 2	3,75	0,70	
			- The displays on the left hand side disturbs the direct vision 5/12
			- It is very easy to get used to this Concept because it resembles the FH 3/12
			- Good and natural positioning of the rear view devices 5/12
			- You get more direct vision without the mirrors 3/12
Concept 3	2,83	1,03	
			- The visual information feels very scattered and messy 5/12
			- The right main rear view device is disturbing me 3/12
			- Spontaneously it feels okey 3/12
			- I don't like the position of the SID 3/12
			- I don't like the position of the cluster 5/12
Experts			
Reference	4,50	0,50	
			- The mirrors are very good 2/4
Concept 1	2,50	1,26	
			- Feels awkward to look down to the right to see the rear views 2/4
Concept 2	4,00	0,71	
			- I like the mirror positions 2/4
Concept 3	3,33	0,94	
			- Easy to find everything, good positions 2/4
			- It feels scattered and messy 2/4
			- Everything is gathered, less head movements 2/4

2. What do you think about the possibility to assimilate different information that you need during country road driving in this concept?			
Drivers	**Avg.**	**Std. dev.**	
Reference	4,17	0,55	
			- It feels easy to assimilate the information, I am used to the layout and it is easy to get all the information you need 5/12
			- The rearview mirrors works very well, they conceal some direct vision but not so much because the mirror houses are so thin 6/12
Concept 1	2,50	1,26	
			- It feels dangerous to look down to the right while driving, it takes attention away from the road and make it hard to keep track on the road environment, 8/12
			- It feels easy to get an overall view of the trucks surroundings 5/12
Concept 2	3,64	0,77	
			- It feels easy to assimilate and find the visual information I need because the positions are similar to how it is positioned in trucks today 8/12
			- The new positions for the camera displays gives more direct vision compared to having mirrors 3/12
Concept 3	3,00	1,29	
			- It is good that the information is gathered together but you need to get used to the layout 5/12
			- There is too much information at the same time, it does not feel logical and it is not good that the rear view displays are positioned asymmetrical 5/12
			- It feels weird with the placement of the right rear view device, I am not used to look there and I lose all the direct vision out of the right window when I look there instead 5/12
			- Good positioning of the instrument cluster, it feels easy to use and it is good that you can see through the cluster and the SID 4/12
Experts	**Avg.**	**Std. Dev.**	
Reference	3,50	0,50	
			- I really like the mirrors and it's easy to use them 2/4
Concept 1	2,67	1,25	
Concept 2	4,75	0,43	
			- I know where to look and the visual information I get is good 2/4
			- It resembles the FH which makes the mirror placements feel natural and easy to use 3/4
Concept 3	4,00	1,00	
			- It feels easy to assimilate the information 2/4
			- I don't have to move my head so much to get the information I need 2/4

3. What is your first impression when driving this concept in a maneuvering environment?			
Drivers	**Average:**	**Std. Dev.**	
Reference	3,83	0,90	
			- The rear view mirrors are very good 4/12
			- The FH is very easy to handle in this environment 3/12
			- Thanks to the big windows really helps the direct vision 4/12
Concept 1	2,36	0,88	
			- I lose focus on the road when I look on the display 7/12
			- It's hard to find the rear view displays 3/12
Concept 2	3,83	0,69	
			- The position of the rear view devices feels good because it is natural and it is like you are used to 6/12
			- I really like the Bird’s Eye view when maneuvering 5/12
Concept 3	2,82	1,19	
			- I find myself looking at the position of the conventional mirrors instead of the new positions 4/12
			- To much information, it feels hard to take in 4/12
			- It is very hard to know where to know where to look 5/12
Experts			
Reference	3,25	0,83	
Concept 1	2,00	0,00	
			- Feels weird, I want the left rear view to the left 2/4
Concept 2	4,00	1,22	
			- Very good overview of what is happening around the vehicle 2/4
Concept 3	3,67	0,47	

4. What do you think about the possibility to assimilate different visual information that you need for maneuvering at low speeds?			
Drivers	**Average:**	**Std. Dev.**	
Reference	3,73	0,45	
			- I mostly use the mirrors in this environment and they are good because I can adjust them and they give a good overall view of the truck's surroundings 7/12
			The mirror houses are thin and have a big gap in between them, this makes it easier to see what is happening behind them 3/12
Concept 1	2,91	1,00	
			- I find the information but the position does not feel good or logical, it is hard to drive with it because I forget to look at the road which could be potentionally dangerous 6/12
			- I don't feel used to position but it is good that the information is gathered in one place 4/12
Concept 2	4,18	0,39	
			- It feels very easy and logical to assimilate the visual information, the positions feels natural and closer in this concept 9/12
			- The Bird's Eye view is helping a lot and have a good position 4/12
Concept 3	3,00	1,21	
			- It feels hard and unlogical to find the information I need, this much information disturbs me 6/12
			- The all-around helps me a lot 4/12
			- It helps to be able to see through the A-pillars 3/12
Experts	**Avg.**	**Std. Dev.**	
Reference	3,75	0,43	
			- It feels good, the mirrors are very good for this kind of driving 2/4
Concept 1	2,75	0,43	
			- It does not feel good to find the visual in the middle 2/4
			- It distracts me, I just use it really quickly and then look at the road 2/4
Concept 2	4,50	0,87	
			- It feels lika a natural, logical and relevant way to assimilate information 3/4
Concept 3	3,25	0,43	
			- The SID and cluster distracts me 2/4
			- It is hard to get used to the new positions 2/4

5. What is your first impression to reverse the truck with the given visual information in this concept?			
Drivers	**Average:**	**Std. Dev.**	
Reference	3,75	0,83	
			- It works very well with the mirrors on the FH 4/12
Concept 1	2,60	1,36	
			- When reversing it feels good to have the information gathered 3/12
			- The Bird's Eye view works very well when reversing 5/12
			- I loose the surroundings of the truck when I look in the display while reversing 6/12
Concept 2	3,92	0,64	
			- The rear view device's positions resembles the FH and are natural and logic 7/12
			- The Bird's Eye view works very well when reversing 6/12
Concept 3	3,18	1,19	
			- I am not used to the positions of the rear view devices and they are hard to spot 5/12
			- The Bird's Eye view display is good when reversing 3/12
Experts			
Reference	3,75	0,43	
			- The rear view mirrors are very good 2/4
Concept 1	3,25	0,83	
			- It feels wierd and potantially dangerous to have all visual information to the right 3/4
			- It is good that the information is gathered 3/4
Concept 2	4,50	0,50	
Concept 3	3,50	0,50	

6. What are your thoughts about this concept in general?			
Drivers	**Avg.**	**Std. Dev.**	
Reference	3,75	0,72	
			- I really like it, it feels logical and have all the information you need 5/12
			- I really like the visual information I get from the mirrors and it's good that you can see in between them so much 4/12
Concept 1	2,58	1,11	
			- It feels wierd to look to the down to the right to get the visual information, you loose focus and control of what is happening around the vehicle which feels dangerous 9 /12
			- When I used the display it was easy to get an overall view of the trucks surroundings 3/12
			- It is good that there is nothing that disturbes the direct vision without mirrors 3/12
Concept 2	4,00	0,71	
			- It feels logical and similar to what you are used to, the information is presented closer to you and is easy to find 6/12
			- The position of the instrument cluster is not good, the steering wheel conceals it 4/12
			- It is good to don't have any mirrors on the outside so you don't have to worry about hitting something with them 4/12
Concept 3	2,67	1,18	
			- There is a lot of information in the windscreen and it feels messy 6/12
			- The "see-through" displays on the A-pillars gives a much better view of the truck's surroundings 5/12
Experts			
Reference	3,75	0,76	
			I get the information I need where I want it 2/4
Concept 1	2,25	0,43	
Concept 2	4,25	0,83	
Concept 3	3,25	0,83	

7. What do you think about the possibility to see through the windows in this concept?			
Drivers	**Average:**	**Std. Dev.**	
Reference	3,91	0,76	
			- The direct vision is not optimal in the through the passanger window 3/12
			- The windows are very big and the A-pillars are thin, that makes it easy to see what's needed and gives a good overall vision 7/12
Concept 1	4,50	0,65	
			- The direct vision is perfect, there is nothing disturbing it. 12/12
Concept 2	4,42	0,49	
			- The instrument cluster disturbs the direct vision a little 3/12
			- Nothing disturbs the direct vision which is really good 11/12
			- Make sure that the A-pillars don't get thicker because of the displays 4/12
Concept 3	3,33	1,03	
			- The direct vision is good because there are no mirrors and you can see through the A-pillars 5/12
			- The projected information distracts and disturbs the direct vision , it is hard to see through them 7/12
Experts			
Reference	4,00	0,43	
Concept 1	4,75	0,43	
			- Can't be much better, nothing is in the way 4/4
Concept 2	4,5	0,50	
			- Very good without the mirrors but the cluster disturbs the direct vision a little 4/4
Concept 3	4,25	0,43	
			- The SID and navigation disturbs the direct vision a little 3/4
			- It is great without the mirrors 3/4

8. What do you think about the layout for the indirect vision in this concept?			
Drivers	**Avg.**	**Std. Dev.**	
Reference	4,08	1,35	
			- It is good, feels natural 3/12
			- The layout is really good and the mirrors are thin and does not take that much direct vision 9/12
Concept 1	2,58	1,32	
			- It is good that the information for indirect vision is gathered but the position of the dislpay feels dangerous because I loose focus of the road 6/12
			- I don't like it 3/12
Concept 2	4,25	0,60	
			- The layout feels natural and logical, it didn't disturb the direct vision much and is easy to get used to 8/12
Concept 3	2,64	1,23	
			- The indirect vision feels scattered and is hard to find when it is assymmetrical 7/12
Experts			
Reference	3,50	0,50	
			- It feels logical and natural 3/4
Concept 1	2,00	0,71	
			- It is dangerous to look away from the road that much 2/4
Concept 2	4,50	0,50	
			- Logical placement, they are on the right sides 3/4
Concept 3	2,75	0,83	
			- I don't like the asymmetry 2/4
			- Difficult to understand that the right rear view is in the middle 2/4

9. What do you think about the positioning of the driver information (such as the instrument cluster)?			
Drivers	**Avg.**	**Std. Dev.**	
Reference	3,67	0,75	
			- It is okey but the steering wheel conceals some of the information 8/12
Concept 1	2,36	1,23	
			- It does not feel good to look down to the right to see the cluster, it could be dangerous because you lose the focus on the road 6/12
			- The information was good when I looked there, it is not as scattered as the FH 4/12
Concept 2	2,58	0,95	
			- I don't like this position for the instrument cluster because it disturbs the direct vision 9/12
Concept 3	2,67	1,25	
			- I like the position because you see it regardless of the settings in your seat 5/12
			- I don't like the position because it disturbs the direct vision and should be moved further down 7/12
Experts			
Reference	3,75	0,43	
			-It's easy to find and is close to the line of sight 3/4
Concept 1	2,25	0,83	
Concept 2	3,00	1,00	
			- It steals some direct vision forwards 2/4
Concept 3	3,75	1,09	
			- I like the position in this concept because it is close to the line of sight which feels safe 3/4
			- It might disturb the direct vision to much 3/4

10. What do you think about the positioning of the secondary information such as the navigation?			
Drivers	**Avg.**	**Std. Dev.**	
Reference	3,50	0,65	
			- It is mostly used for storing stuff in which compromises the function 3/12
			- The position is good and is easy to find when I need it 8/12
Concept 1	2,83	1,14	
			- The position is similar to the one in the FH and is okey because the SID is not so important while driving 5/12
			- It is hard to find the SID in the display 3/12
Concept 2	3,83	0,55	
			- I like the position because it does not disturb my attention or the direct vision, and I don't have to turn my head so much to see it 9/12
Concept 3	3,25	1,09	
			- I like the position because it does not disturb my attention or the direct vision 9/12
Experts			
Reference	3,00	0,71	
			- The SID is too far away 3/4
Concept 1	2,50	0,87	
Concept 2	3,00	0,71	
			- The position is good because it does not disturb but is easy to find 2/4
Concept 3	3,50	1,50	
			- It is not that important so it shouldn't disturb the direct vision so much 2/4
			- I like it because it is close to the line of sight 2/4

11. What do you think about the relation between the different kinds of visual inputs?			
Drivers	**Avg.**	**Std. Dev.**	
Reference	3,75	0,72	
			-I feel used to the relations and it feels logical 10/12
Concept 1	2,33	1,03	
			- It feels messy and to compact, it's hard to find what you're looking for and you lose focus of the direct vision 6/12
Concept 2	3,83	0,55	
			- The information is close to you and in positions I am used to which feels logical 8/12
			- I did not like the position of the instrument cluster 3/12
Concept 3	2,83	0,99	
			- The information is to scattered and I don't like the asymmetry and the horizontal relation between the main- and wide angel rear view devices 7/12
			- It is too much information in the same place 3/12
Experts			
Reference	3,50	0,87	
			- The relation feels good and logical 3/4
Concept 1	3,00	0,82	
			- Less prioritized information takes too much space 2/4
Concept 2	4,25	0,43	
			- The relation feels logical 3/4
			- I find the information where I expect it to be 2/4
Concept 3	3,50	0,87	
			- I don't have to turn my head so much in this concept 2/4

12. What would be your total grade for the concepts now that you have tried them all?			
Drivers	**Avg.**	**Std. Dev.**	
Reference	3,33	0,75	
			- The direct vision is very good and you see everything you need 3/12
			- I liked concept 2 better 3/12
			- The mirrors disturbs the direct vision to much 4/12
			- I like the placement of the indirect vision because it is logical 3/12
Concept 1	2,25	1,01	
			- It is too much information gathered in the same place, it feels messy 3/12
			- You focus too much on the display instead of the road which feels dangerous 5/12
			- It feels good to have the information gathered in one place 2/12
Concept 2	3,83	0,37	
			- I like the rear view devices placements because it is logical and it resembles the FH and you get a better direct vision without the mirrors 9/12
			- I did not like the position of the instrument cluster because it disturbs the direct vision 4/12
			- My favourite concept! 5/12
Concept 3	2,69	1,20	
			- I like the position of the instrument cluster 4/12
			- The instrument cluster was disturbing the direct vision 3/12
			-The information felt very messy and scattered and I don't like the asymmetry for the rear view devices and it disturbed the direct vision 6/12
Experts			
Reference	3,25	0,83	
Concept 1	1,50	0,50	
			- It does not feel logical to look down to the right to get the visual information 3/4
			- I lose focus from the road when looking at the display 2/4
Concept 2	4,50	0,50	
Concept 3	3,00	0,71	

13. What do you think about the possibility to get used to an alternative layout?	
Drivers	
	- I think I would get used to new layouts pretty quickly and easily 6/12
	- Concept 2 was the concept that was easiest to get used to 5/12
	- Concept 1 is very hard to get used to 6/12
	- It is hard to say, it depends a lot on the concept and how long you get to test it 3/12
Experts	