Mirror replacement in trucks

Master of Science Thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, June 2012

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[The cover page figure shows all mirrors that are on today’s Volvo trucks and are further explained in chapter 1.1]

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ABSTRACT

Today it is not allowed to exchange the main and wide angle mirrors on trucks with a Camera Monitor System (CMS). A standardization work within the ISO is though in progress that will set the minimum demands for such a technology change and will serve as basis for the regulation change to come that will allow the replacement of mirrors for a CMS. For Volvo Global Trucks Technology (Volvo GTT) it is important not to just consider the minimum demands for a camera monitor system, but also to consider what extra functionality and performance needed for such a system to increase the quality impression for drivers and fleet owners.

An important factor to consider regarding the quality of a CMS is what field of view that is shown to the driver and how it is displayed. The field of view is what is captured by the camera and the minimum field of view is set by regulation. In addition the mirrors today show a larger field of view than what is set by regulation, and it can also be expanded even more by moving the head. This needs to be considered when designing a CMS. How the field of view is displayed to the driver is determined by how the monitor is placed inside the truck cab. How color and details are shown are also of concern when designing a CMS, since it determines how realistically objects are presented and that critical objects can be detected in time to avoid accidents.

This project has been focused on investigating where to position cameras and monitors and these have been evaluated on legal demands, physical and cognitive ergonomics, how the direct visibility is affected having a CMS instead of mirrors and on a number of other requirements. There have not been in-depth technical evaluations on components in a CMS but rather functional evaluations on the system as a whole. This is something to investigate further when making physical prototypes of such a system and performing tests. These are issues that also will affect the quality impression of a CMS.

ACRONYMS

CAVA – Catia V5 Automotive Extensions Vehicle Architecture

CCD – Charged Coupled Device

CMOS – Complementary Metal Oxide Semiconductor

CMS – Camera Monitor System

ECU – Electronic Control Unit

FH – Front High (see 3.3.3)

FL – Front Low (see 3.3.3)

FM – Front Medium (see 3.3.3)

FoV – Field of View

GTT – (Volvo) Group Trucks Technology (formerly known as 3P)

HMI – Human-Machine Interface

HVS – Human Visual System

ISO – International Standardization Organization

LCD – Liquid Crystal Display

LED – Light Emitting Diode

1 INTRODUCTION

In the rapidly changing and competitive automotive industry it is important to provide the market with the latest technology. For Volvo GTT to be able to constantly deliver high-end products they need to be aware of what is happening in the automotive area at the moment and be able to predict what is going to happen in the future. The ability to understand and make use of the latest technological advances is crucial for an automotive company striving to be among the top players on the high-end market.
In recent years digital technology in automotive applications have increased and impacted many parts of a truck. The technology has enabled performance improvements of the vehicles and provides better working conditions for the drivers. These new technologies are also pushing for new international standards and legislations in the area of indirect vision devices. This opens up many opportunities for Volvo GTT in their effort to stay competitive and develop products aligned with Volvos core values; quality, safety and environmental care.

1.1 Background

There are several different types of camera monitor systems available on the market today. The areas of application are mostly home and public surveillance or vehicle safety systems aiding the indirect visibility (i.e. field of view that is not seen directly by the human eye). On trucks today there are two types of mirrors that can be replaced with a CMS: the curb-side mirror (class V) and the front mirror (class VI), see Figure 1. These monitor systems are generally operated in low-speed situations. The regulations and laws today do not allow the replacement of the main mirror (class II) and wide-angle mirror (class IV) to a CMS. These mirrors operate in both low and high speed maneuvering and are highly important for the truck drivers' indirect vision. A change of regulation is however expected in the near future and is supported by an ongoing ISO-work that will set the minimum requirements on a CMS being able to replace all types of mirrors on both light and heavy vehicles.

Figure 1: Different mirror types found on a Volvo FH truck (Volvo GTT, 2012)

1.2 Purpose

The purpose of this master thesis is to investigate and illustrate with concepts what factors that will be important for Volvo GTT to consider when making the shift from class II and class IV mirrors to a CMS.

1.3 Project limitations

The project will focus on the functional development of a stand-alone CMS and the factors affecting this. The project will not in-depth treat all of the technical implementation aspects or the production aspects due to the project treating only the early phases of a product development process. CMS concepts will be created to illustrate monitor positions and dimensions inside the cab as well as camera positions on the exterior of the cab.
Financial and cost related aspects of the CMS will not be covered in detail and should not be a major constraint for the project. The aim of the project is to investigate what requirements exist on the functions and the use of this system and what requirements this will imply for the technical performance of the system.

1.4 Thesis outline

- **Introduction**: this chapter introduces the reader to what is the background and aim of this project
- **Methods and tools**: this chapter describes the methods and tools used throughout the project
- **Theory**: this section aims to present the reader to foundational theory on CMS:s and the different knowledge areas needed to put requirements on the system
- **Market analysis**: this section gives knowledge in what is on the market today for similar systems and what competitors that are present
- **Product requirements analysis**: In this chapter the CMS is broken down to its core functions and their respective requirements
- **Concept development**: Presents how the different concepts are built up
- **Concept evaluation**: Describes how to evaluate concepts against functional requirements
- **Result from concept evaluation**: Presents the results and winning concepts of the concept evaluation
- **Discussion, conclusions and recommendations for further work:** A broader analysis of the system shift from today’s mirrors to a CMS, and also the most important findings from this project and recommendations for further development

2 METHODS AND TOOLS

The method chapter aims to describe how the work process of the master thesis has been carried out and what methods that have been used.

2.1 Work Process

The master thesis work procedure was based on the product development process given by Ulrich and Eppinger (2008) and can be seen in Figure 2. This process was used in order to result in a technology-push product where the concept development assumes a given technology, which is the CMS. This master thesis has a practice oriented research objective and a qualitative approach utilized in a product development project. The method of data collection has been chosen to gain a high validity and reliability through a description of the case and triangulation in the data collection. Triangulation of methods is resulting in greater confidence of the findings and the results (Bell & Bryman, 2011).

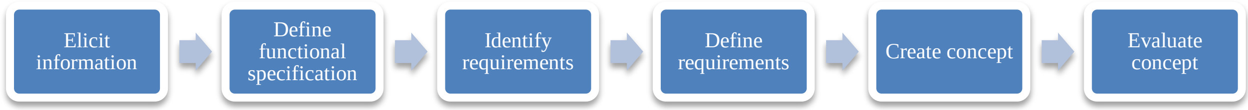

Figure 2 : Work procedure foundation

2.2 Data collection and analysis

This chapter will describe how data were collected, analysed and used during the work process.

2.2.1 Interviews

Interviews have continuously been carried out with a number of key persons inside the Volvo GTT organization. These have been conducted both in informal ways such as shorter discussions regarding a specific topic or problem and in semi-structured ways where presentation material has been presented and questions asked about this. A list of interviews and interviewees can be found in the bibliography.

2.2.2 Documentation

Several different sources of documentation have been consulted in the work process. Internal documentation, reports and drawings at Volvo GTT, research papers, regulations, standards and websites have all been used as input to the thesis. A full list of documentation used can be found in the bibliography.

2.2.3 Questionnaire

A questionnaire with accompanying presentation material was sent out to six key persons located at other sites within the Volvo Group working with HMI, Visibility and Driver Interface to get feedback from other business units within the company. The questionnaire and the results from it can be seen in Appendix G.

2.2.4 Computer aids

To create and evaluate concepts Catia V5 has been used together with CAD-models of a Volvo FH truck and traffic scenarios. It has been used as a graphical tool to visualize concepts but also to evaluate what field of view is needed to be covered by a CMS and how this affects certain technical aspects of the CMS. Catia V5 has also been used with CAD-models of the Volvo FH cab interior to investigate monitor positioning inside of the cab. Several aspects have been studied such as physical ergonomics, direct visibility, driver behaviour and how these interact and comply with standards, regulations and industry practise. For most calculations Microsoft Excel spread sheets have been used.

A tool also used is the Catia V5 extension CAVA (Catia V5 Automotive Extensions – Vehicle Architecture). It is a tool that can be used to investigate indirect vision devices in automotive applications and is used to virtually certify rear-view vision devices. It was used with models of the rear-view mirrors to investigate what field of view is covered in conventional mirrors.

2.2.5 Kesselring evaluation

For evaluation of concepts created a Kesselring evaluation matrix was used which can be found in Appendix B. Criteria were created based on the requirements specification list and grouped together according to their feature area. Weight were put on both the individual criteria and the criteria group which added an extra dimension of weighting compared to the most commonly used Kesselring matrix. This was implemented because of the existence of the criteria groups and their difference in importance.

3 THEORY

This chapter will bring forward important theory and reasoning that will be the base for the report.

3.1 Mirrors and the human visual system

In this chapter basic mirror optics will be explained as well as how the human eye and the human visual system functions. It will provide a framework for comparing the performance of conventional mirrors and a CMS.

3.1.1 Visual acuity and angular resolution of the human eye

The theoretical detection distance of objects by the human eye is limited by its ability to distinguish points of an object that are located at a small angular distance from each other. This is usually referred to as the angular resolution. The smallest angular resolution that the human eye can resolve is usually said to be around 1 minute of arc (arc-min) which is 1/60th of a degree illustrated in Figure 3. (Walker, 2005) This means that the human eye is able to resolve a spatial pattern separated by one arc-min and that objects occupying less than one arc-min of the visual field cannot be seen. To obtain a Swedish driver's license the angular resolution that the drivers needs to be able to resolve with corrective aids such as glasses or contact lenses is 1,25 arc-mins. (Transportstyrelsen)

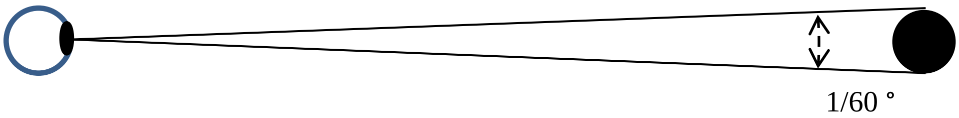

Figure 3 : The smallest angular resolution that the human eye can resolve is 1/60°

3.1.2 Mirror magnification factor and angular resolution

The angular resolution of today's rear-view mirrors, thus the level of detail that can be perceived is mainly dependent on the magnification factor of the mirror. A straight glass mirror will not magnify the field of view and does not affect the angular resolution and the ability for the driver to perceive details compared to direct visibility. With a convex mirror glass the field of view will be expanded and the level of detail that can be perceived will decrease, the objects seen will become smaller. The magnification factor can be calculated using Equation 1. In Figure 4 the mirror variables are defined and basic mirror optics are illustrated.

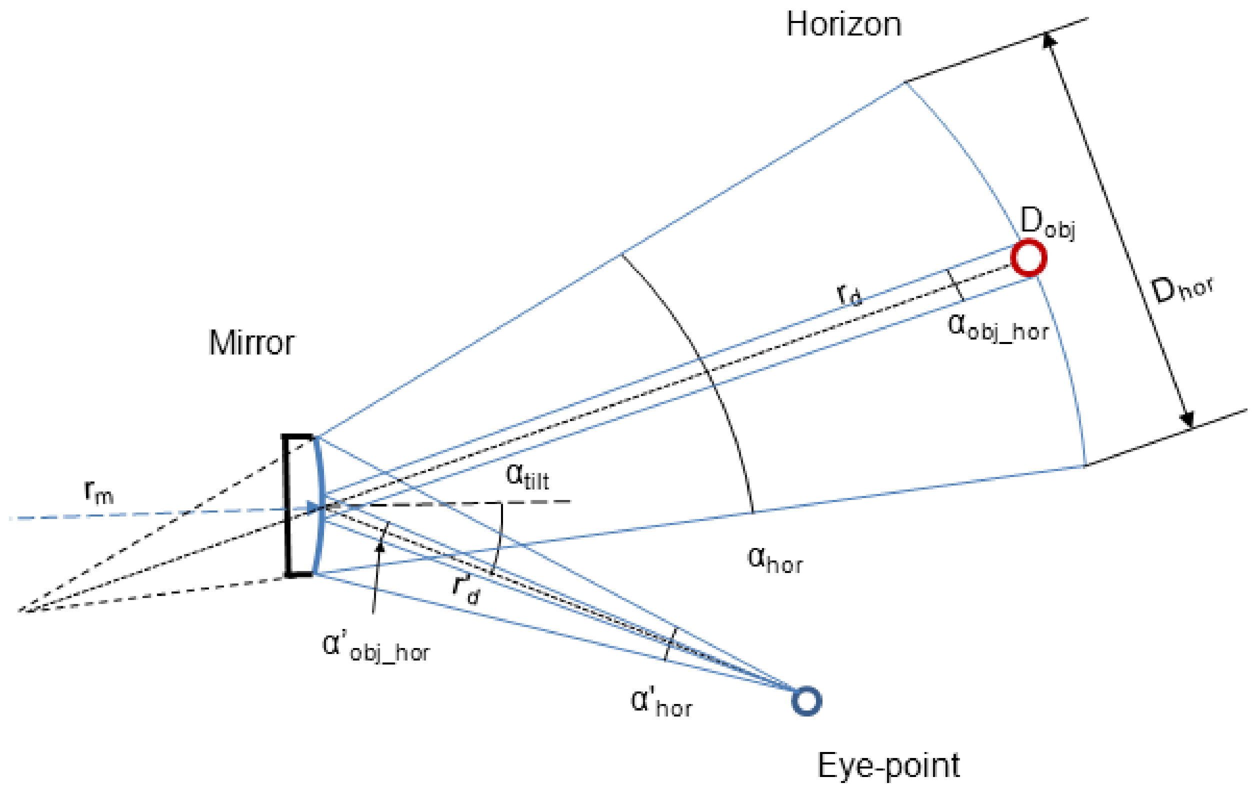

Figure 4 : Mirror optics

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Equation 1 : Mirror magnification factor (Platzer, 1995)

$$M \approx \frac{1}{1+\left(\frac{2r'_d}{r_m}\right)}$$

$where:$
$r_m - mirror\ radius$ [m]
$r'_d - distance\ between\ eye-point\ and\ mirror$ [m]
$M - mirror\ magnification\ factor$

With a magnification factor less than 1 the level of detail that can be perceived will decrease and the angular resolution of the field of view will decrease according to Equation 2.

Equation 2 : Mirror angular resolution

$$\sigma_{mirror} = \frac{\sigma_{eye}}{M * \cos(\alpha_{tilt})}$$

$where$:
$\sigma_{mirror} - mirror\ angular\ resolution$ [arc-mins]
$\sigma_{eye} - visual\ acuity\ or\ angular\ resolution\ of\ the\ human\ eye$ [arc-mins]
$\alpha_{tilt} - mirror\ tilting\ angle$ [°]

3.1.3 Mirror detection distance

A way of comparing the size of objects as perceived in a CMS with conventional mirrors to make sure that objects are detected at the same distance is to look at the so called theoretical detection distance. The theoretical detection distance is the farthest distance on where the human eye can register an object of a given size. This is dependent on the visual acuity or angular resolution of the human eye and any field of view altering objects used such as mirrors or lenses.

The equation used to calculate the detection distance for conventional mirrors can be seen in Equation 3.

Equation 3 : Detection distance calculation for mirrors

$$r_d = \frac{\frac{D_{obj}}{2}}{\tan\left(\frac{\alpha_{obj\_hor}}{2 * M * \cos(\alpha_{tilt})}\right)}$$

$where$:
$r_d - detection\ distance$ [m]
$D_{obj} - diameter\ of\ the\ object$ [m]
$\alpha_{obj\_hor} - given\ object\ angular\ size\ at\ detection\ distance$ [°]

3.1.4 Object size in mirrors

The size of an object in the mirror as seen by the driver will influence at what distance objects can be detected by the driver. This will be determined by the size of the object, the object-mirror and eye-point-mirror distances, the mirror radius and the angle between the mirror surface normal and the line between the eye-point and the mirror mid-point.

The angular size of the object as seen in mirrors can be calculated using Equation 4. This means that the eyes ability to detect and resolve objects seen in a mirror will be decreased with increasing mirror curvature.

Equation 4 : Object angular size as seen in mirrors

$$\alpha'_{obj\_hor} = 2 * M * \tan^{-1}\left(\frac{D_{obj}}{2 * r_d}\right) * \cos(\alpha_{tilt})$$

3.1.5 Depth cues and depth perception

For the human visual system (HVS) to be able to perceive depth and see things in three dimensions it uses several aids which are called depth cues. These are ways for the HVS to interpret different characteristics and features in a static image creating a three dimensional image where distances can be perceived. In a video system it will also provide valuable input for recognizing motion and speed among objects in the image. Monocular depth cues are depth cues that can be used when observing a scene with only one eye, and when using two eyes a number of additional depth cues can be used. The monocular depth cues are (Stockman):

- *Linear perspective* – Parallel lines converging at infinity are used to determine relative distance between two objects.
- *Motion parallax* – When an observer moves the movement of the observed objects in relation to the background and each other provides information to determine relative distance.
- *Interposition* – When objects block each other this provides information to determine relative distance.
- *Shading* – Shadows and effects from light sources on objects and their environment helps determining their relative position.
- *Relative size* – Two objects that are known to have the same size but appear to be of different size provides a cue for determining their relative distance.
- *Relative height* – The vertical positioning of objects in respect to a visible or not visible horizon provides information on the relative distance.
- *Aerial perspective* – Contrast, brightness and color can provide information regarding the relative distance to objects.
- *Texture* – textural detail is perceived differently depending on distance.
- *3D Structure from motion* – As objects move towards or away the observer they change in size and the speed at which they change in size will provide information that can be used to calculate the relative distance of objects.

3.2 Camera monitor system

A CMS is usually built up by cameras, electrical control units (ECUs) and monitors and information flows through the system as shown in Figure 5. Each system component will be further described in the following chapters.

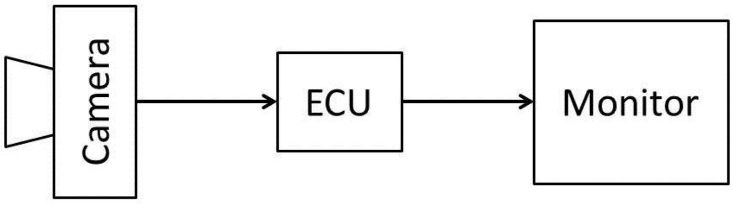

Figure 5: Schematic image of how information flows in a CMS

3.2.1 Camera theory

Cameras are made up of several components and their task is to capture still or moving images. The necessary mechanisms inside a camera might also give rise to optical effects that are not desirable in the final image. The cameras described are presumed to be digital and not analog. How a camera is built up and what image quality issues that can arise are treated in the following sub-chapters.

3.2.1.1 Camera components and focal length

Digital cameras usually include the following components: aperture, lenses, and an image sensor. Image sensors as illustrated in Figure 6 captures photons from light and transform this energy into analog electric signals. Additional circuitry transforms the signal from analog to digital.

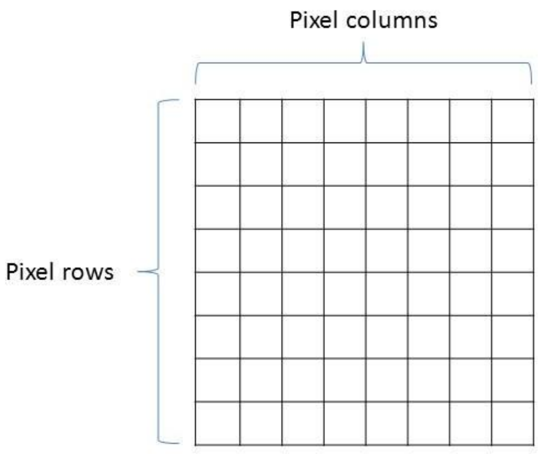

Figure 6: The structure of an image sensor is as a matrix with rows and columns

On the market today there are two major types of sensors: CCD (charge-coupled device) and CMOS (complementary metal–oxide–semiconductor). The CCDs are usually better in creating high quality images compared to CMOSs but are also more expensive (How stuff works, 2011).

Camera lenses are often built up of several optical elements, both convex and concave, in series (McHugh, Understanding camera lenses, 2012). An important variable for a lens is its focal length, which is denoted f in Figure 7. It determines the distance it takes for the lens to focus collimated light passing through it. There are lenses with different qualities which affects their performance, for example there can be differences in their ability to focus light in a finite point and also to not to differentiate the white light rays into its different colors (wavelengths). Lenses with short focal length have a wider angle of view and vice versa for lenses with larger focal length. Lenses with a focal length shorter than 35 mm, which corresponds to an angle of view of approximately 55 degrees, are often denoted as wide angle (McHugh, Using wide-angle lenses, 2012).

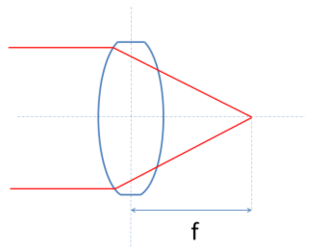

Figure 7: Definition of the focal length

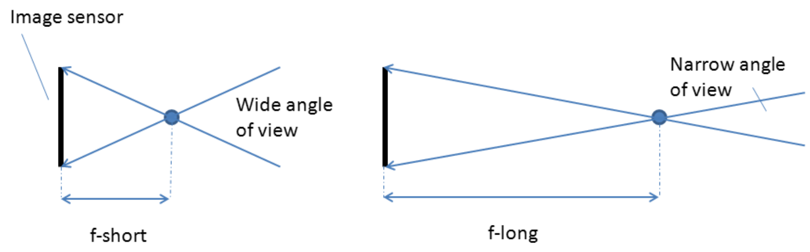

Figure 8: Illustration of why longer focal length gives narrower field of view

3.2.1.2 Camera angular resolution

The angular resolution of a CMS will mainly be determined by the minimum resolution of the camera and the monitor. The angular resolution of a camera will be determined by the lens angle of view and the number of video lines or pixels of the camera sensor in either horizontal or vertical orientation. This determines how small objects can be while still being picked up by the camera sensor. In Figure 9 α_{hor} represents horizontal angle the camera can see. With a specified number of horizontal pixels the angular resolution of the camera can be determined by Equation 5.

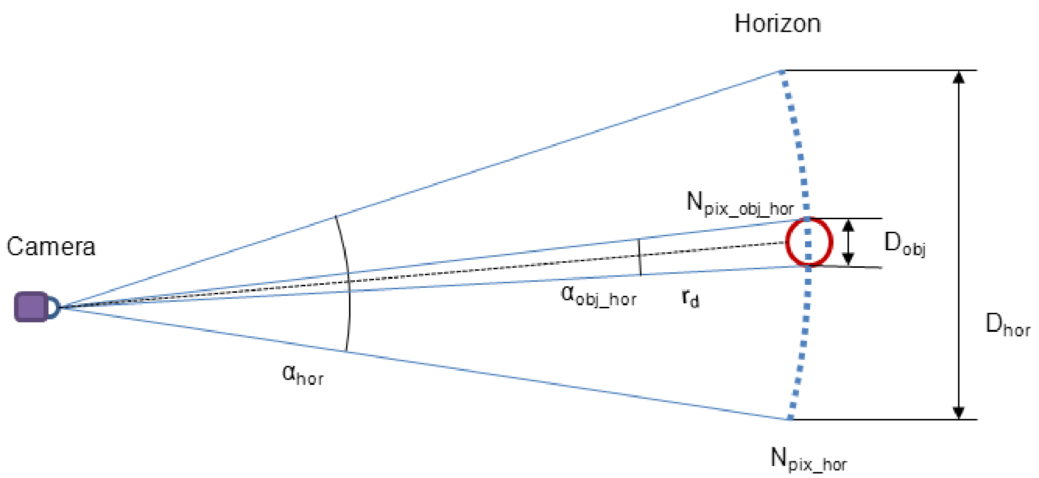

Figure 9 : Camera field of view

Equation 5 : Camera angular resolution

$$\sigma_{camera} = \frac{\alpha_{hor}}{N_{pix\_hor}}$$

$where$:
$\alpha_{hor} - horizontal\ camera\ lens\ opening$ [°]
$N_{pix\_hor} - number\ of\ horizontal\ image\ sensor\ pixels$ [#]

3.2.1.3 Camera detection distance

As for mirrors the detection distance for a CMS can be calculated providing a good value for comparison. The equation used to calculate the detection distance within critical viewing distance has been defined in ECE 46-02 Annex 10 §1.3.1 as:

Equation 6: camera detection distance

$$r_d = \frac{D_{obj}}{\tan\left(\frac{f * \alpha_{hor}}{2 * N_{pix\_hor}}\right)}$$

$where$:
$D_{obj} - diameter\ of\ the\ object$ [m]
$f - threshold\ increasing\ factor$

The threshold increasing factor is the number of lines or pixels that the detected object will be represented by in the image captured by the camera, i.e. number of pixels, the object resolution. This determines the minimum level of detail that the object needs to be picked up with at the defined detection distance.

3.2.1.4 Blooming, dynamic range and other brightness related issued affected by surrounding light sources

When a light source is in the cameras field of view it will have effects on the image being picked up by the camera sensor. Cameras usually have a way of controlling the brightness in an image and adjusting it with respect to the overall brightness in the image. If a strong light source appears in the middle of the image the camera will try to compensate for this by reducing the overall brightness thus making the areas around the light source darker which decreases the quality of the image. Situations where this may be a problem for a CMS is when the headlights of approaching vehicles enter the cameras field of view, sunlight hits the camera directly and street lights entering the cameras field of view. The camera will try to compensate by turning down the overall brightness which may make the areas around the headlights too dark for anything to be seen (Hughes, 2007). Surrounding light sources, such as the sun or artificial light, can also cause glare when observing the monitor, where glare is "to shine with a bright uncomfortably brilliant light" (Merriam Webster, 2012). Glare can cause a reduction of contrast of the image in the monitor.

Blooming is another effect that may deteriorate the quality of an image when strong light sources are apparent in the cameras field of view. The light source will spread out over a larger area of the picture compared to how it is seen by the human eye. This makes large areas of the image surrounding the light source very bright with loss in detail and legibility. (Freeman, 2008)

The limited dynamic range of a camera may also pose problems for a CMS. The dynamic range describes the ratio between the minimum and maximum measureable light intensity and is determined by the camera sensor used. With a low dynamic range objects on the outskirts of the dynamic range (the darkest and brightest areas in the image) will more difficult to identify, they will either be underexposed or overexposed. This can be compensated for by using lens filters with shading of certain areas of the lens opening in order to even out the exposure thus increasing or stretching the dynamic range in practice. (Myszkowski, 2008)

3.2.1.5 Geometric distortions

Radial distortion is an optical phenomenon originating from the camera lens. There exist several forms of radial distortion but the most common ones are barrel and pincushion distortion as seen in Figure 10. In general any lens with focal length below 50 mm will produce a wide-angle image with barrel distortion and focal lengths above 50 mm will produce an image with pincushion distortion. According to Langford (1998) standard lenses with 36–60mm in focal length cover between 45° and 57° and reproduces a field of view that generally looks "natural" to a human observer under normal viewing conditions. At a horizontal lens opening angle at around 45° the lens is considered to produce a non-distorted image and above this the distortions increase. Lens distortions are also dependent on the quality of the lens and the amount of distortion is seldom linear in respect to focal length. Examples of how barrel distortion could look like for different lens angles can be seen in Figure 11.

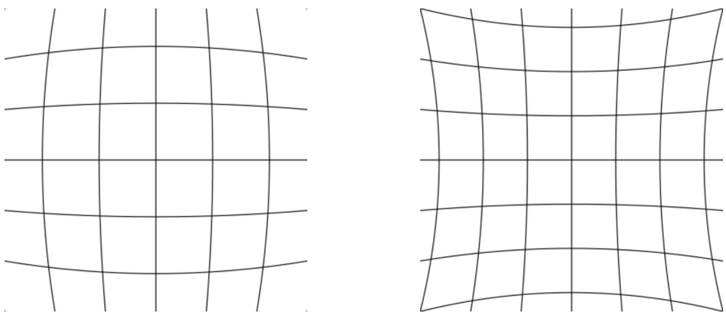

Figure 10: Barrel and pincushion distortion (Wikipedia, Distortion (optics), 2010)

120° lens

92° lens

78° lens

53° lens

Figure 11: Camera lens distortion examples (Promax, 2012)

3.2.2 Electronic Control Unit and image processing

Electrical Control Units (ECUs) are as small computers built up by circuit boards and microprocessors, an example of an ECU can be seen in Figure 12. They are getting increasingly common in vehicles as they can be used within a wide range of areas such as engine regulation, climate control and entertainment systems. ECUs can also be used to process information from the image sensor of a camera and by doing so optical image distortions may for example be corrected.

Figure 12: An ECU from BOSCH (Wikipedia, Electronic control unit, 2010)

3.2.2.1 Correction of geometric distortions

For correction of radial distortion with an ECU several methods and algorithms exist but one often used is the Browns distortion model (Brown, 1971). It is a mathematical model which given a distorted image and distortion coefficients determined by the camera lens will straighten out radial distortion. The result of such a correction can be seen in Figure 13. Correcting radial distortion will be important when implementing a CMS, mainly for the class IV mirrors which has a wide-angle lens with much distortions. Correction of distortion will help straighten out lines that a wide angle lens perceives as bent but it comes at the price of inferior image quality. The corrected image as seen in Figure 13 will have to be cropped in order for it to be displayed in a square format in a monitor as illustrated by the red square. This result in loss of information on the edges of the image and that the full wide angle provided by the camera cannot be shown to the driver. A loss in detail at the edges of the image will also occur since the outer areas of the image will have to be enlarged while the inner areas are squeezed together to straighten out bent lines.

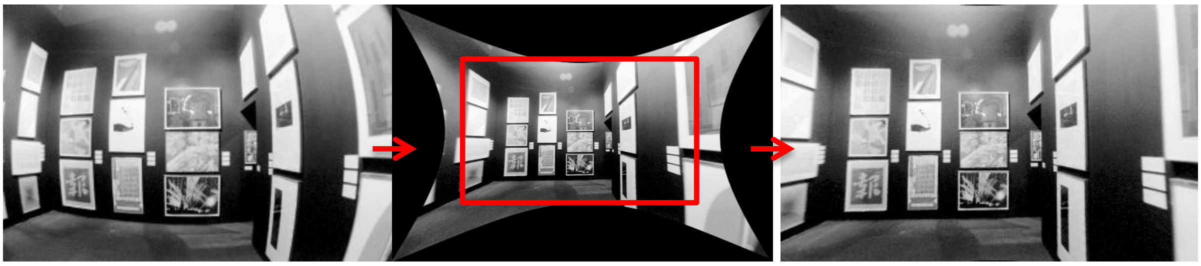

Figure 13 : Barrel distortion and reversed barrel distortion (Becker, 1994)

3.2.3 Monitors

Monitors are used to display still and moving images to the human eye by emitting light. There are several ways to generate light and the different techniques will be described in following subchapters.

3.2.3.1 Monitor types

There are two major monitor technologies on the market today, Liquid Crystals Display (LCD) and Light Emitting Diodes (LED). The LCD uses voltage to orient the crystals in different directions to control the emitted light, which is usually created either by fluorescent lamps (then called LCD TV) or by LED lamps (usually called LED TV). A new monitor technique is coming that is called true LED, which generates light by turning on and off diodes that are usually red, green and blue. LCD’s are good at showing images in bright conditions, but are poor at showing true black because light is leaking through between the crystals. True LED’s are good at showing colors in bright conditions as well as showing true black (Greenwald, 2011).

3.2.3.2 Monitor angular resolution

The angular resolution of a CMS will mainly be determined by the minimum resolution of the camera and the monitor. The angular resolution of a monitor will be determined by the eye-monitor distance and the number of video lines or pixels of the monitor in either horizontal or vertical orientation. This determines the level of detail of the objects displayed. In Figure 14 α'_{hor} represents the horizontal angular size that the entire monitor occupies. With a specified number of horizontal pixels the angular resolution of the monitor can be determined by Equation 7.

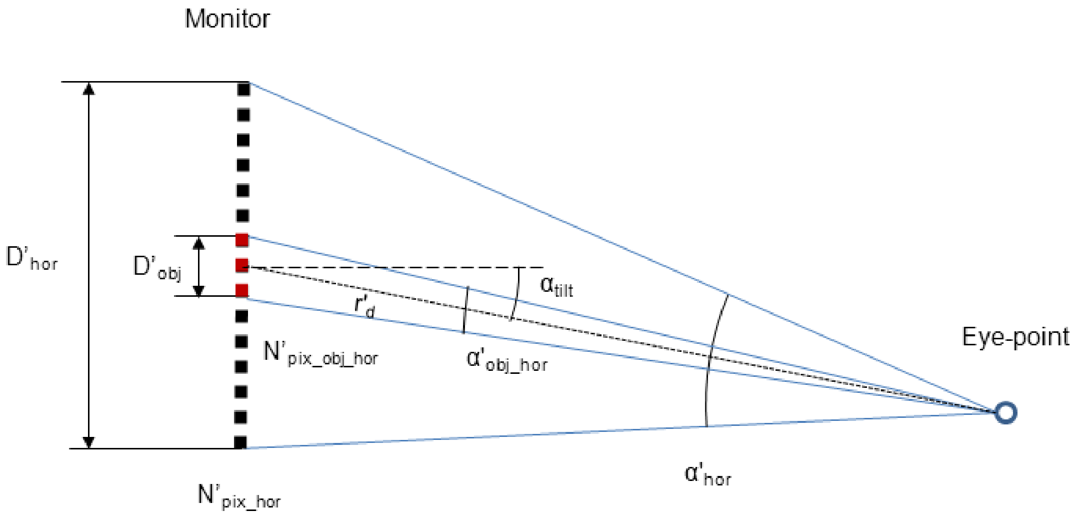

Figure 14 : Monitor variable definition

Equation 7 : Monitor angular resolution

$$\sigma_{monitor} = \frac{\alpha'_{hor}}{N_{pix\_hor}}$$

$where:$

$\alpha'_{hor} - angular\ size\ of\ the\ monitor$ [°]

$N_{pix\_hor} - number\ of\ horizontal\ pixels$ [N]

3.2.3.3 Monitor size

How large a monitor needs to be in a cab depends on its angular resolution and also the distance between the monitor and human eye.

The equation used to calculate the size of the monitor can be seen in Equation 8

Equation 8 : Monitor size

$$D'_{hor} = \frac{\tan\left(\frac{\alpha'_{hor}}{2}\right) * r'_d * 2}{\cos(\alpha_{tilt})}$$

$where:$

$r'_d - monitor\ eye-point\ distance$ [m]

$D'_{hor} - width\ of\ the\ monitor$ [m]

$\alpha_{tilt} - monitor\ tilting\ angle$ [°]

3.3 Truck theory

In this chapter the basic theory and information regarding trucks brought up in the report is provided.

3.3.1 Truck coordinate system

The truck coordinate system used is seen in Figure 15. The x-y-plane is located just above ground level, the z-x-plane in the longitudinal mid-plane of the truck and the y-z-plane located in front of the truck. The exact position of the coordinate system in relation to the truck is not necessary for this report and will not be further described.

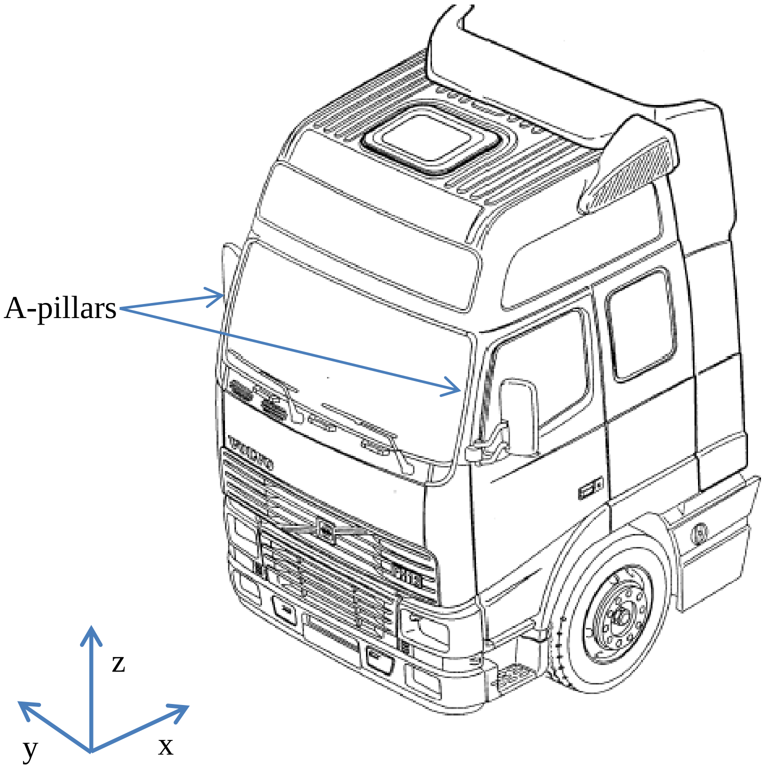

Figure 15 : Truck coordinate system (Volvo GTT, 2012)

3.3.2 Eye-points used for visibility evaluations

Three defined eye-points have been used for evaluation of direct and indirect visibility, F05, M50 and M97,5. F05 is the eye-point for the 5 percentile of women drivers, M50 is the eye-point for the 50 percentile of male drivers (median male driver) while the M97,5 is the 97,5 percentile of male drivers. The M97,5 eye-point is used in many of the evaluations since this is usually defined as the “worst case” driver which needs to be taken into consideration. The relatively tall M97,5 driver is for example used when evaluating indirect visibility since this eye-point is located further above ground and is the hardest to fulfill legal requirements for. M50 on the other hand is usually used when evaluating direct visibility since this “shorter” driver has the hardest to see the ground in front of the cab due to the blocking of the dashboard. F05 represents a very short driver sitting close to the ground and close to the dashboard and windshield. This eye-point is used for evaluation of resolution in monitors since it is the driver sitting closest to the monitor perceiving the highest level of detail.

3.3.3 Truck models used in the evaluations

Truck models taken up in the scope of this project are briefly described below.

Volvo FH	Volvo FH is the largest truck manufactured by Volvo and is mainly used for long-haul transports. It has a fairly spacious cab interior and living area designed for comfort both when driving and living in the truck.
Volvo FM	Volvo FM is a medium-sized truck with smaller cab compared to the FH truck. It is intended as a multipurpose truck and can be used for distribution, construction as well as high way transports.
Volvo FL	Volvo FL is Volvos' smallest truck and is mainly used for local and regional distribution, refuse collection and construction work.

Figure 16 : Volvo truck models FH, FM and FL (Volvo GTT, 2012)

4 MARKET ANALYSIS

To ensure a commercially viable product the customer and user needs has to be considered. A competitor analysis has been made with the purpose to find out what exist on the market today regarding CMS.

4.1 Customer and user

The customers of a CMS are mainly commercial fleet owners who seldom are the drivers of the truck. They have needs that the system has to fulfill to be commercially viable that differs from the user needs. The users of this system are the drivers who use the trucks on a daily basis.

4.2 Description of the need for a new product

In recent year legal and standardization processes have started an investigation to allow the removal of mirrors class II and class IV replacing them with cameras and monitors instead. Volvo GTT is also a part of a standardization process and the company wants to be up to date regarding knowledge about CMS and how to implement it in their trucks when the regulation starts to apply. Due to higher fuel prices and environmental care Volvo GTT wants to remove the rear-view mirrors to reduce air-drag and thus reduce fuel consumption.

The CMS integration in trucks is more of a technology push project where drivers and fleet owners have not expressed any direct need of such a system solution. The main function is already today fulfilled by the rear-view mirrors but there is room for improvements and the fuel reduction potential will make the solution interesting. Other benefits of the system change are for example that the field of view can be adaptable since the cameras can be placed almost anywhere on the truck, while mirrors have to be placed close to the driver to enable vision. The monitors where the field of view is displayed can also be moved around in the truck, offering possibilities to greatly improve the field of view on the passenger side since monitors can be placed closer to the eyes thus enhancing viewing resolution and field of view. As a result of the technology push type of development project the customer and user needs have to be estimated. These needs will be used for a base when setting the requirements for the system. The major overall needs for customers and users of a CMS have been identified as the following;

- Provide or improve the functionality of today's mirror solution
- Improve indirect and direct visibility to increase safety
- Reduce the operational cost and environmental impact of the truck by increasing fuel efficiency

4.3 Stakeholders

The main stakeholder of this project is Volvo GTT since it is a conceptual pre-study with recommendations for Volvo on how to move on with the development of a camera monitor system. Drivers and fleet owners are also stakeholders since they are going to use and buy the trucks with CMSs.

4.4 Competitor analysis and similar system solutions

Since the regulations have not yet changed there is no non-classified information about how Volvo GTT competitors intend to solve their system change from mirrors to a CMS. Information available is pictures of future truck concepts shown on fairs and exhibitions. Mirrors of class V and VI can today be replaced with a CMS but they only operate in low speeds with narrow field of views and are not comparable with the reliability requirements and real-time behavior that is needed in class II and IV mirrors. As an example of this a camera system for replacing the class VI mirror sold by Scania can be seen in Figure 17.

Other camera systems available today are also camera systems designed for trucks in certain areas such as garbage disposal and logging to provide increased visibility for their specific operations. These are sold as either stand-alone systems or integrated with the trucks navigation and entertainment system.

Figure 17 : Class VI front view camera system from Scania (Scania, Broacher 2011-02 sv1598608)

Another camera system available for Nissan Rogue is a system providing the driver with a birds-eye view of the car and its surroundings as seen in Figure 18. This integrates several cameras to provide a single top-view with the vehicle in the middle and is intended to be used as an aid when performing low speed maneuvers but also aid the driver when departing lanes in higher speeds. Similar systems have earlier been tested on trucks.

Figure 18 : Birds-eye-view camera system (Bowman, 2011)

The main difference between the CMS's seen today and the one being investigated is that the rear-view mirrors to be replaced are more frequently used than the ones that are possible to replace today. They are also used at higher speeds and are more critical from a safety perspective. Demands on a system replacing class II and IV rear view mirrors will be higher than the ones put on the camera systems used today.

An area where high speed capturing of moving images with high quality is important is automated number plate recognition systems. These are designed for number plate recognition in real time and are designed to be able to distinguish number plates on vehicles moving at high speeds. This puts demands on high frame rates, high image resolutions and real-time image processing capabilities. Many cameras used for this application are monochromes which will not be sufficient for rear-view automotive cameras.

5 PRODUCT REQUIREMENTS ANALYSIS

In this chapter the product requirements will be identified, analysed and defined in order to result in the requirements specifications list found in Appendix A. The input for the identification of requirements for the CMS has been compiled from a number of sources such as internal documentation, scientific papers, driver studies and expert opinions.

5.1 Functional decomposition

To facilitate the requirements specification the functions of the CMS have been identified and the functional decomposition of the system can be seen in Figure 19.

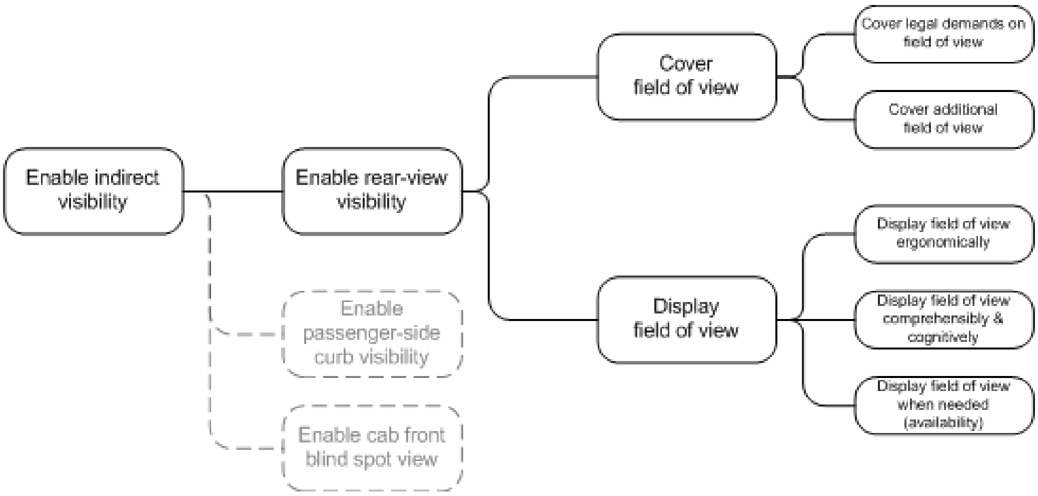

Figure 19 : Functional decomposition

The main function that should be delivered by the system to the truck driver is to enable rear-view visibility. Since large parts of the cab are limiting the field of view, this is a necessary function to increase safety for both the driver and other road users.

One of the sub-functions is "Cover field of view". When the driver turns to today's mirror for rear-view visibility, this is done with a purpose. What the reasons are will partly determine what field of view that the system has to cover. There are also legal requirements set which determine the minimum field of view that has to be covered. Another sub-function is that the system has to present the field of view to the driver. This has to be done in such a manner that the information is shown in an ergonomic and comprehensible way. In addition the system availability has to be regarded, as for example when the field of view should be shown and when not.

Apart from the main function and the sub-functions there are several other features that are affected by the system. These need to be taken into account during development of the camera monitor system and they have been named "Important features affected by the system". They cover aspects that will influence the CMS and will set many of the requirements for the system. They are not functions provided by the system directly but are major determinants for these and can be seen in Figure 20.

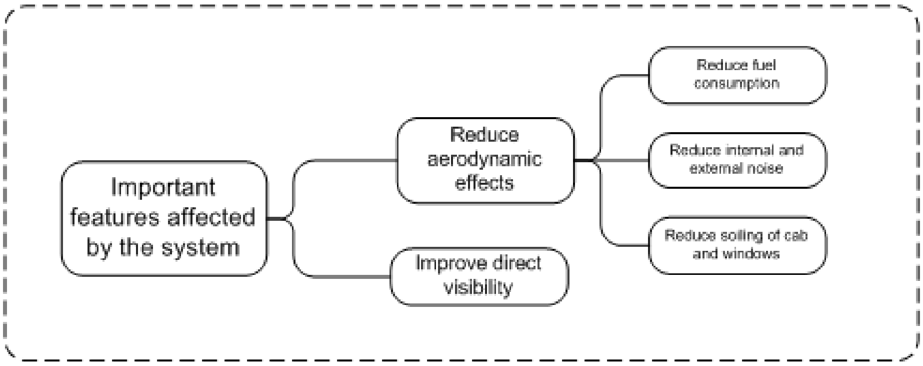

Figure 20 : Important features affected by the system

An important feature affected by the system and a major reason for replacing rear-view mirrors with a CMS is to reduce fuel consumption for environmental and economic reasons. Furthermore the internal and external noise has to be reduced for driver comfort. The system shall also reduce the soling of the cab and windows so that direct and indirect visibility are not affected. The direct vision shall also be improved compared to existing mirrors.

5.2 Functional requirements

5.2.1 Cover field of view

The indirect vision provided by today's rear-view mirrors has been designed to aid the driver in a number of traffic situations where it may be needed. When designing a CMS for replacing the rear-view mirrors both what is seen in today's rear-view mirrors need to be investigated as well as any additional needs that the drivers may have that have to be fulfilled by the new system.

5.2.1.1 Cover horizontal field of view

In this chapter the horizontal field of view that needs to be covered by the CMS is analyzed. This will be used as input for setting the required horizontal camera lens opening angle.

5.2.1.1.1 Legal demands on horizontal field of view

The strictest legal demands on field of view provided by rear-view vision devices are the United Nations regulation (ECE 46-02, 2010). This dictates the minimum field of view on ground level which needs to be provided through indirect vision devices and is the legal regulation European automotive manufacturers follows.

Class II

The field of view required by ECE 46-02 for the class II rear-view mirrors as seen in Figure 21 can be found in (ECE 46-02, 2010) paragraph 15.2.4.2.1 and 15.2.4.2.2.

Class IV

The field of view required by ECE 46-02 for the class IV rear-view mirrors as seen in Figure 22 can be found in (ECE 46-02, 2010) paragraph 15.2.4.4.1 and 15.2.4.4.2.

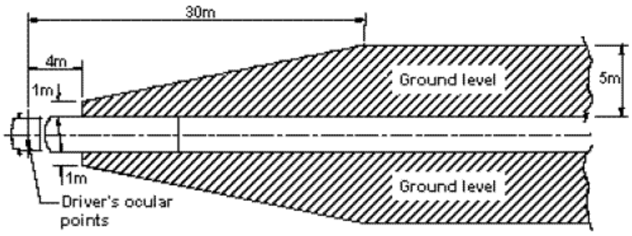

Figure 21 : Field of view required in ECE 46-02 for class II rear-view mirrors (ECE 46-02, 2010)

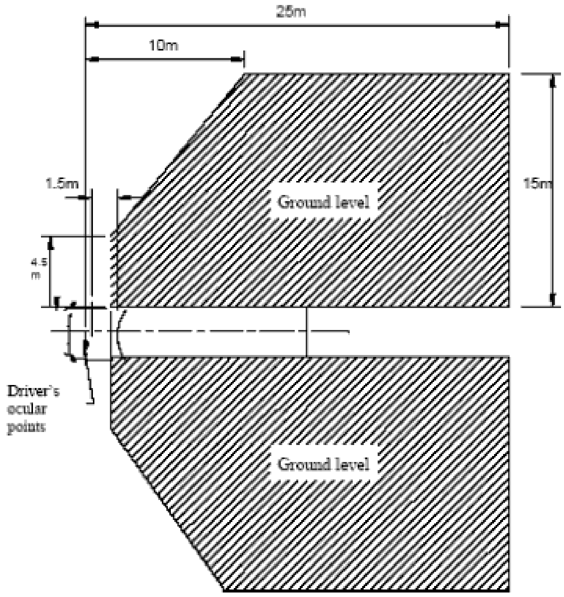

Figure 22 : Field of view required in ECE 46-02 for class IV rear-view mirrors (ECE 46-02, 2010)

5.2.1.1.2 Additional requirements on horizontal field of view

The horizontal field of view on the ground as provided by the class II and IV rear-view mirrors in today's Volvo FH truck can be seen in Appendix D. In Figure 72 in Appendix D the legal demands on horizontal field of view can be seen as well. The CMS must at least fulfill this field of view for respective mirror class which can be found in to ensure that the CMS will not decrease the rear-view visibility provided by today's mirrors. (GTT, Mirror Drawing 20735623, 2010)

5.2.1.1.3 Extended horizontal field of view obtained through head movements

With a CMS being used as a device for indirect vision the possibility to extend their field of view by moving the head will disappear and this will have to be compensated for. It can be done either by introducing the possibility to manually pan and tilt the camera or the image shown in the monitors or by increasing the default field of view to include a larger area so that head movements will not be needed.

A survey including ten truck drivers was conducted at the Hällered test track to investigate how they moved their head in different traffic situations (Blomdahl, 2012). The results found in Table 1 shows three different traffic situations and how much drivers estimated length of their head movement and its direction in percentage in each of these situations. They also mentioned which mirror they found most useful in these situations and how much they benefitted from moving the head compared to the other situations.

Table 1: Results from head movement survey at Hällered test track.

Situation	Direction of head movement				Average/ maximum head movement	Benefit moving head	Which mirrors are used to increase what is seen?
	Forward	Backward	Left	Right			
Round about	83 %	17%	50 %	50 %	17/30 cm	4/5	**83%** Main mirror driver side **67%** Main mirror passenger side
Reversing	100 %	0 %	71 %	71 %	33/50 cm	4,8/5	**100%** Main mirror passenger side **57%** Main mirror driver side
Turning	75 %	0 %	50 %	50 %	17/20 cm	4,5/5	**75%** Main mirror passenger side **50%** Wide angle mirror passenger side

What can be seen in the results is that drivers found moving their head to increase the field of view most useful while reversing and that they also moved their head the farthest in this situation. What also can be seen in the results is that the head is mainly moved to increase what is seen through the class II mirror and not the class IV mirror.

5.2.1.1.4 Two-dimensional investigation of extended horizontal view through head movement in Catia V5

To investigate the effect of head movements on the covered field of view, two-dimensional investigations were conducted with the help of Catia V5 as seen in Figure 23 and Figure 24. The mirror, eye-point and field of view obtained in today's FH truck was inserted into the horizontal plane and a line was reflected in the outermost point on the mirror surface to find the outer limit of the field of view seen in the mirror. Then the eye-point was moved 33 cm so that the line created between the old and the new eye-point and the line created between the new eye-point and the outermost point on the mirror was 90°. The distance 33 cm was chosen because it was the average head movement while reversing found in the Hällered survey. The effect on the field of view was observed and the change in viewing angle due to head movements was found.

This investigation was conducted on the driver side mirrors because these are the mirrors where the field of view is affected the most by head movements. Since one of the desirable effects when replacing mirrors with a CMS will be decreased difference in performance between the driver and passenger side indirect visibility the driver side performance will be governing.

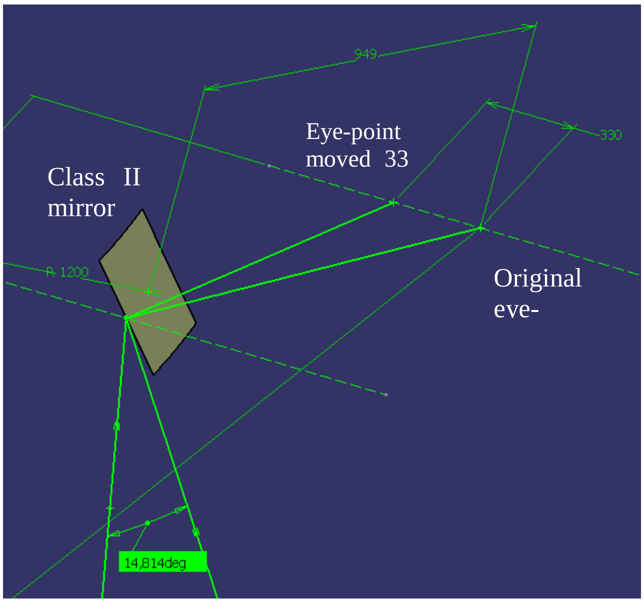

Figure 23 : Head movement impact on class II driver side mirror.

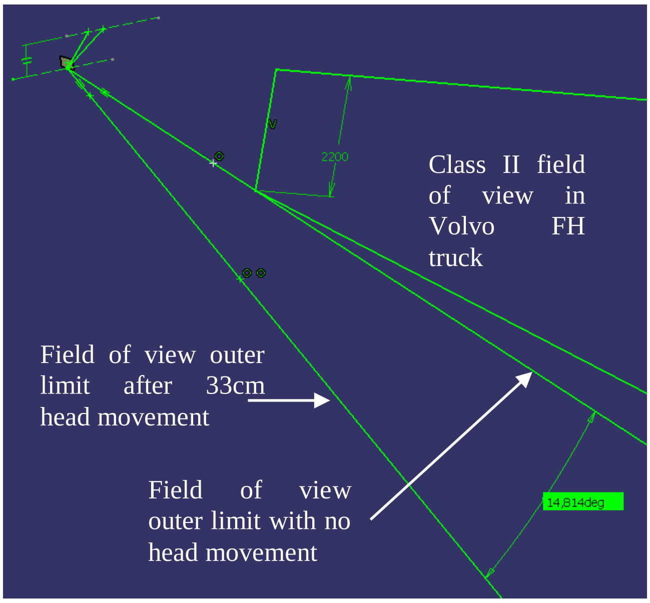

Figure 24 : Head movement impact on class II driver side mirror and FoV

The two-dimensional investigation of head movement impact on the field of view in Catia V5 found that the viewing angle for class II mirrors was increased with 14,7° and for class IV with 19,7° as seen in Table 2.

Table 2 : Head movement impact on the field of view as seen in a two-dimensional investigation

Mirror	Head movement	Angular change in field of view
Class II driver side	330mm	14,7°
Class IV driver side	330mm	19,7°

5.2.1.1.5 Three-dimensional investigation of extended horizontal view through head movement in CAVA

To verify the results from the two-dimensional investigation in Catia V5 a three-dimensional investigation in CAVA was carried out. CAVA is a tool in Catia V5 used to verify and certify rear-view visibility in vehicles. The eye-point and mirror surfaces were inserted into CAVA and ray-tracing was used to visualize the field of view seen through the mirrors on ground level. With these investigations the exact shape and position of the mirrors could be used and the field of view in today's Volvo FH trucks could be observed in three dimensions as seen in Figure 25. In Figure 26 the class II field of view for driver and passenger side as seen on the ground level is found. The field of view as seen from the original position of the eye-point, the field of view seen from the eye-point moved 33 cm and the angles between the outer limits of these field of views can be seen.

The investigations in CAVA verified the previously conducted two-dimensional investigations and in Table 3 the changes in viewing angle when moving the eye-point 33 cm can be seen for the driver and passenger side. The driver side viewing angle is clearly affected more by head movements than the passenger side and the 15,8° change in angle on the driver side corresponds fairly well with the previously calculated 14,7° seen in Table 2.

Table 3 : Head movement impact on the field of view as seen in a three-dimensional investigation in CAVA

Mirror	Head movement	Angular change in field of view
Class II driver side	330mm	15,8°
Class II passenger side	330mm	8,4°

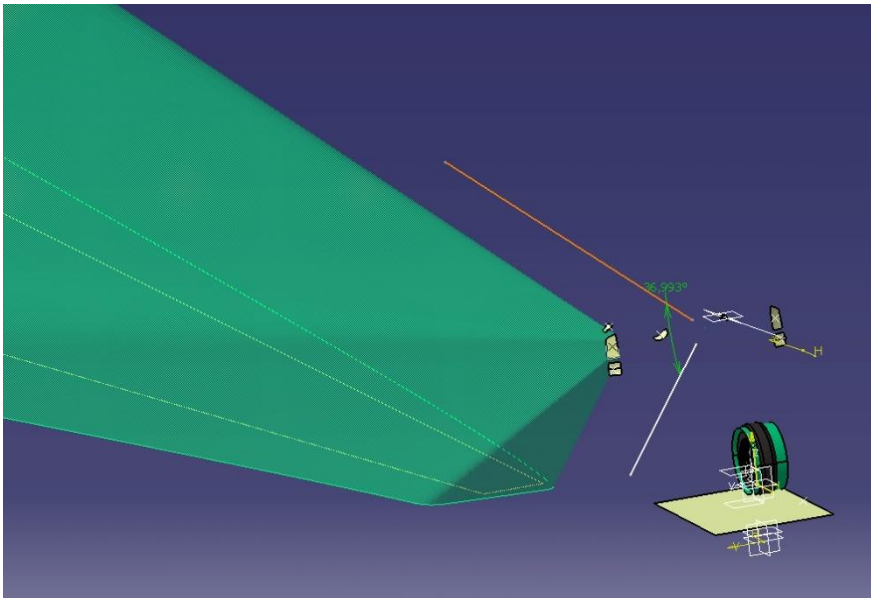

Figure 25 : CAVA simulation of passenger side class II mirror field of view

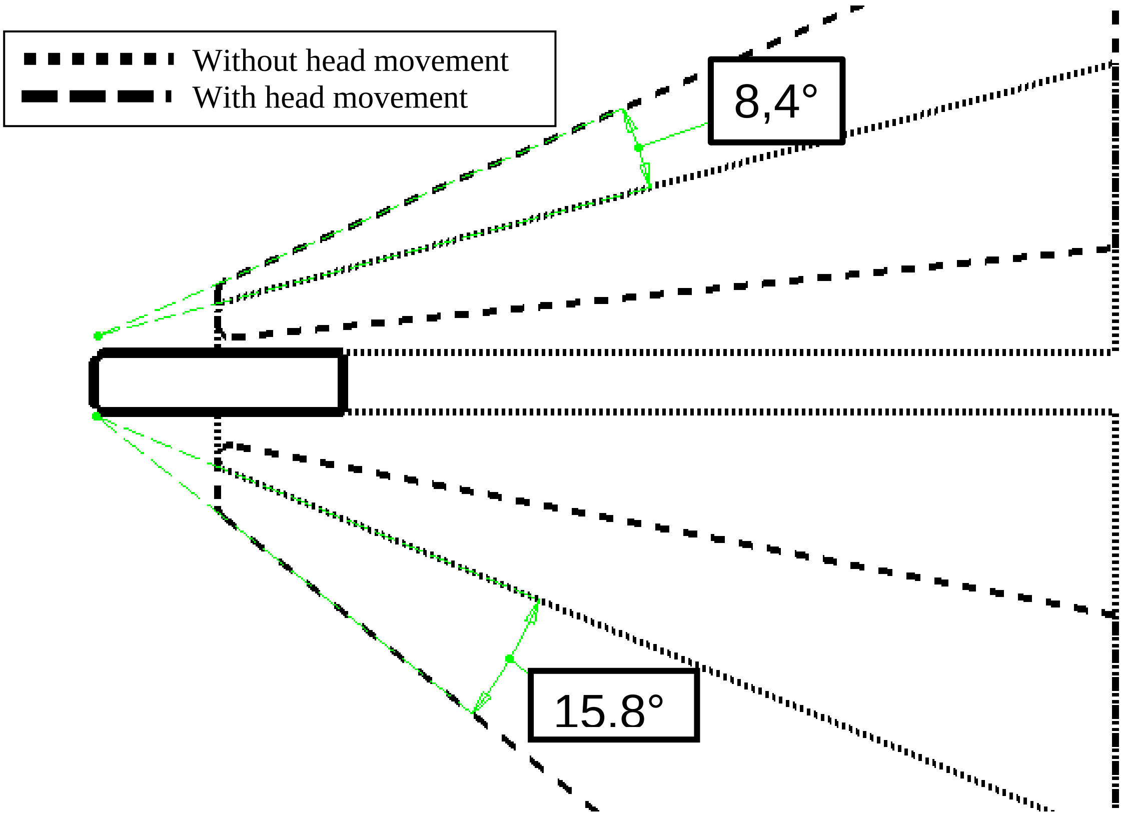

Figure 26 : CAVA simulation of 33cm head movement and its effect on the class II mirror field of view on ground level

5.2.1.2Cover vertical field of view

In this chapter the vertical field of view that needs to be covered by the CMS is analyzed. This will be used as input for setting the required vertical camera lens opening angle.

5.2.1.2.1 Legal demands on vertical field of view

The legal demand on vertical field of view is determined by the demands on horizontal ground level field of view described earlier and the position of the viewing point and can be seen in Figure 27. The required viewing angle will depend upon the position of the viewing point and the legal requirement on distance between the ocular point and the closest part of the road that the rear-view device shall cover. The determinants for the required vertical field of view are the distance between the ground and the viewing point and between the ocular point and the viewing point. The difference between class II and IV mirrors will be determined by the different requirement on distance between the ocular point and the closest point on the ground which needs to be covered according to ECE 46-02. For class II this is 4 m behind the eye-point and for class IV 1,5 m.

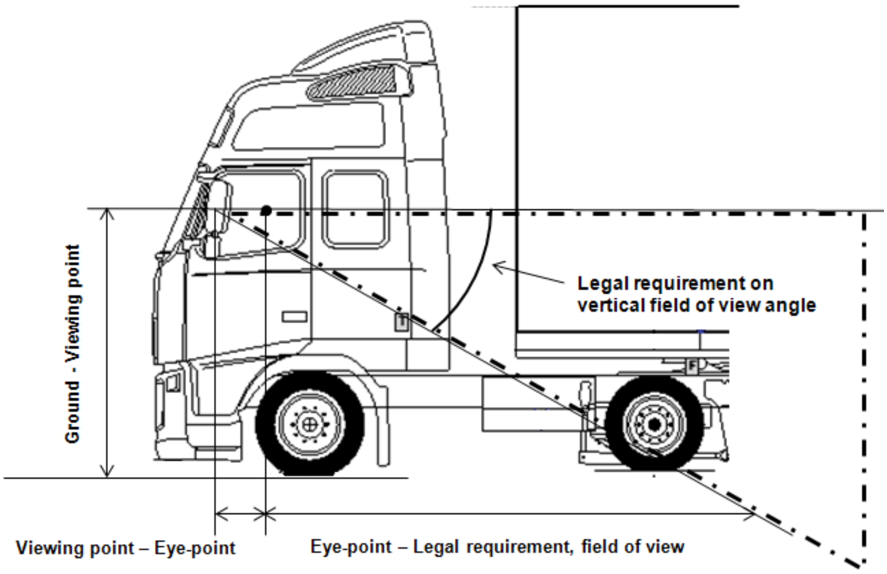

Figure 27 : Legal demand on vertical field of view (Volvo GTT, 2012)

5.2.1.2.2 Additional requirements on vertical field of view

In discussions with feature specialists in visibility and analysis of requirements of today's mirrors the vertical field of view for conventional class II and IV mirrors have been identified. To provide the same vertical field of view the CMS should be designed so that the following parts of the vehicle are seen;

- Upper forward corners of the trailer
- Rear trailer axle

These opinions regarding what the driver would like to see concerning the vertical field of view were put forward in a survey conducted by Volvo GTT (GTT, Driver preferences of mirror adjustments and visibility, 2011):

- *Cab body sides rearwards from doors (air deflectors)*
- *Half meter of chassis fairings visible in front of rear wheel, even more if possible*
- *Sidelines should be easily detectable/visible/understandable in relation to rear wheels*
- *Full trailer length when driving straight*
- *Rear end of tractor and last axle of trailer in lower corner of mirror*
- *Maximum vision sideways, but reference to own vehicle should/must always be kept*
- *Upper forward corner of trailer viewed without difficulty on both sides (Class II or Class IV)*

With these requirements and opinions in mind the vertical field of view found in Figure 28 was created. The additional requirements for class II and IV mirrors include the upper forward corner of the trailer. (GTT, Technical Requirement Mirrors 82374493_05_1_TR, 2012)

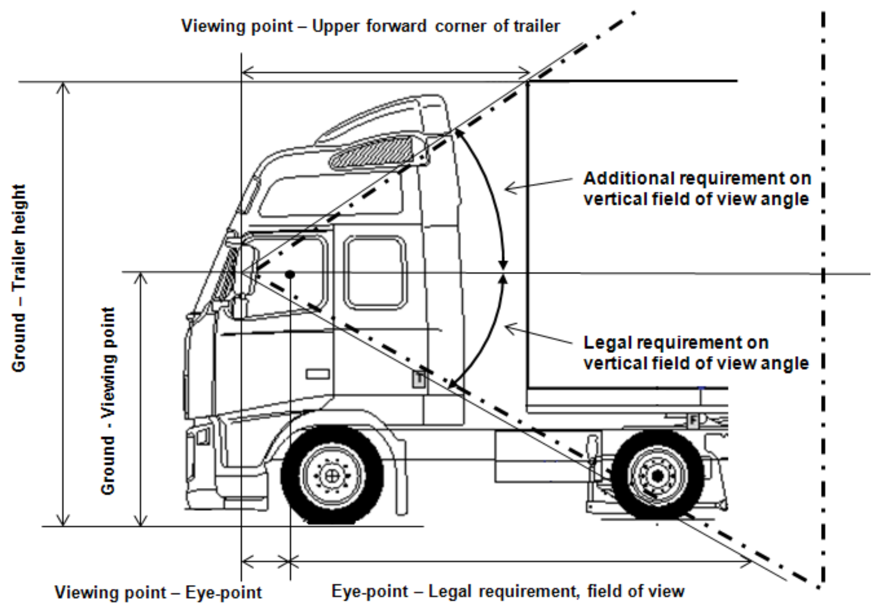

Figure 28 : Vertical field of view required (Volvo GTT, 2012)

5.2.1.2.3 Three-dimensional investigation of the vertical field of view in CAVA

The vertical viewing angles in today's rear-view mirrors have been investigated in CAVA to provide a comparison with what is covered in today's rear-view mirrors. An example of how this was carried out can be seen in Figure 25. A table with the vertical angles can be found in Table 4.

Table 4 : Vertical viewing angles in mirrors investigated in CAVA

Mirror	Field of view angle
Class II driver side	55,2°
Class II passenger side	37,0°
Class IV driver side	75,1°
Class IV passenger side	65,5°

5.2.1.3 Position of horizon

In a survey among drivers this comment was put forward regarding the position of horizon (GTT, Driver preferences of mirror adjustments and visibility, 2011):

- *Vision above horizon is less important than below horizon*

The positioning of the horizon will in the end be determined by the requirements for the class II and IV vertical field of view. Both these include elements positioned above and below the horizon thus automatically positioning it in the field of view. It is important that the horizon is positioned horizontally the same way as it is seen in conventional mirrors. This will require that monitors and cameras are positioned in the same way relative to the horizon so that the horizon displayed to the driver will be parallel to the real horizon.

5.2.1.4 Adjustability

According to ECE 46-02 section 6.1.1.1 all mirrors shall be adjustable. If or how this demand will be included in an upcoming legal regulation for a CMS will have to be monitored.
The ability to adjust mirrors and hence what will be seen in today's mirrors is something that a CMS will have to take into account. The need for adjustments due to physical ergonomics will be fulfilled with monitor adjustments but the desire to adjust mirrors to obtain a certain field of view may become more difficult to fulfill.

5.2.1.5 Providing depth cues to facilitate depth perception and speed estimation

In order to provide the driver with enough information in order to determine speed and distances while driving today's rear-view mirrors extend from the cab body of the truck. This is done to cover the legally demanded field of view for situations when the cab body width is less than the trailer width and to provide the driver with a cab and trailer side reference used when determining depth and speed of other vehicles.

Regulations state that a truck with trailer cannot exceed 2,6 m in width and that the truck with rear-view mirrors cannot exceed 3 m in width as seen in Figure 29. ECE 46-02 also states that an individual mirror cannot extend more than 250 mm from the maximum cab body width where any part of the mirror is less than 2 m from the ground. With today's mirrors their extension from the maximum width of the cab is maximized in order to provide the driver with a proper reference to the truck and cover the best field of view.

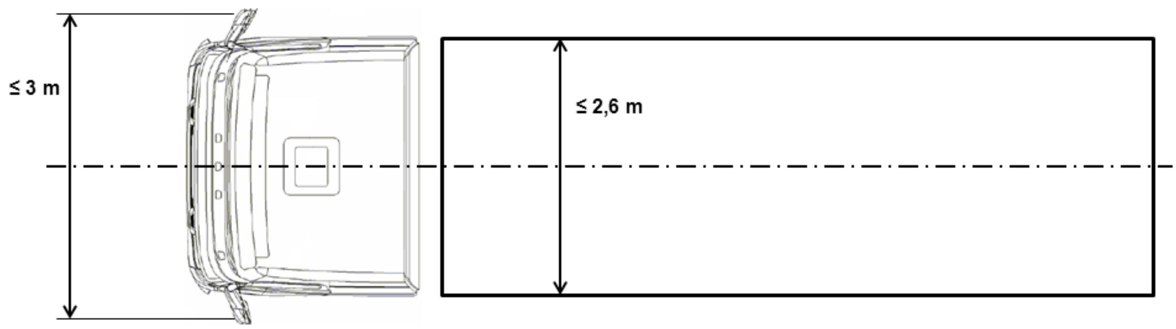

Figure 29 : Width of truck, trailer and mirrors (Volvo GTT, 2012)

A study by Flannagan (2006) concluded that a very important depth cue when determining the relative speed and distance to an approaching vehicle in a CMS is a reference to your own vehicle. This confirms that seeing the side of the truck is important for the driver and that the position of the camera relative the cab side should not be changed which would decrease the quality of the reference compared to today's mirror solution. Retaining depth cues to provide the possibility to determine relative speed and distance in a CMS will be very important to ensure that the performance of the CMS will not be considered inferior to conventional mirrors.

When positioning a camera in relation to the ground it will affect several of the depth cues described in chapter 3.1.5. It is important to provide as many of these depth cues as possible while making sure that objects in the field of view are clearly visible, not hidden behind each other and not distorted.

An important factor that also should be taken into consideration when positioning a camera in relation to the ground is the perspective gained for the image displayed. The perspective of the image displayed should be kept similar to the one gained in conventional mirrors to ease the transition from mirrors to a CMS. It can also be presumed that the perspective on the field of view presented to the driver should be approximately the same as the perspective the driver has when observing traffic with his eyes. This makes positions around the same height as the drivers' eye-point and where the mirrors are situated today a suitable for a camera.

5.2.1.6 Reduce the presence of driver and passenger side blind-spots

The presence of driver and passenger side blind-spots as marked as C and E in Figure 30 is a safety problem for truck drivers. Especially hazardous are right turns in city traffic due to the big blind spot on the passenger side and the presence of bicyclists and pedestrians. Although the main function for the CMS is not to reduce blind spots this is an important safety factor and reducing blind spots should be taken into account during development work.

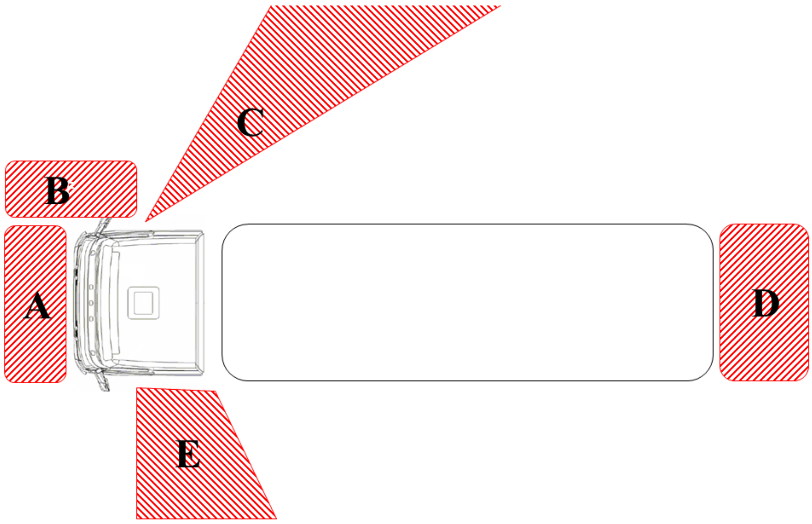

Figure 30 : Typical truck blind spots

5.2.2 Display field of view

With today's mirror solution displaying of the indirect vision provided is restricted to the positions where the mirrors are placed in order to best reflect the correct field of view. The position of today's mirrors block an important part of the direct visibility but with a CMS the possibility to place monitors at more suitable locations in the cab interior appear. How factors such as or example physical position and quality of the image of the displayed indirect visibility affect the way indirect visibility is perceived will be analyzed in this chapter.

5.2.2.1 Display field of view ergonomically

When the driver sits in the driver seat, the main body movements to change field of view is by moving the head when tilting or turning it, or by moving the eyes when changing direction of line of sight (the line that connects the midpoint between the two pupils and the point of fixation that is observed) (International Organization for Standardization, 2008). Another factor influencing the placement of the displayed field of view is the eye strain when focusing on objects close-by. This limits how close the displayed view can be while still observed with comfort.

5.2.2.1.1 Monitoring task

In monitoring tasks the driver actively moves the eyes to seek information (International Organization for Standardization, 1999). For this task there are certain angles that are more suitable to put the intended monitoring view in for driver comfort, which can be seen in Figure 31. The areas in Figure 31 are classified according to suitability, see Table 5.

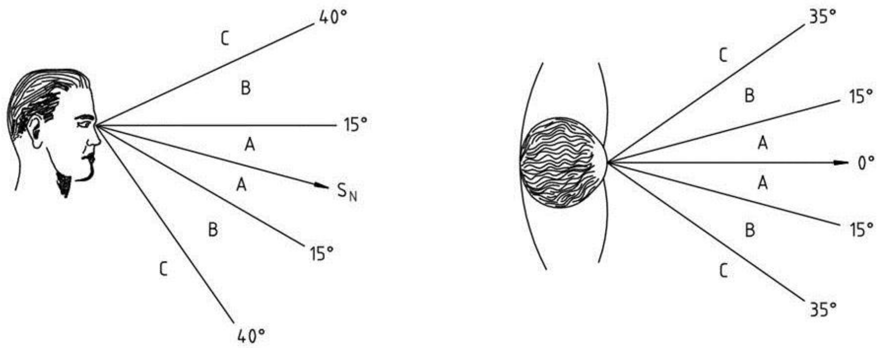

Figure 31 : Suitable positions for the field of view when monitoring. S_N is the line of sight and it is usually 15° to 30° below horizontal direction (International Organization for Standardization, 1999)

Table 5: Suitability grades for zones in Figure 31 (International Organization for Standardization, 1999)

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

5.2.2.1.2 Distance between field of view and eye

The human eye has varied ability to accommodate focus to nearby objects. This can differ with age and eye condition, where younger persons often focus more easily on close objects than senior, see Figure 32. The distance between the eyes and the field of view is called the designing viewing distance. The recommended value for this feature is minimum 400 mm (International Organization for Standardization, 1992) for adults with normal emmetropic eyes (eyes with perfect vision), see Figure 32. In this way all drivers from 18 to about 47 will be able to view the screen with no problems to accommodate focus.

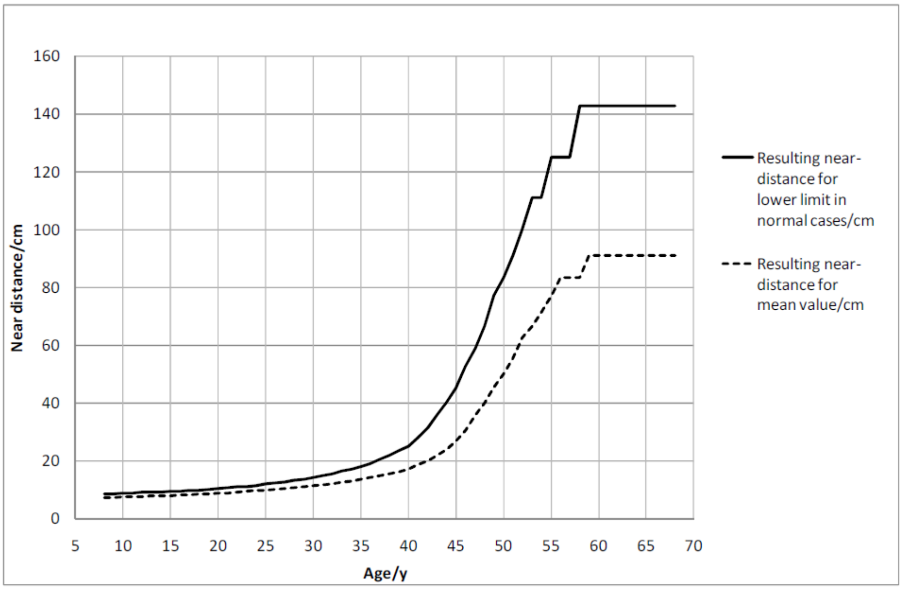

Figure 32 : Table of eye accommodation depending on viewing distance and age (Schiller, 2011)

5.2.2.2 Display field of view comprehensibly

How system properties such as resolution, size of objects displayed and physical positioning of monitors affect the way the field of view presented is perceived and how objects are detected will be analyzed in this chapter.

5.2.2.2.1 System resolution

An important factor when determining how objects seen through the CMS will be perceived is the resolution of the system. This determines the level of detail that can be registered and displayed to the driver. The system resolution of the CMS is determined by resolution of the camera and the monitor as seen in Equation 9 and should at least be the same as for conventional mirrors. This will set the minimum requirement on the system resolution.

Equation 9 : CMS system resolution

$$\sigma_{CMS} = MAX(\sigma_{camera}; \sigma_{monitor}) \leq \sigma_{mirrors}$$

Camera resolution

The camera resolution will have to be set so that the required field of view can be observed with enough detail. For it to fulfill the minimum requirement and deliver the same performance as conventional mirrors the angular resolution of the camera will have to be the same or better than of the mirrors as seen in Equation 10.

Equation 10 : Camera angular resolution requirement

$$\sigma_{camera} \leq \sigma_{mirrors}$$

The camera resolution will also have to be higher or the same as the minimum monitor resolution to make sure that the monitor image quality isn't decreased due to a low camera resolution.

Equation 11 : Camera resolution requirement

$$N_{pixels\_camera} \geq N_{pixels\_monitor}$$

Monitor resolution

The TCO certification version 5.2 for displays has put a minimum required pixel density for monitors at ≥30 pixels/degree visual angle which corresponds to an angular resolution of 2 arc-mins (TCO, 2011). This is the level they have determined to be enough in order to not experience visible "jaggies" being seen by the user as illustrated in Figure 33.

Figure 33 : "Jaggies", informal name for artifacts in raster images most commonly from aliasing, pixelation occur (Wikipedia, Jaggies, 2011)

This requirement should at least be fulfilled by the system in order to obtain a sufficient level of detail on the closest ergonomically acceptable viewing distance defined as 400mm in Chapter 5.2.2.1.2.

Equation 12 : Monitor angular resolution for minimum viewing distance requirement

$$\sigma_{monitor\_400mm} \leq 2\ [arc - mins]$$

For the minimum normal viewing distance defined by the F05 eye-point described in Chapter 3.3.2 the angular resolution requirement of 1 arc-min must be fulfilled as this is the "worst-case" scenario for regular use of the monitors. This is required for drivers sitting closest to the monitor having the best visual acuity not to experience or perceive the image as having a low resolution.

Equation 13 : Monitor angular resolution for minimum viewing distance requirement

$$\sigma_{monitor\_F50} \leq 1\ [arc - mins]$$

5.2.2.2.2 System detection distance

The CMS detection distance which is the distance on which objects are picked up by the camera and presented by the monitor to the driver with a specified size will have to be the same or better compared to conventional mirrors. This requires that objects of a defined size and at a specified distance from the vehicle shall be presented at the same size as defined in Equation 14.

Equation 14 : CMS angular size of objects requirement

$$\alpha'_{obj\_hor\_CMS} \geq \alpha'_{obj\_hor\_mirror}$$

5.2.2.2.3 Monitor angular size

For a given object at a defined distance to be displayed to the driver with the same size or larger as defined in Chapter 3.1.3 while still covering the field of view as defined in Chapter 5.2 the angular size of the monitor will have to follow the relation found in Equation 15. The equation determines the angular size that the displayed field of view will have to have which in turn puts demands on the physical monitor size at a given position in the cab. The definition of the variables can be found in Chapter 3.2.3.2.

Equation 15 : Monitor angular size and aspect ratio

$$\frac{\alpha'_{obj}}{\alpha'_{hor}} = \frac{\alpha_{obj}}{\alpha_{hor}}$$

5.2.2.2.4 Blooming and other brightness related issued affected by surrounding light sources

To avoid blooming and other brightness related issues it is important to position a camera in an area not subjected to strong light sources. In discussions with specialists in the area at Volvo GTT it was concluded that cameras should not be positioned at distances from the ground below 1m. It was also concluded that with respect to the effect of headlights on camera performance a mounting location as high above ground as possible would be most favorable.

To avoid negative effects from direct sunlight hitting the camera it is also favorable to position the camera high above ground. When doing so the camera will be directed more towards the ground and less towards the sky due to its high position and the ground area that needs to be covered. To avoid these effects protective visors should also be designed to prevent direct sunlight from reaching the camera lens and degrading the image quality. This could for example be incorporated into the camera housing.

5.2.2.2.5 Monitor positioning in relation to line of sight

How to place monitors in relation to the driver's direct line of sight is a factor that needs to be investigated. This affects how the CMS is perceived by the driver and how objects in a CMS are detected.

Relation between the line of sight and indirect vision devices through side-windows

When direct and indirect visibility have to be used at the same time it is necessary to have the monitors close to the line of sight to reduce eye and head movement from the situation observed in the line of sight, see Figure 34. An example is when driving in roundabouts where the driver looks out in the driver side window to see the traffic, while at the same time monitoring how the trailer moves in the mirrors.

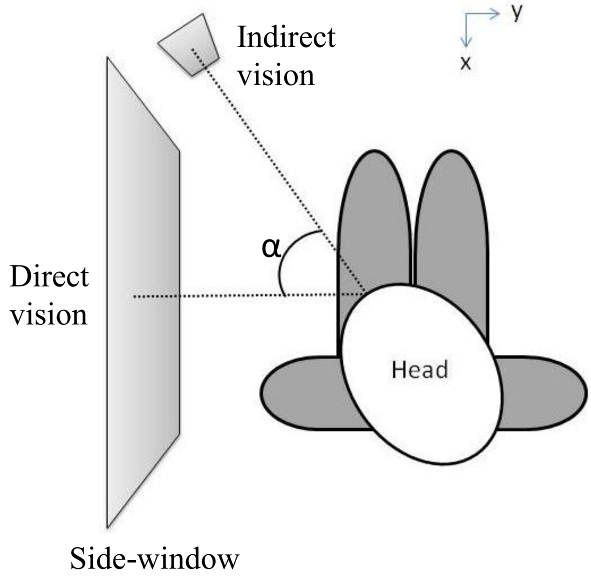

Figure 34: Relation between indirect and direct vision when viewing traffic situation through driver-side side-window

Disturbance caused by motion and brightness in monitors

It is also important not to position monitors close to the drivers' line of sight when watching straight ahead, see Figure 35. This is to avoid driver annoyance from having bright monitors close to eyes when driving at night, but also by having monitors displaying a lot of movement close to the line of sight.

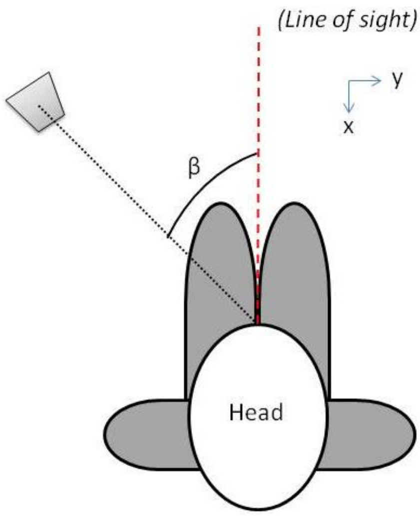

Figure 35: How monitors are positioned in relation to line of sight

5.2.2.3 Display field of view when needed, availability of the CMS

Compared to conventional mirrors a CMS is dependent upon a power supply to provide vital functionality. Today's mirrors usually include a heating function used for defrosting and demisting of the mirrors which requires power supply but this is rarely used for longer periods and is not crucial for the functionality of the mirrors. For a CMS, power supply will be needed for the system to provide any functionality at all but since power supply from batteries and generators is limited the CMS cannot be constantly turned on. Wear and life length issues of electronic equipment are also factors that would speak for actively managing the availability of a CMS and not have it running when it isn't needed.

5.2.2.3.1 CMS states

When investigating how a CMS could be used and how drivers would want to use it, three CMS states that are needed have emerged. These are "*Active*", "*Not Active*" and "*Manual activation possible*" and they are described in Table 6. Since a CMS is an important safety function it will have to be turned on and provide the legally required rear-view when the truck is operating. Besides driving, the truck can be used for other purposes as well where the CMS does not need to be active such as sleeping and other recreational activities. In this situation the CMS does not need to be turned on constantly but some situations where rear-view would be needed exist which require the possibility to manually activate the CMS. A driver may for example want to see what is next to the truck before exiting after having used the cabin for recreational purposes which is a mode where the CMS by default would be turned off. In order to avoid the CMS from being left on too long in situations where it isn't needed which may drain the batteries the CMS should automatically be turned off after a certain amount of time.

Table 6 : Description of CMS states

CMS state	Description
Not active	Unconditionally turned off
Manual activation possible	The CMS can be manually turned on and stay turned on for a certain amount of time
Active	Unconditionally turned on

5.2.2.3.2 CMS availability

When reviewing in which situations rear-view visibility is needed it has been seen that using certain vehicle modes as a base for deciding when to have the CMS enabled would be appropriate when combined with a manual override possibility in certain situations. The vehicle modes and the state of the CMS that was decided upon can be seen in Table 7.

Table 7 : Vehicle modes and CMS state

Vehicle mode	CMS state
Parked with no driver in cab	Not active
Parked with driver in cab	Manual activation possible
Ignition turned on	Active
Engine running	Active

5.2.2.3.3 Availability of extended field of view

When driving trucks with mirrors drivers tend to move their head to expand the field of view as discussed in Chapter 5.2.1.1.3. This is not possible in a CMS since the view is fixed by what field of view the camera can capture. The expanded field of view might not be a necessity when for example driving long-haul trucks on highways but in low speed traffic situations where the trailer is angled out from the truck and there is a lot of activity around the truck it might be needed more often. In these situations drivers want to see where the trailer is in relation to the road, other vehicles and pedestrians. A study conducted also showed that drivers moved their head mainly to see more in the driver and passenger side class II mirrors and not in the class IV mirrors (Blomdahl, 2012).

The legally demanded field of view and the field of view obtained in today's rear-view mirrors need to be covered at all times for both class II and IV CMS. The expanded field of view can either be shown at all times or only in specific situations. If it is to be displayed always then the monitor sizes will increase and the angular size of the monitor will be greater than for the corresponding mirror due to the requirement that a critical object shall be displayed at the same size as in mirrors at a defined distance.

By analyzing in which situations drivers move their head to expand the field of view it can be seen that it is more important in three situations (Blomdahl, 2012):

- Reversing
- Driving in a roundabouts
- Turning left and right

These are all low speed situations and as said earlier the class II mirror is mainly used to expand the field of view in these situations so therefore the requirement that the extended field of view obtained through head movements should be displayed to the driver in low speed situations.

5.2.3 Reduce aerodynamic effects

When a vehicle moves it induces a turbulent air flow that depends on the exterior design and speed of the vehicle. The turbulent air will produce an air drag that increases fuel consumption, create noise around the vehicle when the air moves over the exterior of the cab and contribute to the soiling of the cab when particles are drawn into the turbulent air around the cab.

5.2.3.1 Reduce exterior and interior noise

According to Tenstam (2008) most literature states that the major sources of aerodynamically induced noise can be found in the regions of a vehicle subjected to high wind speeds. This makes the position of today's rear-view mirrors very sensitive from a noise perspective and makes the design of the mirrors very important if noise is to be reduced. Noise originating from a camera housing placed on the exterior of the cab has two major ways of reaching the interior of the cab; it can be air borne or structure borne. Air borne noise reaches the interior through exterior noise propagating through the air and the cab such as noise from the air turbulence created by today's rear-view mirrors. Structure borne noise propagates from a vibrating component through the structure of the cab and reaches the interior through the parts attachment point. Both of these work together contributing to the interior noise that may be created from the camera housing.

Through discussions with Theresia Manns, feature responsible for in-cab noise at Volvo GTT (2012), and consultation of technical reports about in-cab noise at different Volvo truck models a list of recommendations for positioning and design of a camera housing have been developed. These should be taken into consideration if the camera housing contribution to the overall interior noise is to be lowered.

- Positioning around areas where wind speed is highest should be avoided
- Reduce the angle between the camera housing and the wind direction
- Grooves, joints, holes, cavities, narrow gaps or air passages shall be avoided

- No sharp edges or transitions should exist
- The attachment point on the cab should be well damped and a proper bushing should be used
- The attachment point on the cab should not be close to the head of the driver

5.2.3.2 Reduce soiling of the cab and its windows

The shape of the mirrors, A-pillar, gaps and grooves and their relative position to each other in the A-pillar region result in an air flow which has a direct effect on the soiling distribution on the cab and the cab windows thus limiting visibility. Wind tunnel tests performed at Volvo GTT where the soiling of cab windows was measured show that the soiling contribution from mirrors is substantial. Removing mirrors would decrease the soiling of the cab and its windows thus improving direct. Reduced soiling also leads to a less dirty and more aesthetically appealing cab with decreased need for cleaning. These tests show that the shape and position of the cab body itself, as well as all parts in the A-pillar region have to be designed in a favorable way to ensure a good soiling situation.

Soiling of the cab, its windows and the mirrors are today an important safety-factor taken into consideration when designing the exterior of a truck. Replacing rear-view mirrors with a CMS may result in decreased soiling if the design and positioning of the camera housing is done correct. To find an optimal placement of a camera with respect to soiling a discussion was held with feature specialist in aerodynamics and soiling at Volvo GTT, Linus Hjelm (2012). What can be concluded from the discussion and the rating of the cab side areas are:

- The farther away from the road the less soiling
- The area around and behind the front wheel is subjected to heavy soiling and should be avoided
- Positions around the sun visor and today’s mirrors may cause soiling on the cab side window but this can usually be reduced with a good design

5.2.4 Improve direct visibility

Direct visibility through front and side windows is important for drivers when taking in what is happening around the vehicle. In this chapter the requirements on a CMS regarding how much direct visibility that can be allowed to block is analyzed.

5.2.4.1 Cover legal demands on direct visibility

The strictest legal requirements regulating the direct field of view are the German regulations StVZO35b (InterRegs, 2006). These regulate the direct vision and how much of it can be obstructed using a semicircle of view located in front of the drivers eye position. The amount of direct visibility obstruction tolerated by the regulation depends on which sector of vision it is located in. With mirrors being crucial for safety the obstruction of direct vision caused by these can be ignored when determining if the legal demands have been met. If this will also apply to parts of a CMS will have to be further investigated.

5.2.4.2 Additional requirements on direct visibility

The direct field of view is today obstructed by the class II and IV rear-view mirrors. The results from a survey where drivers where asked which part of the truck or its interior that blocks the direct visibility the most can be seen in Figure 36. They point in the direction of rear-view mirrors being the number one obstruction of direct visibility. With today's FH mirror the obstructed field of view is 15.9° on the driver side and 6° on the passenger side. The desire is to decrease the obstructed direct field of view caused by mirrors and increase the gap between the A-pillar and the mirror. When replacing mirrors with a CMS the obstruction of direct visibility could be lowered substantially.

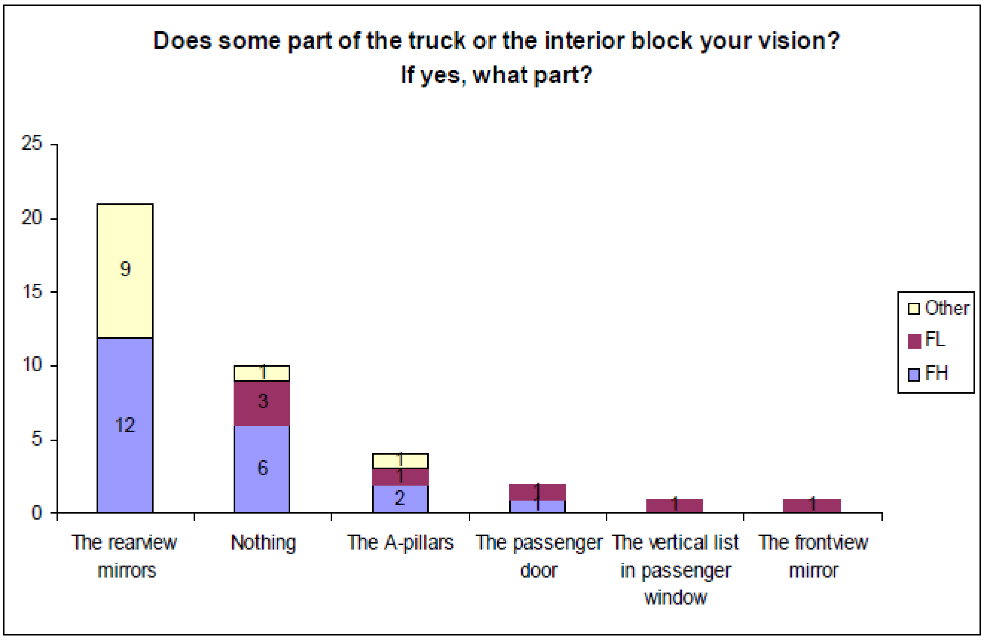

Figure 36 : Which parts block direct vision the most (Danielsson, 2011)

6 CONCEPT DEVELOPMENT

In this chapters concept solutions for how to deliver the functions defined in Chapter 0 are presented.

6.1 Camera positioning

In discussion with feature leaders affected by the camera and it's positioning on the exterior of the cab six possible mounting positions for cameras have been identified. These will be evaluated in cooperation with the involved feature leaders based on the requirements set up for the system found in Appendix A. The positions can be seen in Figure 37.

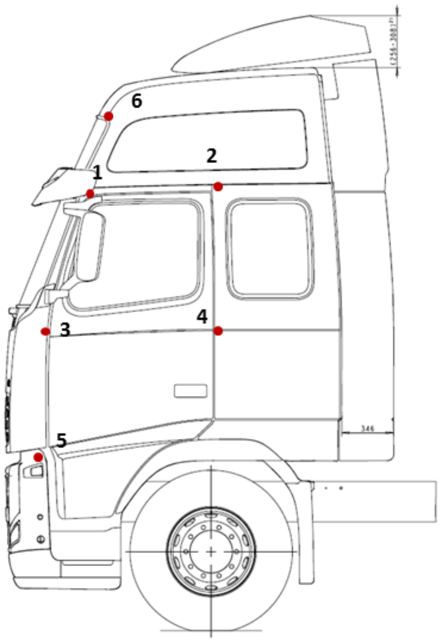

Figure 37 : Possible camera positions on the cab (Volvo GTT, 2012)

They have intentionally been located at split lines between the cab body and the door to enable mounting on either of these parts. Mounting location number 6 is situated above the door where different truck variants may differ in design but it was considered to be interesting so therefore it will be evaluated despite this fact. For every camera mounting location the same distance from the "centerline" of the truck to the camera focal point has been kept the same as seen in Figure 38 to be able to evaluate the locations regardless of this.

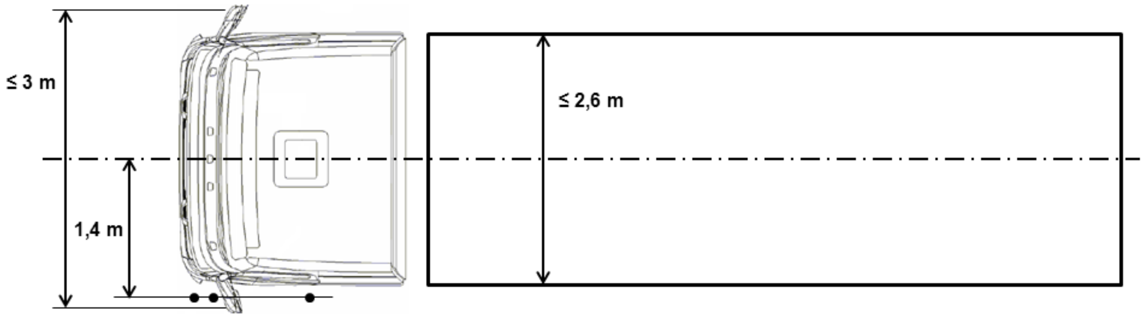

Figure 38 : Z-axis camera mounting location (Volvo GTT, 2012)

The upper trailer corner is used to define the upper limit of the vertical field of view and a point on the deflector is used to define the inner limit of the horizontal field of view to provide the driver with parts of the cab side as a reference object. In Figure 39, Figure 40 and Figure 41 the views gained for the class II and class IV camera in the camera positions proposed can be seen.

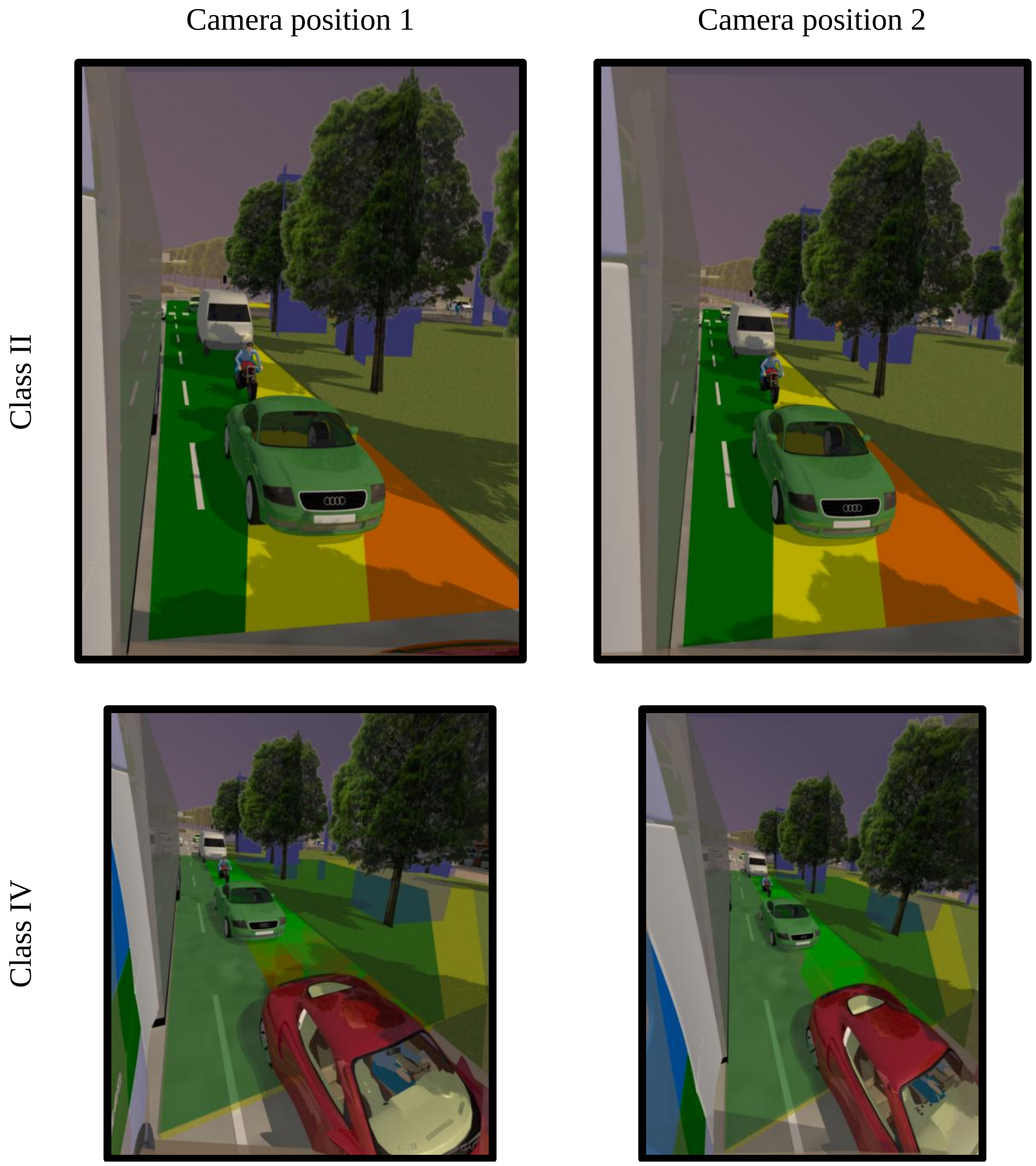

Figure 39 : Views gained from camera positions 1 and 2

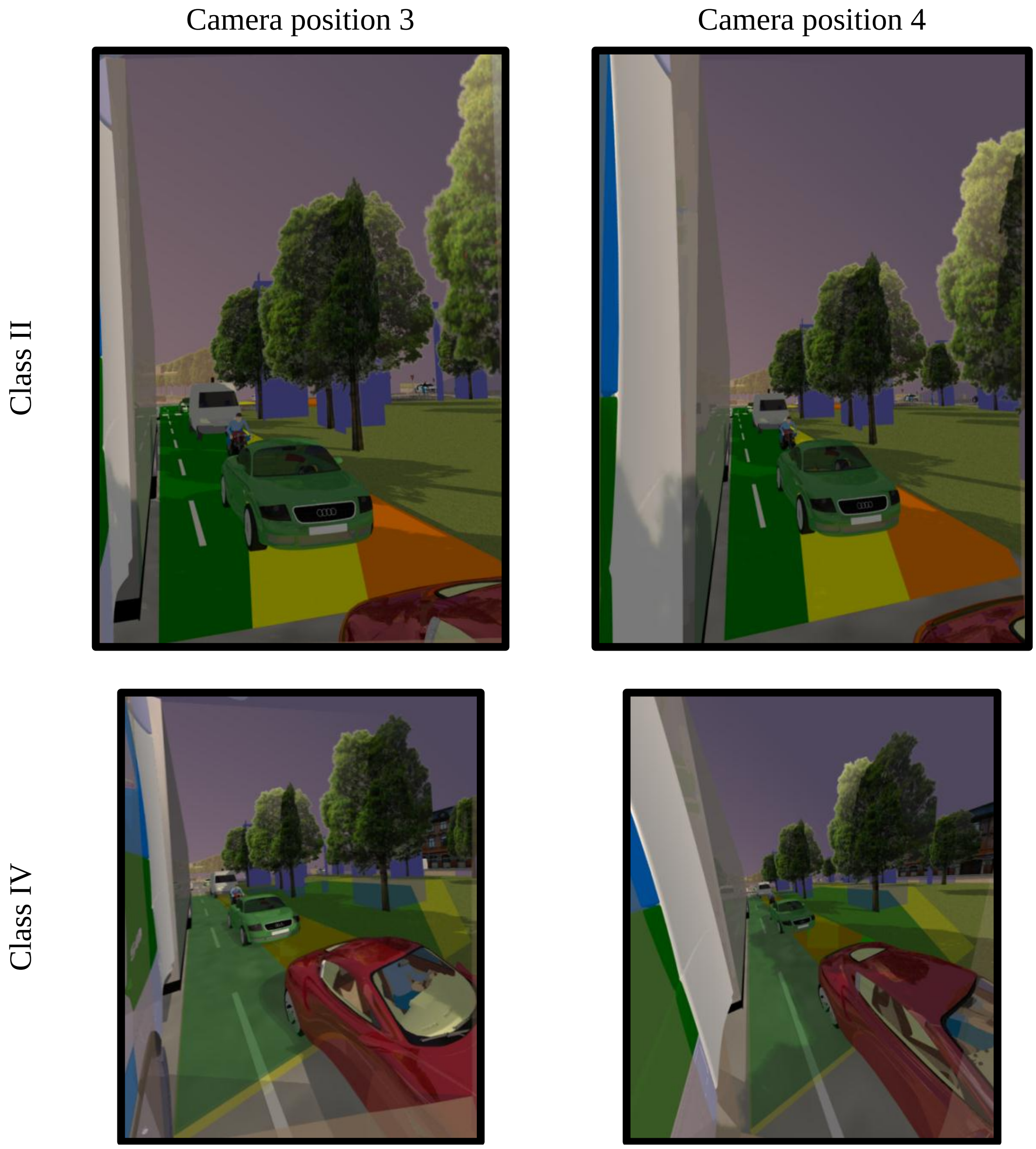

Figure 40 : Views gained from camera positions 3 and 4

Camera position 5 Camera position 6

Class II

Class IV

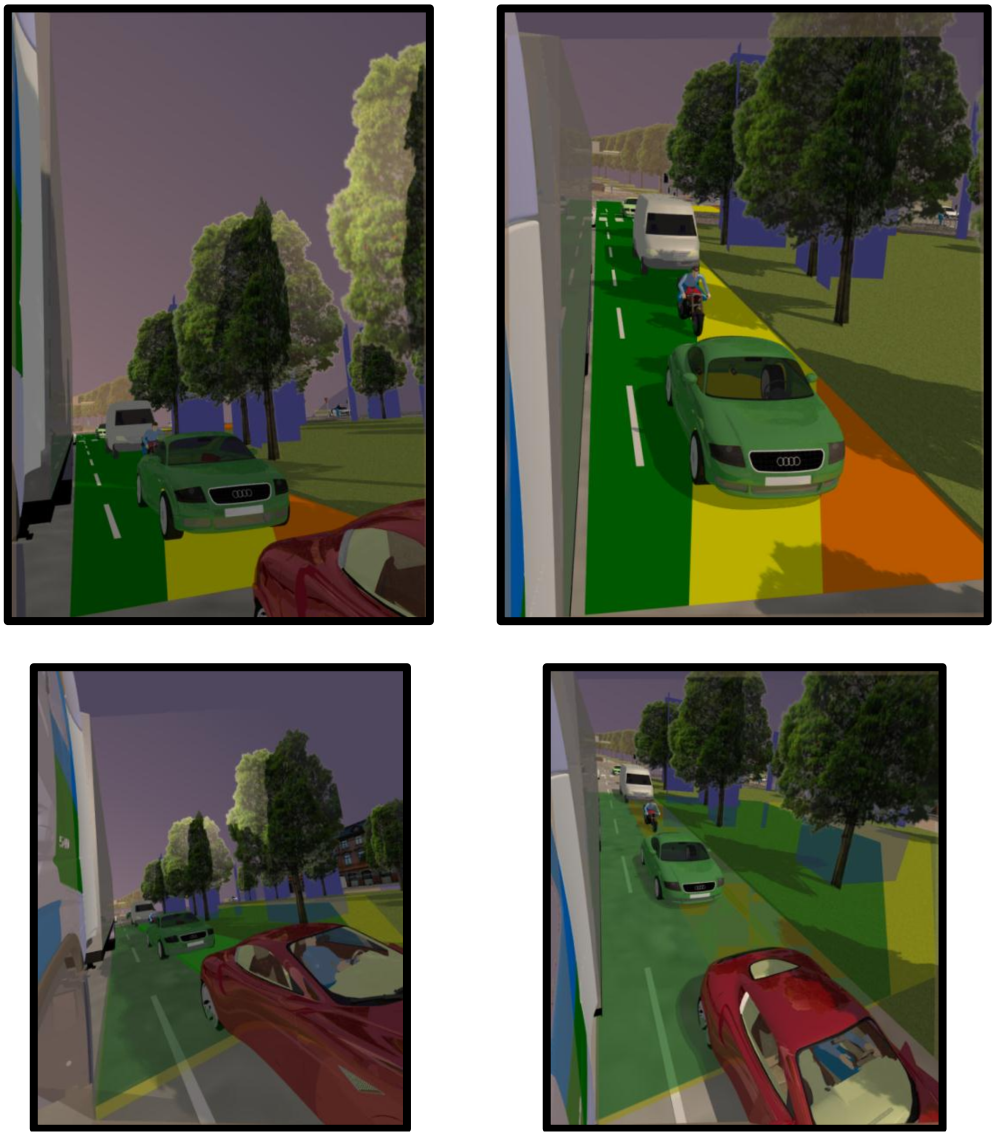

Figure 41 : Views gained from camera positions 5 and 6

6.2 Monitor positioning

Monitors can be placed at many different positions in the interior of the cab. The distance between the monitor and eye-point in combination with field of view and detection distance of critical objects determines the size of the monitor. A monitor closer to the eye-point can be made smaller in size and vice versa. If the detection distance increases then so will also the monitor sizes. In the concepts described in following sub-chapters red crosses will represent monitors corresponding to class II mirrors and white crosses to class IV mirrors. A basic presumption is that monitors showing driver side fields of view are to be placed on the driver side and vice versa. This is to not disturb the drivers' natural behavior when using mirrors.

In concept one the monitors are placed on the cabs A-pillars where the class II monitors are placed at the top and the class IV monitors at the bottom, see Figure 42. In concept two the monitors are placed on each side of the steering wheel, see Figure 43. The class II monitors are placed furthest out and the class IV monitors in the middle. Concept three merges the class II and IV monitors on respective side into one view, see Figure 44.

In concept four the driver side monitors are placed on the A-pillar whilst the passenger side monitors are placed on the dashboard to the right of the steering wheel as seen in Figure 45. Concept five consists of monitors placed at the windshield as seen in Figure 43. In concept six the driver side class II monitor is placed on the middle of the A-pillar whilst the driver side class IV mirror is placed on the dashboard to the left of the steering wheel, see Figure 47. The passenger side monitors are placed as in concept four with the class II and IV monitors on the dashboard to the right of the steering wheel.

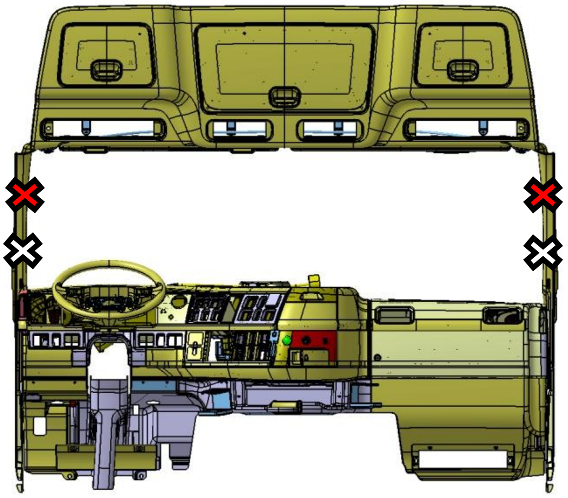

Figure 42: Monitor placement in concept 1.

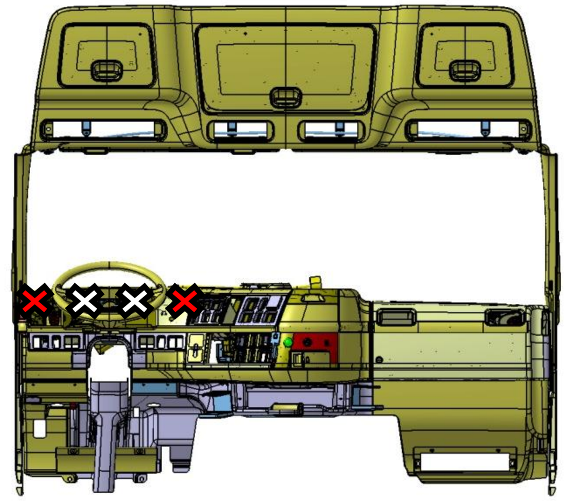

Figure 43: Monitor placement in concept 2.

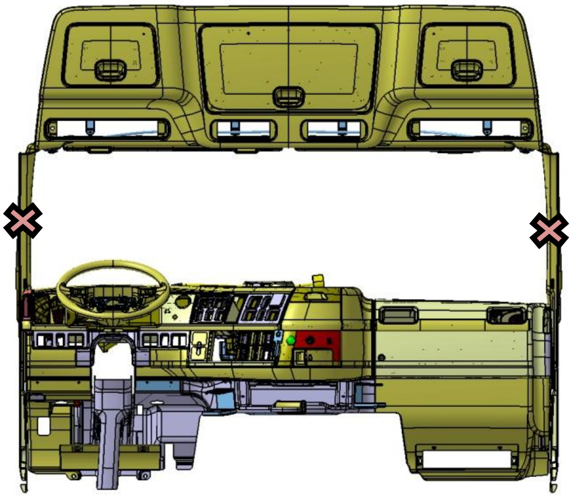

Figure 44: Monitor placement in concept 3.

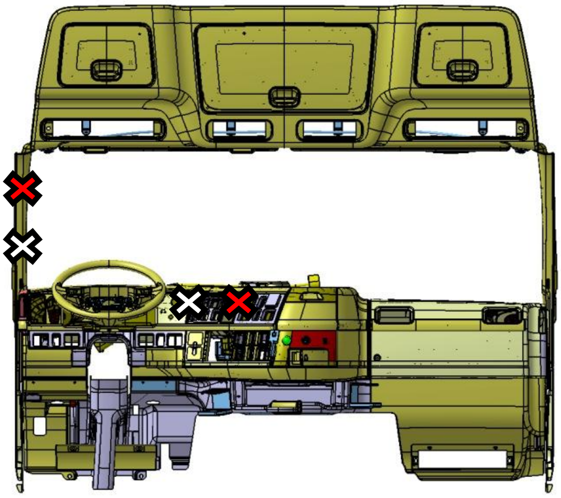

Figure 45: Monitor placement in concept 4.

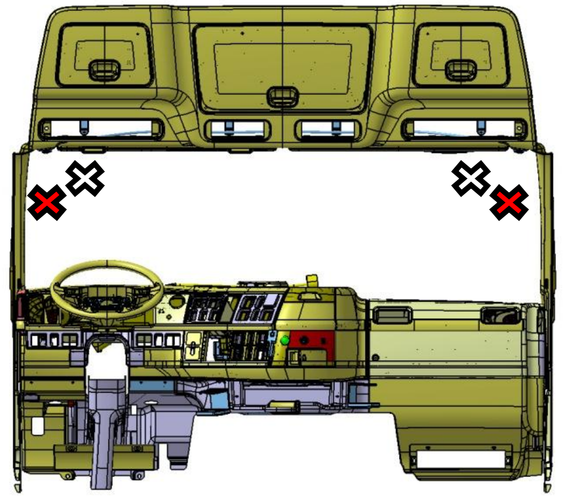

Figure 46: Monitor placement in concept 5.

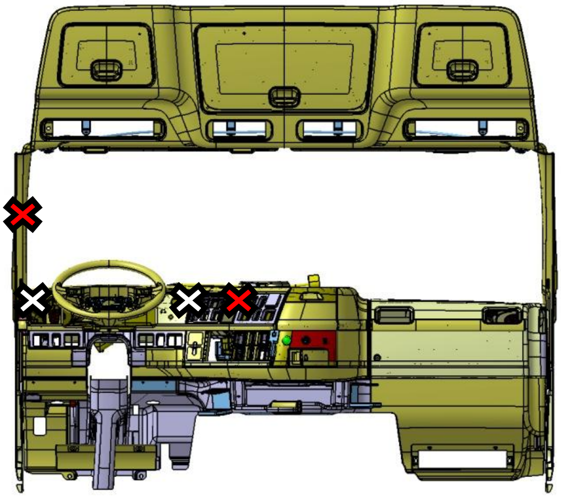

Figure 47: Monitor placement in concept 6.

6.3 When and how to show the extended field of view obtained through head movements

If the extended field of view were to be displayed constantly with the same performance as in today's mirrors the monitors used would have to be made larger compared to the angular size of today's mirrors as seen in Figure 48. This would negatively impact direct visibility and the possibilities to decrease the monitor size without losing too much in performance have been investigated.

Show the extended FoV obtained through head movements in a ***large*** monitor, ~25 x 30 cm

Show the FoV as seen in today's mirrors without head movements in a ***small*** monitor, ~15 x 30 cm

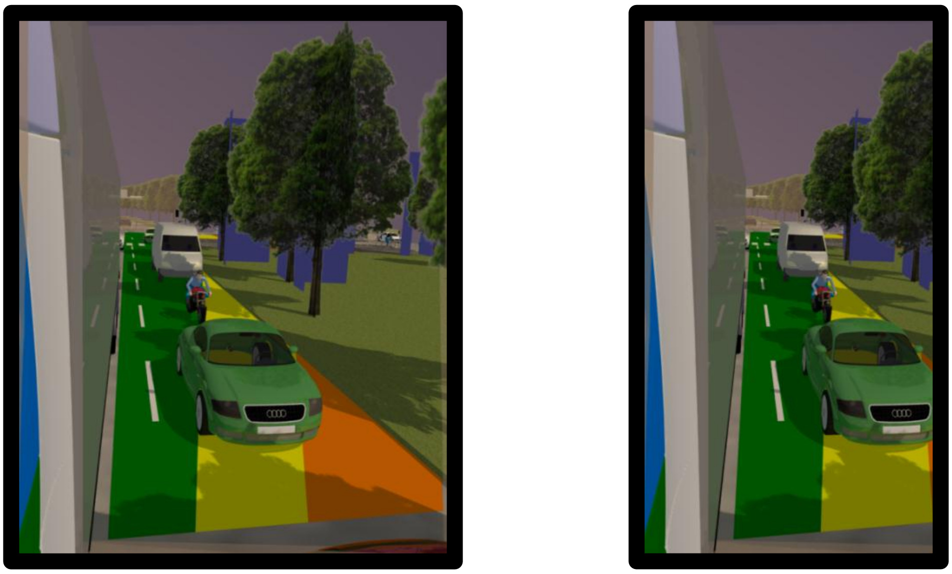

Figure 48 : Monitor size comparison

To be able to show the field of views seen in Figure 48 the monitors will have to be of the size seen in Figure 49 and Figure 50.

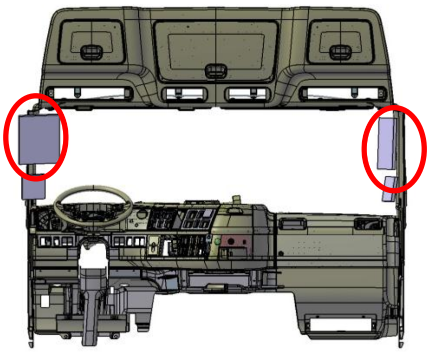

Figure 49 : Monitors showing the extended field of view obtained through head movements with the same size and resolution as in today's mirrors

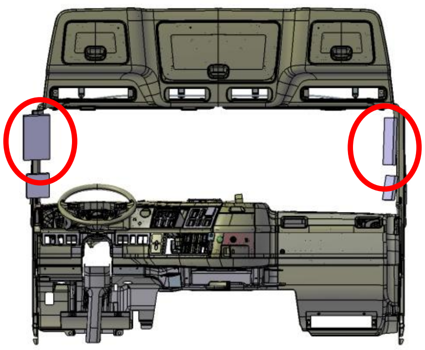

Figure 50 : Monitors showing the field of view obtained without head movements with the same size and resolution as in today's mirrors

With the input from Chapter 5.2.2.3 and Blomdahl (2012) four alternatives for when and how the extended field of view obtained through head movements should be displayed have been created. They all use speed as input for determining how and when to show the field of view to the driver.

Another input considered and that may be very interesting to investigate further is the use of reverse gear as a trigger for when and how to show the extended field of view. The study regarding head movements and their impact on the field of view displayed that the need for head movements to increase the field of view was greatest when reversing. This may imply that the fully extended field of view only needs to be shown to the driver when reversing and that a narrower field of view can be shown in other situations such as low speed forward driving.

A short description of the alternative developed can be seen in Table 8 and a more in-depth description follows.

Table 8 : Short description of the alternatives for displaying the extended field of view

Nr	Description
1	Squeeze the entire FoV to show the extended FoV obtained through head movements in low speed situations in *small* monitors
2	Squeeze only the extended FoV obtained through head movements and show it in low speed situations in *small* monitors
3	Enlarge today's FoV and squeeze the extended FoV obtained through head movements and show in low speed situations in *large* monitors
4	Show the extended FoV obtained through head movements when manually activated through panning of the FoV in *small* monitors

Alternative 1 – Image squeeze

With alternative 1 the extended field of view obtained through head movements will be shown to the driver in low speed situations by horizontally squeezing the image as seen in Figure 51. The size of objects in low speed will be decreased compared to conventional mirrors.

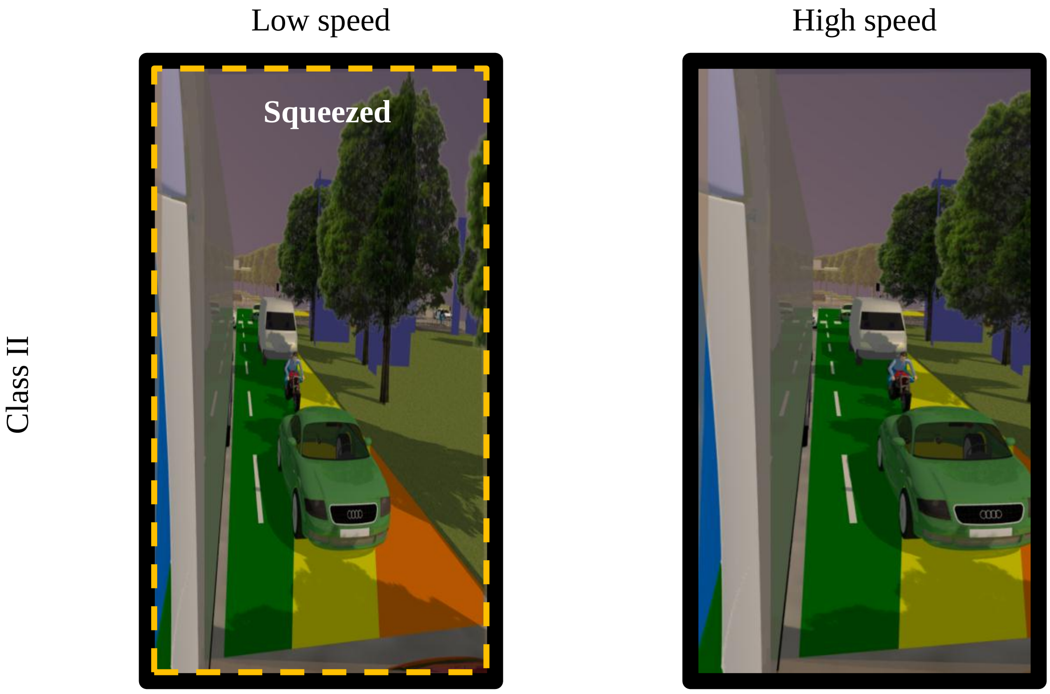

Figure 51 : Display of extended FoV alternative 1

Alternative 2 – Aspherical mirror simulation

With this alternative the field of view as seen in conventional mirrors will be displayed to the driver in high speed with the same size and resolution. In low speed the outermost field of view (outside the legally demanded area) will be horizontally squeezed as seen in Figure 52 imitating an aspherical mirror.

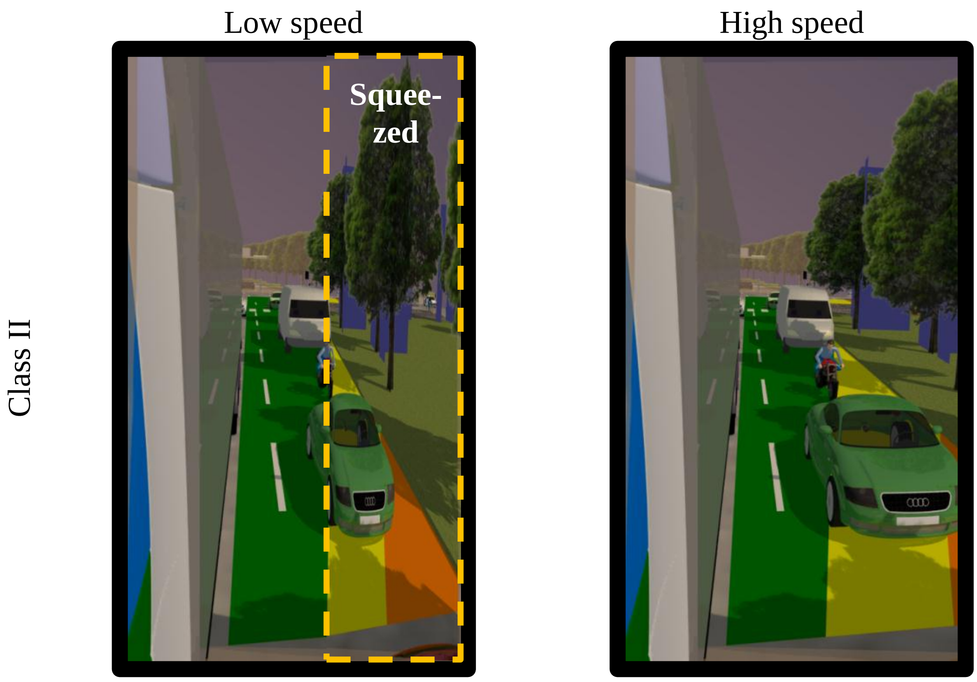

Figure 52 : Display of extended FoV alternative 2

Alternative 3 – Zoom and squeeze

With this alternative the FoV obtained through head movements with the same size and resolution as in conventional mirrors will be seen in low speed. In high speed the FoV seen in today's mirrors will be enlarged while the FoV obtained through head movements will be squeezed at the outermost part of the monitor imitating an aspherical mirror.

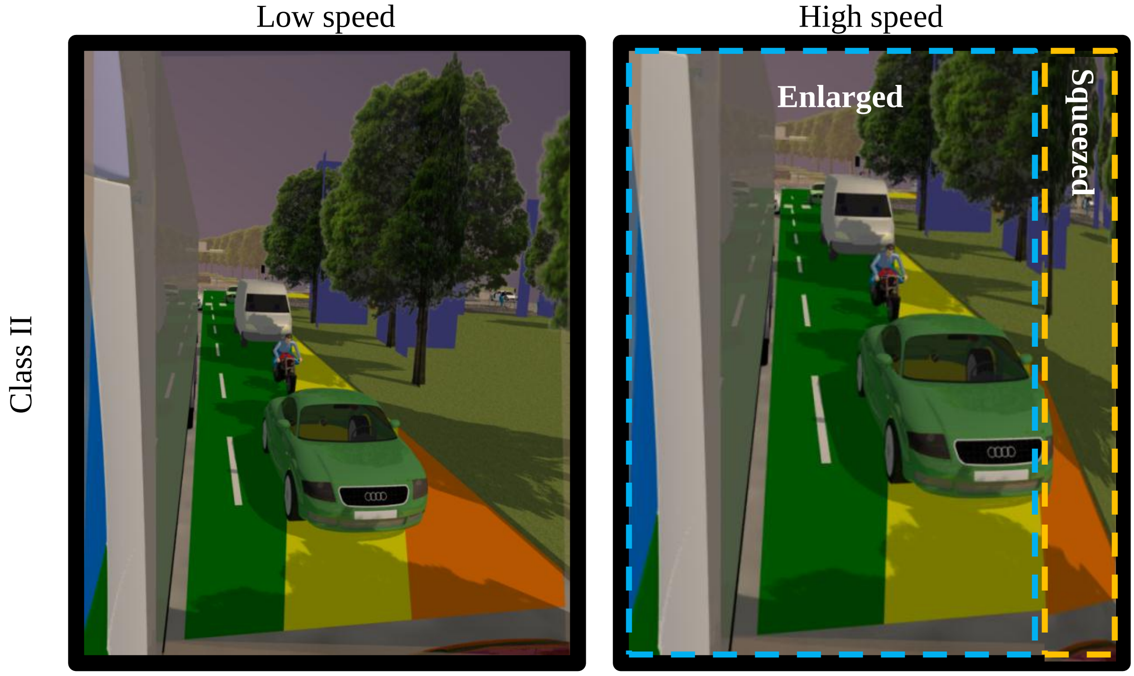

Figure 53 : Display of extended FoV alternative 3

Alternative 4 – Head movement simulation

With this alternative the field of view obtained in conventional mirrors will be displayed in high speed where objects will appear with the same size and resolution as in mirrors. In low speed the possibility to during a certain amount of time manually pan the field of view to include the extended field of view obtained through head movements will be offered to the driver. This will most realistically imitate how the field of view is changed when a driver moves his head to expand the field of view in conventional mirrors.

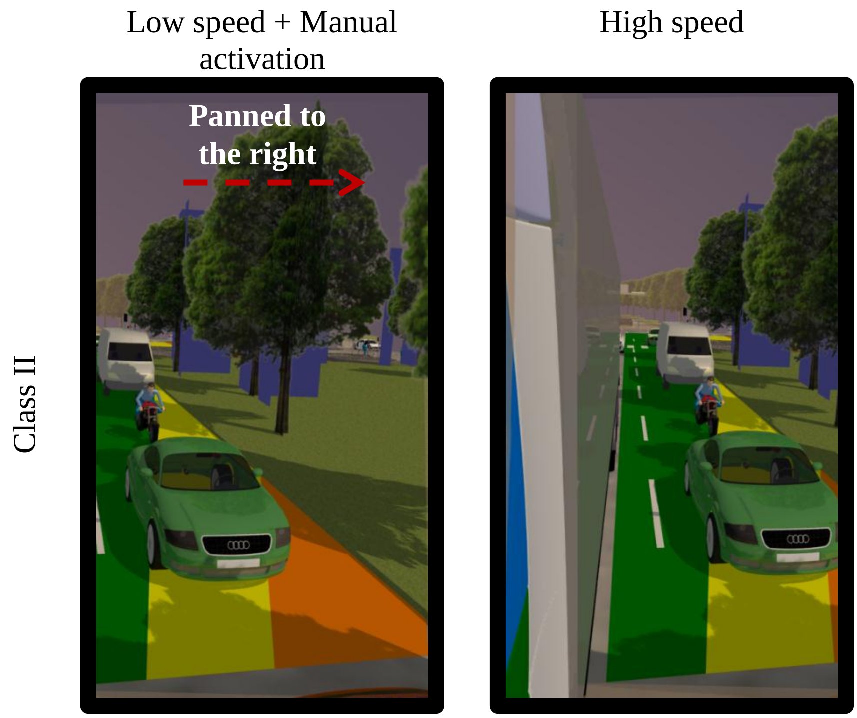

Figure 54 : Display of extended FoV alternative 5

7 CONCEPT EVALUATION

This chapter contains concept evaluations of cameras and monitors based on the requirement specification list. Camera positions will be evaluated first hand, and the “winning” concept will be used for generation of monitor concepts. A Kesselring matrix will be used as a tool for evaluation and can be found in Appendix B. Criteria in the matrix originates from the requirements that were weighted both individually and as a part of a feature area. In the individual Kesselring evaluation for camera and monitor positions criteria that were not applicable to the sub-solution evaluated were not included.

7.1 Camera positioning evaluation

The camera positions have all been evaluated with respect to the requirements set in Chapter 0 to eliminate unfavorable positions and to come up with an optimal position. They have been graded with respect to how well they fulfill each requirement and the grades have been weighted and summed up to find the camera positions that best fulfills the requirements.

7.1.1 Cognitive ergonomics

For a CMS to make the driver aware of what is happening in his indirect field of view the information displayed must aid the detection and identification of objects in the field of view. In this chapter the camera positions and their ability to facilitate this have been evaluated.

Angular resolution

The requirement on the camera to have the same or smaller angular resolution compared to conventional mirrors is dependent on the camera lens opening angle and the resolution of the camera sensor as described in Chapter 3.2.1.2. The camera lens angles are determined by the required field of view.

The camera positions defined in Chapter 6.1 together with a model of a truck with trailer were used in order to investigate the horizontal and vertical camera angles needed to cover the class II and class IV field of view defined in Chapter 5.2. The camera angles needed in the respective position can be seen in Figure 56 and Figure 57 and an example of how this investigation was carried out can be seen in Figure 55.

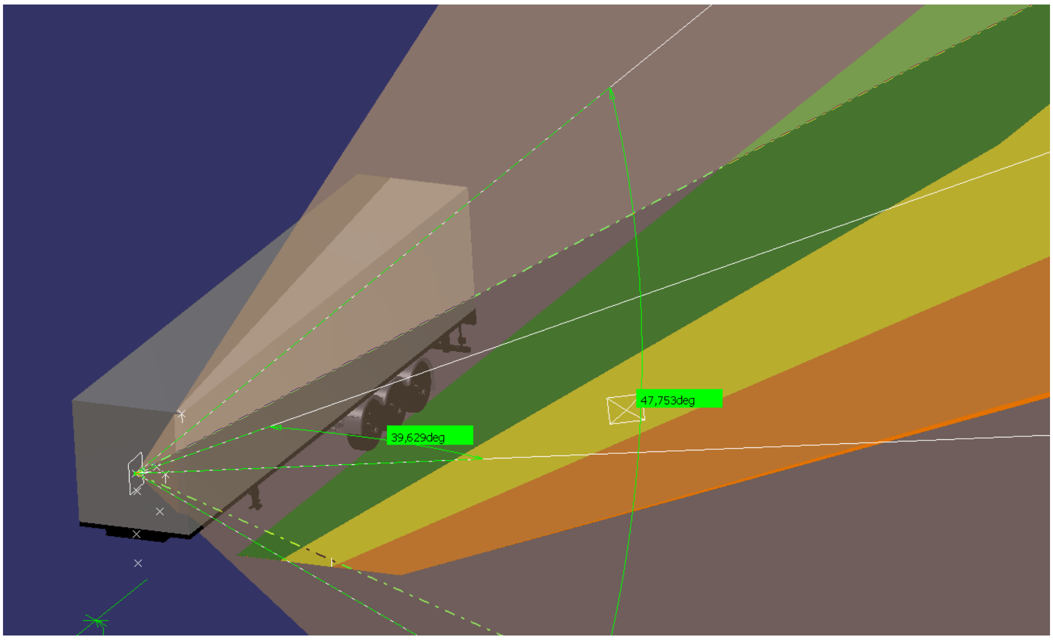

Figure 55: Evaluation example of camera mounting locations, class II, position 6

This evaluation shows that the further away from the ground and the further in the vehicle driving direction the position is located the smaller camera angles are needed to cover the required field of view. This can be seen for both class II and class IV cameras.

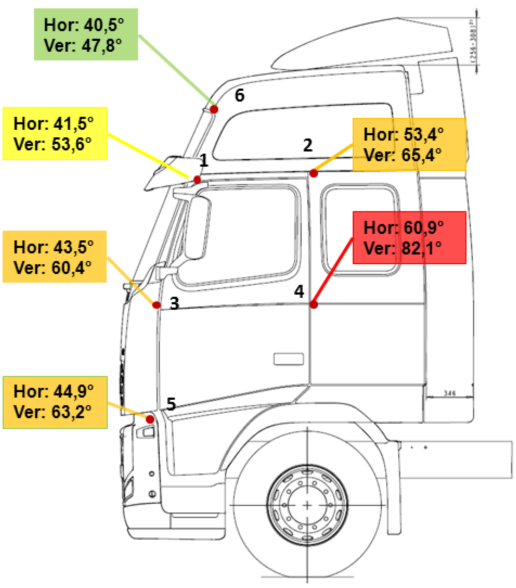

Figure 56 : Camera angles needed to cover the required class II field of view at the different camera positions

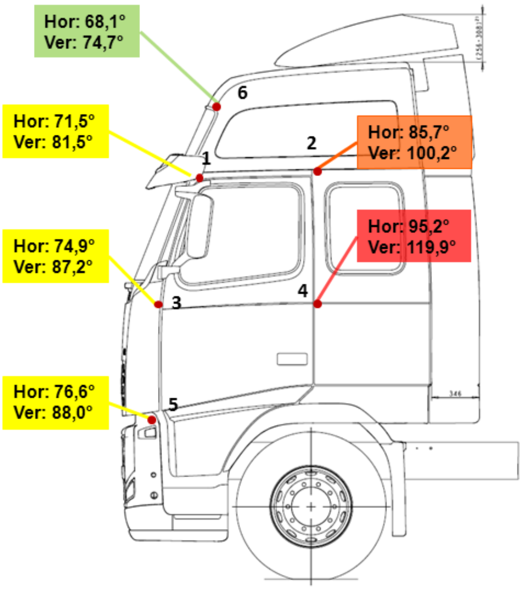

Figure 57 : Camera angles needed to cover the required class IV field of view at the different camera positions

This means that an increased camera lens angle will require a higher camera sensor resolution to achieve the same angular resolution in object space. Decreased camera lens angles will lead to better angular resolution and results in smaller camera lens angles getting the best grading as seen in Table 9 for this requirement in the Kesselring matrix.

Table 9 : Kesselring grading for object size and resolution

Maximum camera lens angle	Grading Class II	Grading Class IV
40-50°	5	
50-60°	4	
60-70°	3	
70-80°	2	5
80-90°	1	4
90-100°		3
100-110°		2
110-120°		1

Cover parts of the cab body for reference

The requirement to cover parts of the body and the trailer to provide reference objects has been used as input to the camera angle calculations in Catia V5 to make sure that all of these positions include certain parts of the cab and trailer side. The main differences between the positions are how large part of the field of view that is taken up by the cab and trailer and in what perspective they are seen. In general it is easier to cover a larger part of the cab side with the same increase in camera angle at positions located further front on the cab. Therefore the positions 1,3,5 and 6 received a higher grading than position 2 and 4 in the Kesselring matrix for both class II and IV positions.

Reduce the presence of driver and passenger side blind spots

The requirement to reduce the presence of driver and passenger side blind spots has been evaluated by looking at how the blind spots are influenced by the position of the camera. It was seen that cameras positioned closer to the ground and further in the trucks driving direction reduced blind spots on the ground the most which resulted in these positions getting the best Kesselring scoring for this criteria.

Providing depth cues to facilitate depth perception and speed estimation

The requirement that as many depth cues as possible available in conventional mirrors should be provided to facilitate distance and speed estimation has been subjectively evaluated. Through a survey with visual aids including the views gained in the different camera positions as seen in Chapter 6.1 and through discussions with feature responsible within HMI, Visibility and Driver Interface at Volvo GTT with the help of visual aids and it was concluded that:

- The x-position of the camera didn't influence the way objects were perceived
- The z-position of the camera greatly influenced the way objects were perceived and a high z-position made it easier to detect objects in a static image

This resulted in that camera positions situated higher received a better Kesselring grading compared to the lower positioned ones. Since the evaluation was conducted with static images an evaluation with moving images must be conducted to validate these results. The full survey can be found in Appendix G.

Reduce optical distortions

The requirement that objects presented to the driver should have as little optical distortions as possible is related to the camera lens opening angle. Optical distortions are dependent on many factors but the focal length and lens opening angle are contributing factors that are affected by the camera position. In general a shorter focal distance and a larger lens opening angle will produce more optical distortions. A maximum lens angle of 45° will produce a minimum amount of distortions and with angles above this distortions will increase. With this in mind the Kesselring grading for objects size and resolution found in Table 9 have been used for this requirement as well.

Reduce negative effects from self-soiling

The requirement that the displayed field of view should not be deteriorated by self-soiling has been evaluated in discussions with aerodynamics specialist Linus Hjelm at Volvo GTT (2012). The different cab side areas were graded with respect to how affected they are by soiling as seen in Figure 58. This will affect the amount of soiling on the camera lens which will decrease the image quality and has been used as input to the Kesselring evaluation matrix.

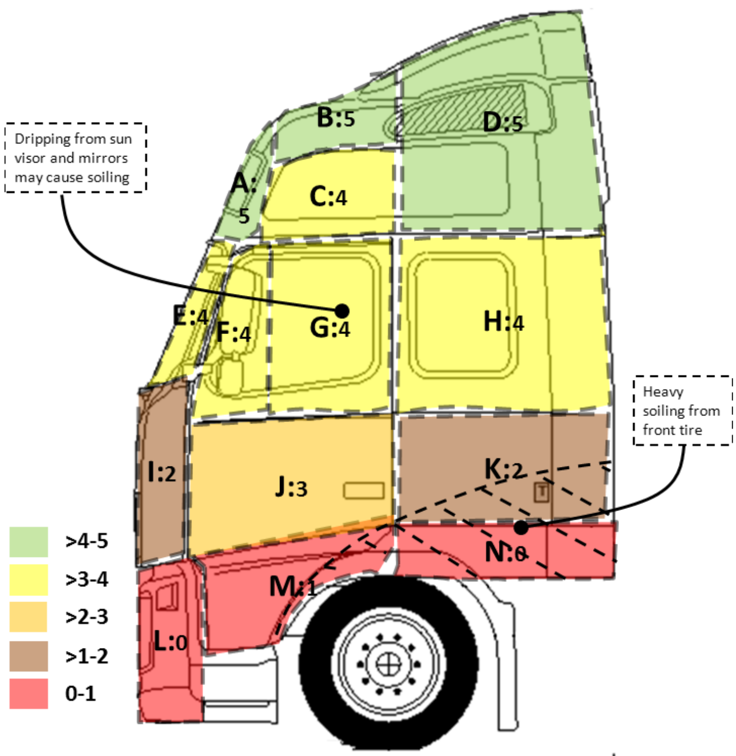

Figure 58 : Cab side area evaluation of cab soiling and self-soiling

Reduce negative effects from surrounding light sources

The requirement that negative effects from surrounding light sources such as headlights of other vehicles, the sun and street lighting should be minimized have been evaluated in discussions with headlight specialist Stig Elofsson at Volvo GTT (2012). It was concluded that positions below 1m in height above the ground should be avoided and that the higher above ground the camera was positioned the less influenced by headlights from other vehicles it was. The effect from the sun and street lighting will also be decreased with a high camera position because a high position means that the camera will be directed more towards the ground and less towards the sky due to its high position and the ground area that needs to be covered. This was used as a base for grading the different camera positions as seen in Table 10.

Table 10 : Kesselring grading for headlight effect on image quality

Height above ground	Grading
>3 - 4 m	5
>2 - 3 m	4
>1 - 2 m	3
>0 - 1 m	2

7.1.2 Reduce exterior and interior noise

The requirement for minimizing noise originating from the CMS will be affected by the position of the camera on the cab and the design of the camera housing. To evaluate the effect of the camera position on the cab the assumption has been made that the camera housing design is kept constant for all the mounting positions. When this is assumed the major factor that affects the noise is the wind speed at the different mounting locations. With increased wind speed the noise induced increases exponentially. With this in mind the Kesselring grading has been developed in cooperation with interior noise feature leader at Volvo GTT where positions has been graded depending on how high wind speeds they experience.

7.1.3 Reduce soiling of the cab and its windows

The requirement that the soiling of the cab and its windows should be minimized is as for self-soiling affected by the positioning of the camera and the design of the camera housing. The turbulence around the camera housing causes particles in the air to attach to the cab and cause soiling so therefore the amount of dirt in the air will influence most and according to aerodynamics specialist Linus Hjelm at Volvo GTT the same Kesselring grading as seen in Chapter 7.1.1 for self-soiling can be used to evaluate soiling of the cab and its windows.

7.1.4 Improve direct visibility

The requirement that direct visibility should be improved will be influenced by where a camera is placed and how big the camera housing will be. In a survey conducted at Volvo GTT regarding direct visibility drivers were asked how important certain areas of the direct visibility are. These results can be seen in Figure 59 for FH and FM trucks, 1 showing the most important area for direct visibility, and 2 the less important and so on. (Danielsson, 2011)

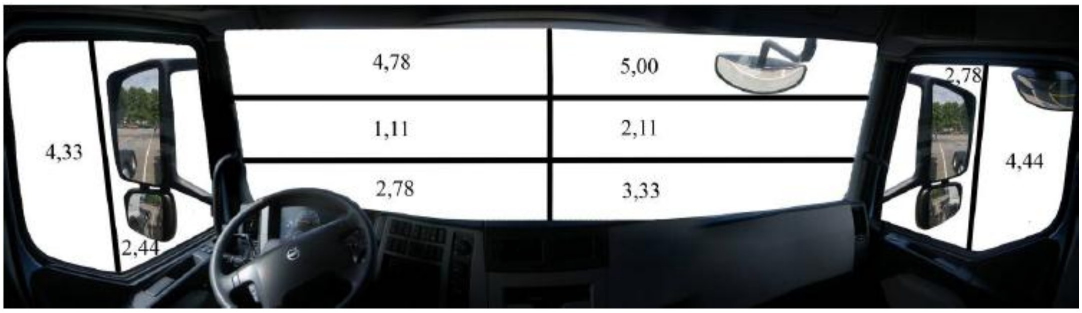

Figure 59 : Relative importance of different zones of direct visibility in FM/FH trucks (Danielsson, 2011)

The results from this survey have been used as direct input when grading the camera positions in the Kesselring matrix. The area blocked by the camera housing has been assumed to be the same for the positions that obstructs any direct visibility and the camera positions that do not block any direct visibility have been given a 5 in grading as seen in Table 11.

Table 11 : Kesselring grading for direct visibility

Direct visibility rating	Grading
None	5
4 – 5	4
3 – 4	3
2 – 3	2
1 – 2	1

7.2 Monitor concept evaluation

The monitor concepts have been evaluated on if they fulfill the German Vision regulation for direct visibility, but also how well they fulfill both physical and cognitive ergonomics. To do this monitor positions are not enough, the size of each display must be known. How monitor sizes are calculated is described in Appendix C.

The monitor size for class II monitors will differ depending on if it is on the driver or passenger side; this is also true for class IV displays. This can disturb the cognitive ergonomics for the driver since there will then be four different sized monitors which can make it hard to understand which monitor shows what field of view. A solution to this problem is to make monitors of the same class the same size. The biggest monitor for each class will set the size to not to reduce the performance compared to today's mirrors. This is also more economic since the purchase volume for each monitor will double. There is no housing on the monitors.

7.2.1 Legal demand for direct visibility

There are regulations that need to be fulfilled by each concept before passing on for further development. An important regulation for direct visibility, which affects monitors inside truck cabs, is the German direct vision legislation.

The German regulation evaluation is based upon a cone that has its center and top value in the M50 eye-point and cuts the ground level plane at a semi-circle with 12 m radius; see Figure 60 and Figure 61. Objects on and inside a truck cab can only be of a certain size not to violate the German vision regulation, see Figure 62. The requirements are extra strict if objects lie inside the sector of vision, which is the triangular area with a chord of 9,5m as seen in Figure 60. All concepts are evaluated on the German regulation and those who do not pass will be eliminated from further development. Objects that obstruct direct visibility can maximum be of a certain size according to the German regulation, as is illustrated and regulated by the graphs in Figure 62.

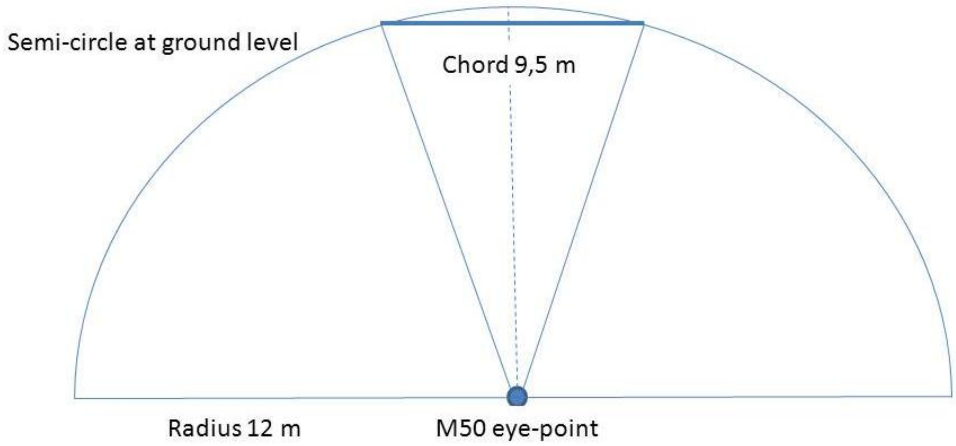

Figure 60 : The German regulation’s semi-circle of direct vision, where the triangular sector of vision is included

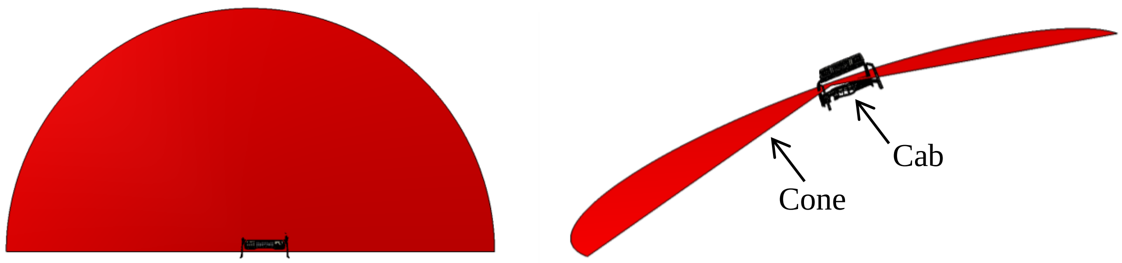

Figure 61 : The German regulation's semi-circle of vision implemented in a Volvo FH cab in Catia

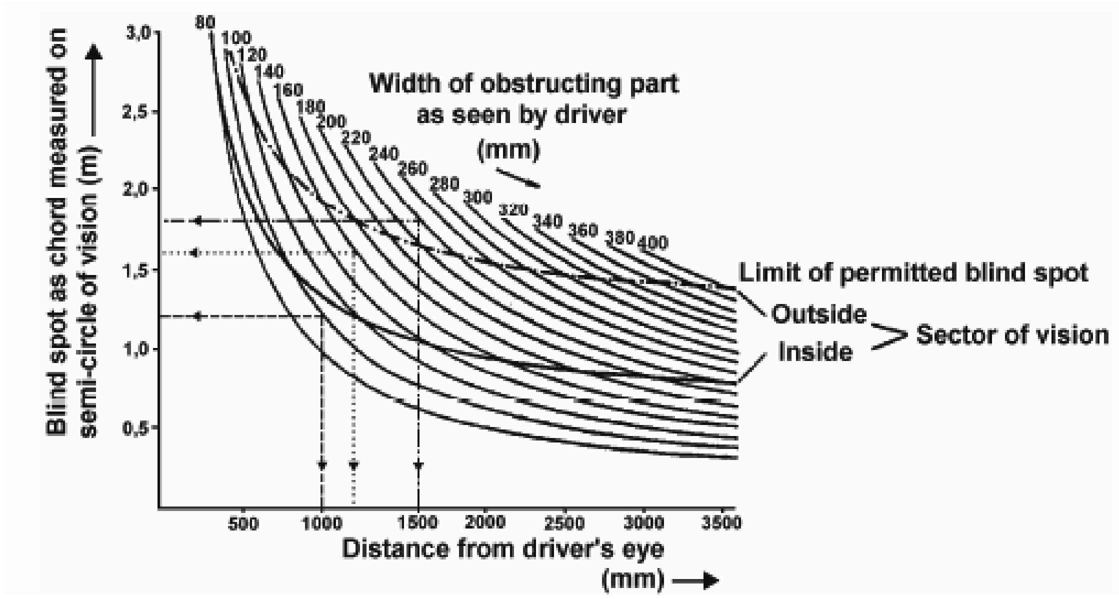

Figure 62: Allowed blind-spots on the semi-circle of vision

7.2.2 Physical ergonomics

A CMS should not cause physical problems or nuisances when used. In this chapter the monitor concepts have been evaluated on how well they follow standards and practices regarding physical ergonomics for eye movements.

Monitoring angles

In order for the CMS to be comfortable to use it has to strive to fulfill the ergonomic standard ISO 9335-3 (International Organization for Standardization, 1999). The different monitor angles in the standard are implemented inside a cab interior as shown in Figure 63 and Figure 64.

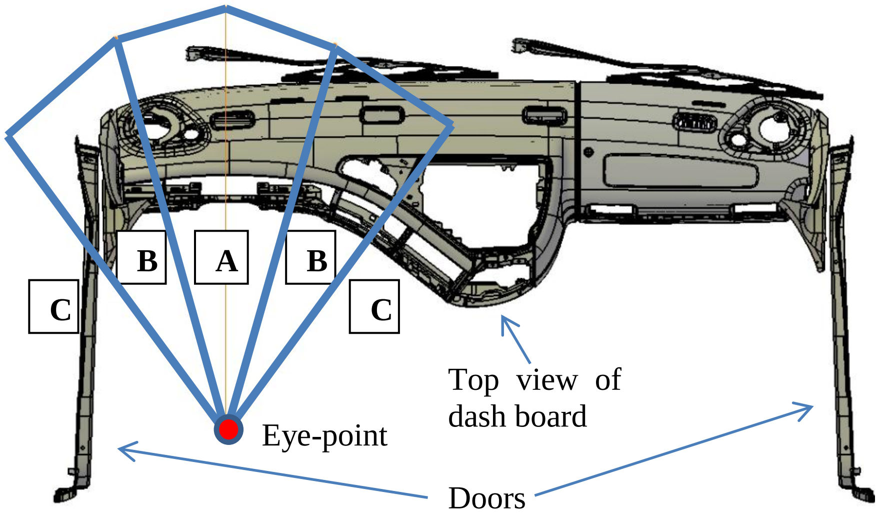

Figure 63:The horizontal monitor angles from ISO 9335-3 implemented in a Volvo FH cab environment for the M97,5

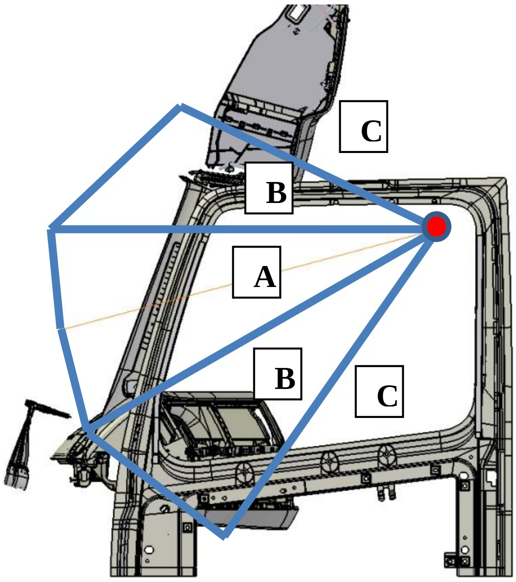

Figure 64: The vertical monitor angles from ISO 9335-3 implemented in a Volvo FH cab environment for the M97,5 eye-point (red dot)

The meaning of each monitor zone A-C is described in Chapter 5.2.2.1. Depending on which area the monitor is in and how much of that area it covers it gains different amount of points. Area A is the best possible position to place monitors in whilst C is the worst, which is reflected in the grading of each area, see Table 12.

Table 12: Amount of points depending on monitor placement

Area	Points
A	10
B	5
C	0

If a monitor has 90 % of its area in A and 10 % in area B then the final points for that concept will be:

$$Points\ concept = 0{,}9 \cdot 10 + 0{,}1 \cdot 5 = 9{,}5$$

The average of all monitors in each concept leads to a gathered concept point. The concept point is then graded according to Table 13 to get a grading for the Kesselring evaluation.

Table 13: Grading of monitor concepts regarding monitoring angles

Points:	Grading:
0-2	1
2-4	2
4-6	3
6-8	4
8-10	5

7.2.3 Cognitive ergonomics

For a CMS to make the driver aware of what is happening in his indirect field of view the information displayed must aid the detection and identification of objects in the field of view. In this chapter the monitor concepts and their ability to facilitate this have been evaluated.

Angular size and detection distance

When the monitors of each class are to be of the same size, as described in Chapter 7.2, then either the driver or passenger side monitor will get a better detection distance, thus improved angular size of critical objects. The improvement is calculated in percentage for each monitor in all concepts comparing the previous detection distance, as is as corresponding mirror, to the enhanced one. To get an overall grading for every concept an average of all monitors in each concept is calculated. The grading for Kesselring is as seen in Table 14.

Table 14: The percentage of improvement of the detection distance for whole concepts is in the left column, while the right one is the corresponding Kesselring grading for each percentage span

Percentage	Grading
<20-30	5
<10-20	4
0-10	3

Relation between the line of sight and indirect vision devices through side-windows

In some traffic situations the truck driver is in need of both the direct and indirect vision of one side of the truck to make a safe judgment of where the trailer is heading and how other vehicles and pedestrians are placed in relation to the truck. When looking out through the side window and turning the head 90°, how close is the monitors providing indirect vision to the direct line of sight? It is desired to have these vision fields as close to each other as possible in this criteria. The evaluation is done in Catia V5 by measuring the angle between the line of sight and the center of each monitor in all concepts, see Figure 65.

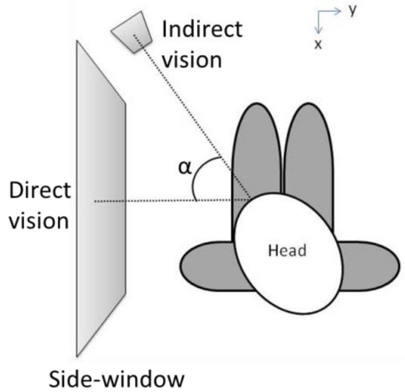

Figure 65: Illustration of how driver has to move the head between direct and indirect vision. The M50 eye-point has been used for evaluation.

Each monitor is graded according to Table 15. All concepts have four monitors, so the grading for each concept for Kesselring is gained through taking the median value of all four monitors.

Table 15: The amount of points a monitor will get depending on its angle to the line of sight

Degrees	Point
0-30	5
<30-60	3
<60-90	1

Disturbance near line of sight

When monitors are close the line of sight in the forward direction there is a risk for distraction and annoyance for truck drivers. This can be due to distracting motion in the monitors or that they are bright when driving in the dark. Thus a criterion for monitor positioning is that they should not be close to the forward line of sight.

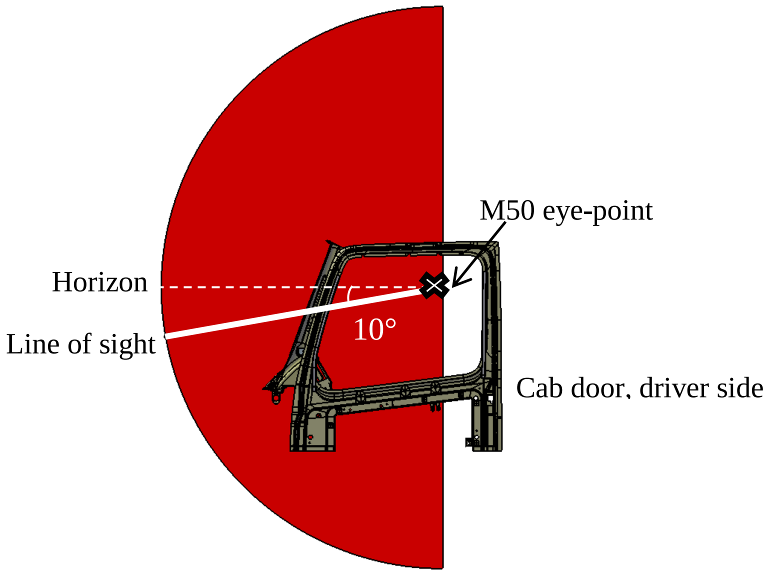

Figure 66 : The red field is the plane which the line of sight lays on when the driver is looking straight forward

The evaluation is based on a line of sight plane (see red surface in Figure 66) onto which the center points of each monitor is projected in the direction normal to the plane. The horizontal angle is measured between the three points: center point on monitor, the M50 eye-point and the projected point on the line of sight plane. The vertical angle is measured between the outmost point of the line of sight, the M50 eye-point and the projected point on line of sight plane. Depending on the size of the angle the monitors gain certain grading, see Table 16.

Table 16: Grading of monitors depending on the horizontal or vertical angles

Degrees	Grading
0-30	1
<30-60	3
<60-90	5

The median of the grades are then taken for all monitors in each concept for horizontal and vertical angles. The last step is then to take the average between the median for each concept for both vertical and horizontal measures. These resulting values for each concept will be the grading for Kesselring.

7.2.4 Improve direct visibility

At Volvo GTT they use so called visibility zones in the direct field of vision to evaluate direct visibility, see Figure 67. The zones are located on a sphere with 10 m radius with its center in the M50 eye-point and in Figure 67 obstructing surfaces in the interior cab have been projected onto the vision zones (Johansson, 2012).

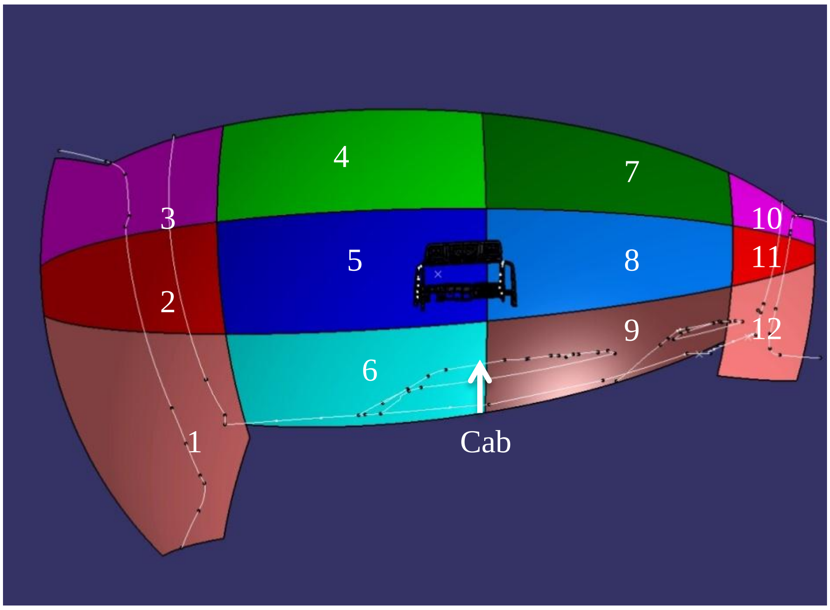

Figure 67 : Volvo GTT vision zones with obstructing surfaces

To compare different monitor concepts against each other the monitor surfaces are projected onto the vision zones. The resulting unobstructed area in each zone is then multiplied with a weight factor, which is based in the importance of respectively zone for the direct visibility. The product of the unobstructed area of each zone and the weights are then added together for each concept, which results in a total concept score. Depending on the value of the concept score each concept will get certain grading for the Kesselring evaluation, see Table 17.

Table 17: Concept scores and the corresponding grading for Kesselring evaluation

Concept score	Grading Kesselring
<1465-1520	4
1410-1465	3

7.3 Evaluation of when and how to show the extended field of view obtained through head movements

Through discussions and focus group sessions with HMI, Visibility and Driver Interface specialists at Volvo GTT comments, thoughts and remarks have been put forward regarding the alternatives for displaying the extended field of view as described in Chapter 6.3.

Alternative 1 – Image squeeze

Squeezing the entire extended FoV obtained through head movements into small monitors in low speed situations will influence both the resolution and size of objects seen and the length and width ratio for them. This will happen over the entire FoV including the legally demanded FoV which may cause problems depending on how new standards and legislations in the CMS areas will be formulated.

- Size of the monitors can be decreased to around W:15 cm and H:25 cm

- Performance (size and resolution of objects in the monitors) in the entire FoV will be temporarily decreased compared to conventional mirrors
- Minor distortions and H/W-ratio alterations temporarily for the entire FoV (horizontally squeezed)

Alternative 2 – Aspherical mirror simulation

To squeeze only the outermost part of the FoV presented to the driver, the FoV as seen in today's mirrors and the extended FoV obtained through head movements will be similar to the aespheric rear-view mirrors seen in passenger cars today. It has the advantage that performance in the legally demanded FoV will not be decreased which may remove some of the problems that could occur with alternative 1. The trade-off for this will be that the outermost part of the FoV will be much distorted and it may be hard to detect and identify objects located there.

- Size of the monitors can be decreased to around W:15 cm and H:25 cm
- Performance (size and resolution of objects in the monitors) in the legally demanded FoV will be kept the same as for conventional mirrors
- Heavy distortions and H/W-ratio alterations temporarily in the outermost parts of the FoV

Alternative 3 – Zoom and squeeze

This alternative will increase the performance of the CMS in certain situations compared to conventional mirrors but this comes at the price of larger monitors.

- Size of monitors increased to around W:25 cm and H:30 cm
- Performance (size and resolution of objects in the monitors) in the legally demanded FoV will be increased compared to conventional mirrors
- Minor distortions and H/W-ratio alterations temporarily in the outermost parts of the FoV
- Temporarily decreased vertical FoV due to cropping, the top part of the FoV is temporarily removed

Alternative 4 – Head movement simulation

This alternative resembles how the FoV is changed when a driver moves his head to change what is seen in conventional mirrors. Since the FoV can temporarily be changed the legally demanded FoV will not be constantly be shown which will have to be allowed in upcoming standards and legislations for this alternative to be possible.

- Size of the monitors can be decreased to around W:15 cm and H:25 cm
- Performance (size and resolution of objects in the monitors) in the entire FoV will be kept the same as for conventional mirrors
- Parts of the legally demanded FoV will temporarily be hidden

7.4 Concept questionnaire evaluation

To provide feedback on the concepts concerning camera positioning and monitor set-ups a questionnaire was sent out to six key people working within HMI, Visibility and Driver

Interface at other global sites within the Volvo Group. The questionnaire and the answers received can be found in Appendix G. In the answers received the following opinions and comments were put forward;

Opinions and comments regarding camera positions 1,4 and 5

- Camera position 1 was ranked the highest among the ones presented (position 1,4 and 5)
- Camera position 1 provides a high view point where other vehicles and traffic situations more easily can be detected
- Camera positions 4 and 5 situated lower than position 1 resulted in vehicles being hidden behind other vehicles
- Camera position 5 may experience problems with vibrations and getting hit by other objects
- A camera position at the same height as the eye-point would provide the driver with the same perspective as seen by their own eyes

Opinions and comments regarding monitor set-up concepts 1,4 and 5.

- Monitor concept 1 was ranked the highest among the concepts presented (1,4 and 5)
- Monitor concept 1 resembles the way mirrors are placed today the most and is this more intuitive and can more easily be accepted by drivers
- Monitor concept 4 can be problematic due to the already crowded dashboard
- Monitor concept 5 moves the indirect visibility closer to direct visibility reducing head movements
- Having monitors aligned differently at the driver and passenger side is not intuitive and may cause problems
- Monitor concept 5 causes problems if there is a passenger in the truck
- Monitor concept 4 may cause problems because the monitors are not situated on the same horizontal plane
- Should a monitor concept where the monitors are placed in the bottom of the dashboard be considered?

General opinions and comments about introducing a CMS

- The market acceptance for a system like this may take a very long time and regulation will have to change
- Having a CMS complementing mirrors may be a good way to introduce the system

Summary

Overall the comments and opinions regarding the concepts and solutions were well in line with what was concluded so far. The camera position and monitor concept that the Kesselring evaluation found the most promising were also top ranked by the participants. Aspects put forward that were not included in the Kesselring evaluation that have to be taken into account when further developing a CMS were;

- A camera position at the same height as the eye-point would provide the driver with the same perspective as seen by their own eyes

- Having monitors aligned differently at the driver and passenger side is not intuitive and may cause problems
- Monitor concept 4 may be problematic due to the already crowded dashboard
- Monitor concept 5 causes problems if there is a passenger in the truck

8 RESULTS FROM CONCEPT EVALUATION

In this chapter the results from the concept evaluation in Chapter 0 and a proposal for how a CMS providing the functions and fulfilling the requirements identified in Chapter 0 is presented. A summary of the findings for a CMS in this result section can be found in Appendix H.

8.1 Camera monitor system specifications

After analyzing customer needs and defining system requirements concepts were developed and evaluated based on these. A Kesselring evaluation matrix along with opinions from persons at Volvo GTT was used to eliminate weak concept solutions and finally come up with a winning concept. The winning concept solutions are here presented and the technical system specifications needed to fulfill all the requirements are stated.

8.1.1 Camera specifications

In this section the camera specifications derived from the system functionality and its requirements are set.

Camera position on the cab

The result of the Kesselring evaluation matrix found in Appendix B resulted in the following rating of the six evaluated camera positions. The rating is expressed in a percentage of how close the position was in gaining the best scoring among all the evaluation criteria. As seen the ranking is the same for both cameras covering class II and IV field of view which indicate that one camera position and housing could be used for both these cameras.

Table 18 : Ranking and rating of the camera positions according to the Kesselring evaluation matrix

Ranking	1	2	3	4	5	6
Class II	Position 6 (95%)	Position 1 (87%)	Position 2 (80%)	Position 3 (69%)	Position 5 (69%)	Position 4 (62%)
Class IV	Position 6 (95%)	Position 1 (87%)	Position 2 (75%)	Position 3 (73%)	Position 5 (73%)	Position 4 (62%)

As seen in Table 18 camera positions 6 and 1 were ranked as the top two positions for both class II and IV cameras. These are both located above the door in the vicinity of the A-pillar. The fact that position 2 came out as the third best position also confirmed that positions above the door are most favorable.

During evaluation it was seen that camera position 1 and 6 only differed in the evaluation criteria 2.6 and 4.1 which had to do with soiling of the cab and self-soiling of the camera. The reason for position 6 to gain a higher grading in these were that it was situated farther away from the ground and farther away from the window than position 1. An aspect that was not used as evaluation criteria but was brought up in Chapter 6.1 was the fact that position 6 was not common for all cab types. This would mean that the design of the camera housing would have to change and its position would have to be moved depending on the type of truck variant manufactured. In discussions with engineers at Volvo GTT a position on the cab was found that was located in between position 1 and 6 but still on a position common for all cab types. The area chosen for positioning of the camera housing is seen in Figure 68.

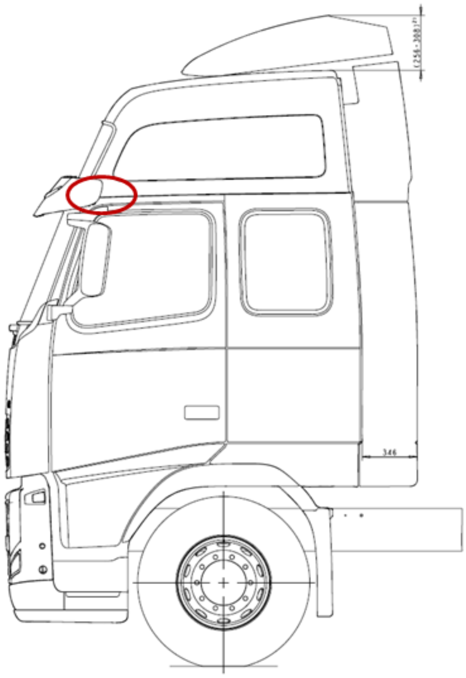

Figure 68 : Most suitable area for mounting of the camera housing for class II and class IV cameras

Camera housing attachment and integration with the cab

Through further discussions it was concluded that a mounting of the camera around the attachment point above the door where the sun visor is attached would be a suitable mounting location for the camera housing. Aerodynamics specialists pointed out that the air flow in this area could cause a potential problem with air induced noise so an aerodynamic design preferably integrated with the sun visor would be desirable. If this is to be achieved two options exist;

- Integrate the sun visor and the camera housing into one part

The benefit with integrating the sun visor and the camera housing into one part is that the aerodynamic properties of the part can be optimized. A possible problem that can arise from this is that the camera housing and the sun visor may have different tolerances and the cost associated with this. Another issue may be that the sun visor will have to be a mandatory part of the truck whereas it today is optional and sold as an accessory.

- Keep the sun visor and the camera housing as two separate parts but with an integrated design of the individual parts

The benefit of this solution is that the sun visor and the camera housing will still be two separate parts and the sun visor can still be an optional accessory. The sun visor is also a part that mainly exists because drivers are used to it and not because it delivers a function that cannot be implemented by another feature (for example a tinted window top-part). This may indicate that the sun visor could disappear or in other ways radically change in the future which also may speak for a design with separate parts.

Camera lens opening angles

The position of the camera on the cab and the required field of view that needs to be covered sets demands on how big the camera lens opening angles will be have to be. The camera lens opening angles needed for the position above the door close to the attachment point for the sun visor as earlier described can be found in Table 19 and in Figure 69. The “Class II legal” describes the lens opening angles needed to cover the legally demanded field of view, “Class II FH” describes the lens opening angles needed to cover the field of view seen in today’s FH mirrors and the “Class II FH with head movements” include the field of view obtained through head movements. Since this area will have to be displayed in certain situations and a mechanically moving camera should be avoided the lens opening angle will have to be increased and set according to the “Class II FH with head movements”.

Table 19 : Camera lens opening angles needed

Mirror replacement	Horizontal	Vertical
Class II legal	15,7°	48,9°
Class II FH	26,8°	49,4°
Class II FH with head movements	**40,3°**	**50,6°**
Class IV FH	**69,5°**	**77,7°**

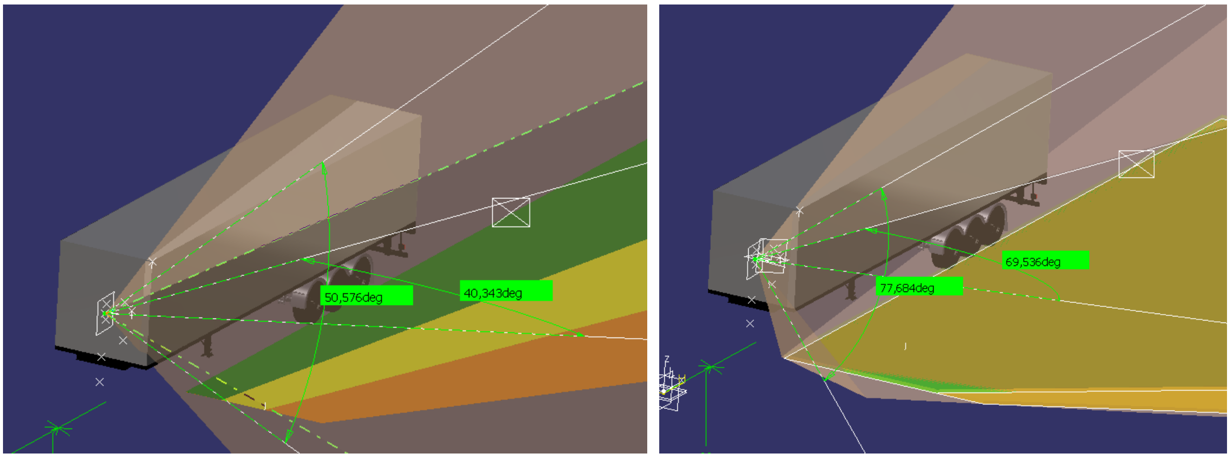

Figure 69 : Catia V5 investigation of camera lens opening angles needed

Resulting horizontal field of view on ground

The resulting horizontal field of view on ground for class II and IV can be seen in Appendix D, Figure 73 and Figure 74. The inner area is the legal requirement, the middle one the additional area covered with today’s FH mirrors and the outer one the area covered when moving the head to expand the field of view seen in today’s FH mirrors. What needs to be covered by the camera and what determines the camera lens angles needed is the field of view obtained through head movements on the driver side in FH mirrors which also has been used on the passenger side to increase the performance and the field of view seen there.

Camera resolution

Requirements on the camera resolution were defined in Chapter 5.2.2.2 as the best resolution gained in conventional mirrors or determined by the resolution of the monitor used. The resolution gained in conventional mirrors is calculated using the formula in Chapter 3.1.2 and the results can be seen in Table 20. The horizontal mirror tilting angles can also be seen in the table and the visual acuity used was 1 arc-min which is the minimum level of detail that the human eye can perceive as described in Chapter 3.1.1.

Table 20 : Angular resolution in conventional mirrors

	Driver side		Passenger side	
	Class II	Class IV	Class II	Class IV
Horizontal mirror tilt angle [°]	12,8°	12,8°	38,7°	38,7°
Angular resolution in conventional mirror [arc-min]	2,51	7,62	5,85	19,99

This angular resolution in object space will put demands on the resolution of the camera that is needed to deliver the correct amount of detail to the monitor as seen in Table 21. Since the same camera should be used for both the driver and passenger side the resolution in object space will be set to the driver side performance because this is the highest due to the proximity of the monitors on this side.

Table 21 : Camera resolution needed to fulfill the requirements for angular resolution perceived in driver side conventional mirrors

	Class II		Class IV	
	Horizontal	Vertical	Horizontal	Vertical
Camera lens opening angle	40,3°	50,6°	69,5°	77,7°
Camera pixels needed set by the mirror resolution	**964**	**1210**	**548**	**612**

The angular resolution needed to provide the driver with enough detail in the monitors not to experience the image as low resolution as defined in Chapter 5.2.2.2 will set requirements for the camera resolution needed as seen in Table 22. This requirement makes sure that pixels are mapped one-to-one between the camera and the monitor when showing the field of view as seen in today's FH mirrors. When the extended field of view needs to be shown the angular resolution may be altered in order to fit this view into monitors of the same size used when showing the FH FoV.

Table 22 : Camera resolution needed to match the monitor resolution

	Class II		Class IV	
	Horizontal	Vertical	Horizontal	Vertical
Total camera lens opening angle	40,3°	50,6°	69,5°	77,7°
Angle needed to show the FH mirror FoV	26,8°	49,4°	69,5°	77,7°
Relation between FH mirror FoV and total camera lens opening angle	66,5%	97,6%	100%	100%
Monitor pixels required for concept 1	897	1595	722	778
Monitor pixels required for concept 4	779	1423	704	758
Camera pixels required set by the monitor resolution	**1349**	**1635**	**722**	**778**

By looking at Table 21 and Table 22 it can be concluded that the requirements on camera resolution set by the monitor resolution is the highest. This camera resolution will be used to ensure that requirements on system resolution will be fulfilled at all times.

8.1.2 Monitor specifications

Chosen monitor concepts

The evaluation of the concepts against the German sight regulation resulted in that monitor concept 3 was eliminated. It did not pass the German regulation due to too big obstruction of the sector of vision, the chord is 1942 mm and the distance to drivers eyes is 693 mm, see Figure 62 in chapter 7.2.1. For pictures of all concepts and how they lie in relation to the German sight cone, see Appendix E.

The Kesselring evaluation resulted in that monitor concept 1 and 4 were top ranked, see Table 23. The entire Kesselring for monitor concept evaluation is located in Appendix B. Figure 70 shows the winning monitor concepts from the concept evaluation.

Table 23: Table showing the resulting Kesselring ranking of the monitor concepts

Ranking	1	2	3	4	5
Monitor Concept	1 (71.4%)	4 (70.6%)	5 (67%)	6 (63%)	2 (59%)

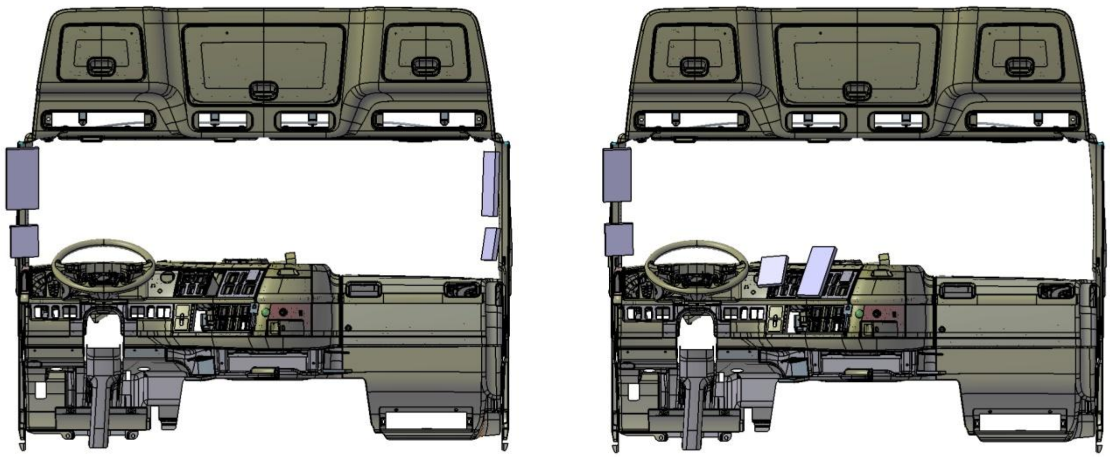

Figure 70 : The picture to the left shows the monitors in concept 1 and the picture to the right shows the monitors for concept 4

The monitor concept 1 is better than concept 4 at the vertical placement of the monitors in relation to the forward line of sight, whilst concept 4 is better on placing monitors in a good horizontal monitoring angle. Concept 1 is better on placing the monitors in line with the direct line of sight when watching out through the truck side-windows, but also at not having the monitors too close to the line-of sight that may cause distractions. The monitor concept 4 is better than concept 1 in improving the angular resolution of objects compared to today's mirrors. An issue with concept 4 is the placement of the passenger side class II and IV monitors. The dashboard is very crowded today with buttons, displays, air-outlets or other equipment that cannot be blocked.

Monitor size

The monitor sizes are calculated as stated in Appendix C for the M97,5 eye-point because this person will be furthest away from the monitors and therefore having most difficulties seeing critical objects with the right angular size. The resulting monitor sizes can be seen in Table 24.

Table 24: Monitors width and height for the two monitor concept who received the highest grading in the Kesselring evaluation

		Concept 1 (mm)	Concept 4 (mm)
Class II	Width	150	130
	Height	270	240
Class IV	Width	130	130
	Height	140	140

Monitor resolution

There are two requirements determining the pixel resolution of the monitors. The first requirement is based on that the resolution is most critical to the driver sitting closest to the monitors, which in Volvo trucks are F05 as described in Chapter 3.3.2 and Appendix F. This driver will more easily be able to distinguish low monitor resolution and experience image quality issues due to the driver's proximity to the monitor. The angular resolution requirement for this driver is defined in Chapter 5.2.2.2 as 1 arc-min being the smallest angular resolution distinguishable by the human eye.

The second requirement is that the minimum angular resolution needs to be 2 arc-mins at the closest ergonomically recommended eye to monitor distance as recommended by TCO (TCO, 2011). The closest ergonomically recommended eye to monitor distance is defined in Chapter 5.2.2.1.2 as 400mm. This requirement is necessary to ensure that "jaggies" and other effects from low resolution do not appear even if a person leans forward towards the monitor to have a closer look at what is displayed.

Based on these two demands the pixel resolution is calculated for each monitor in concept 1 and 4. The highest resolution will be dimensioning for how many pixels each monitor shall have, see Appendix F. The pixel dimension for each monitor can be seen in Table 25, and the pixel density in Table 26.

Table 25: Pixel dimension for monitor concepts 1 and 4

		Concept 1 (pixels)	Concept 4 (pixels)
Class II	Horizontal	897	779
	Vertical	1595	1423
Class IV	Horizontal	722	704
	Vertical	778	758

Table 26: Pixel density of monitor concept 1 and 4

		Concept 1 (pixels/cm)	Concept 4 (pixels/cm)
Class II	Horizontal	60	60
	Vertical	59	59
Class IV	Horizontal	56	54
	Vertical	56	54

8.1.3 Chosen solution for availability of extended FoV

The solution for when and how to display the image captured by the camera to the driver has been discussed with feature leaders in HMI and Driver Interaction at Volvo GTT and it was concluded that the following alternatives were the most promising:

- Alternative 2 – Aspherical mirror simulation
- Alternative 4 – Head movement simulation

These have not been fully evaluated and will need to be further investigated in driver studies. The main reason for why these two alternatives were chosen was the fact that they mostly resembled existing solutions available within automotive applications and would probably be more easily adopted by drivers. Another important reason was also that these blocked direct visibility the least and could be realized in relatively small monitors.

8.2 Comparison between the CMS and today's conventional mirrors

By replacing conventional rear-view mirrors with the CMS described the performance of the indirect visibility has been improved in many ways. By using the same cameras for both driver and passenger side and designing these to have the performance as the driver side mirrors there will be an increase in the performance on the passenger side which facilitates detection of objects on the passenger side of the truck. A comparison of the performance of conventional mirrors and the CMS can be seen in Table 27.

Table 27 : Increased performance in passenger side indirect visibility

		Driver side		**Passenger side**	
		Class II	**Class IV**	**Class II**	**Class IV**
Horizontal FoV shown to the driver	Mirrors	26,8°	69,5°	21,8°	66,5°
	CMS	26,8°	69,5°	26,8°	69,5°
	Increase	**0%**	**0%**	**23%**	**5%**
Vertical FoV shown to the driver	Mirrors	50,6°	77,7°	37,0°	65,5°
	CMS	50,6°	77,7°	50,6°	77,7°
	Improvement	**0%**	**0%**	**37%**	**19%**

<table>
<tr><td rowspan="5">Detection distance</td><td>Mirrors</td><td colspan="2">63,1m</td><td colspan="2">19,9m</td><td colspan="2">28,8m</td><td colspan="2">8,3m</td></tr>
<tr><td rowspan="2"></td><td colspan="8">Monitor concept</td></tr>
<tr><td>1</td><td>4</td><td>1</td><td>4</td><td>1</td><td>4</td><td>1</td><td>4</td></tr>
<tr><td>CMS</td><td>71m</td><td>63,1m</td><td>19,9m</td><td>19,9m</td><td>28,8m</td><td>51m</td><td>9m</td><td>18m</td></tr>
<tr><td>Improvement</td><td>12%</td><td>0%</td><td>0%</td><td>0%</td><td>0%</td><td>44%</td><td>8%</td><td>54%</td></tr>
</table>

<table>
<tr><td rowspan="5">Obstructed area, direct FoV</td><td>Mirrors</td><td colspan="2">8%</td></tr>
<tr><td rowspan="2"></td><td colspan="2">Monitor concept</td></tr>
<tr><td>1</td><td>4</td></tr>
<tr><td>CMS</td><td>2%</td><td>5%</td></tr>
<tr><td>Improvement compared to mirrors</td><td>71%*</td><td>43%*</td></tr>
</table>

*: Nor mirror or monitor housings are included, only the active surfaces are used for evaluation

9 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

The purpose of this master thesis was to investigate and illustrate with concepts what factors that will be important for Volvo GTT to consider when making the shift from class II and class IV mirrors to a CMS. This was done by identifying requirements, creating concepts and then evaluating the concepts based on how well they fulfilled the requirements. What can be concluded from the thesis is here summarized and proposals for further work are presented.

Camera positioning on the truck

By replacing mirrors with cameras for providing rear-view visibility a world of possibilities arise for positioning of the camera on the truck. When the laws of reflective optics do not need to be taken into consideration for the design of a system for rear-view visibility the degree of freedom for the designer and the possibilities for improvements increase. This also poses several new challenges such as how to position a camera to cover a large area while gaining the best perspective view for detection of objects around the vehicle while still providing an intuitive and easily understandable image.

In this thesis a minor study was conducted with static images of the view gained from several different camera positions on the truck. A camera position high above ground provided the driver with more of a top view on surrounding traffic which resulted in better detection of other vehicles and objects. Since the study used only static images it is hard to determine how these camera positions would affect the driver behavior in a dynamic traffic situation. User opinions from using a birds-eye view system as shown in Chapter 4.4 state that when using a system like this it was harder to relate to the image seen and a feeling similar to playing a video game appeared when operating it while the vehicle was moving. This could lead to increased risk taking because the view gained in a birds-eye view system is far from something that can be seen directly by the human eye in the driving seat. The effects on driver behavior and risk assessment when positioning a camera on different places on the truck needs to be further investigated.

Another aspect when it comes to positioning cameras on the truck for replacing rear-view mirrors is driver acceptance. The view in a CMS should be similar to the view gained in conventional mirrors. Drivers are used to having the rear-view visibility presented with the perspective seen in today’s mirrors and to ease the transition from mirrors to a CMS this perspective should initially be kept the same.

The field of view on the passenger side can be increased when replacing mirrors with a CMS due to the fact that cameras can be placed without respect to the location of driver’s eye-point. This reduces blind spots on the passenger side of the truck which increases safety. The level of detail and the detection distance can also be increased on both passenger and driver side without decreasing direct visibility compared to conventional mirrors.

Self-soling of the camera lens is something closely linked to the positioning of the camera and was briefly discussed in the thesis. Regardless of the camera position self-soiling can probably not be fully avoided and because the area of the camera lens is so much smaller than the area of today’s mirrors even a small amount of soiling on the lens may cause big problems. A system for actively cleaning the camera lens will most likely have to be used and several methods for this are available today such as revolving camera lens protection glass and water cleaning. The effects of self-soiling of the camera lens and how to actively and passively avoid this will have to be further investigated.

Monitor positioning in the cab

The inside of the cab and especially the dashboard is today a crowded space and the introduction of new large monitors is a challenge. At areas on the interior of the cab within the driver's field of vision there is not much space not occupied by buttons, indicators or other necessities that should not be covered. At the same time monitors should not be placed on the windscreen and side-windows where they would obstruct direct visibility.

In an evaluation of different monitor set-ups a substantial increase in performance on the passenger side was seen for set-ups where the passenger side monitors were moved closer to the driver. Direct visibility was improved and blind spots in front of the truck created by the mirrors were reduced with up to 83% when replacing them with a CMS utilizing the blind spots already created by the A-pillars. This shows that replacing rear-view mirrors for a CMS may contribute to increased indirect visibility and safety without decreasing direct visibility.

Standards regarding physical and cognitive ergonomics recommend how monitors in a CMS should be placed and trade-offs between how a monitor should be mounted and how it in practice can be fitted in the cab interior will have to be made. Another challenge when placing monitors in the driver's field of vision is the risk for disturbing luminance and distracting motion. Having light emitting or moving objects in the field of vision can be disturbing when for example looking straight forward observing traffic, this increases when driving in low light conditions where luminance in the peripheral vision is perceived as even more disturbing.

Glare is a factor that needs to be looked into more deeply. In a worst case scenario the sunlight might reflect directly on the monitor into the driver's eyes. If too much light reaches the monitor surface then also the contrast might degrade so that critical objects become unrecognizable.

When setting the monitor size for each concept only the necessary active image surface has been regarded. In reality not all pixels on displays are used and housing is added to prevent from glare and to protect the pixels and electronics from water, dust and shock. This will result in larger monitors than the monitor concepts presented in this work.

How perception and acceptance of monitors used for replacing rear-view mirrors is affected by different monitor locations and set-ups in the cab will have to be further investigated in a driver study with physical prototypes.

Image quality and real time factors

When mirrors are used to provide rear-view visibility they portray what happens around the truck in real-time, with almost perfect color reproduction and with a resolution only limited by the human eye and the curvature of the mirror glass. When introducing cameras, computers and monitors in between the observer and the covered field of view they will affect what is presented to the driver due to their limitations in performance compared to the human visual system.

The image quality of a CMS may suffer from distortions in time, color and geometry. Processing and relaying of data between the camera and the monitor may suffer from latency and due to the fact that a camera captures a limited amount of frames every second there will always exist an information loss and a delay in what is shown in the monitor. Color distortions coming from the camera and monitors inability to record and display the entire range of colors that the human eye can perceive may also alter how the driver perceives objects and reduce the detectability of objects. Geometric distortions may cause straight lines to bend in a monitor which may reduce the legibility of what is seen in the monitor and phenomena such as blooming, optical flares and veiling glare may influence the image quality negatively. A CMS transforms photons into electrical signals, which introduces a new field of knowledge namely signal processing and frequency analysis. The image captured by camera is sent through wires and computers, which might alter the original image. There is a need for knowledge on how to measure and deal with frequency distortions in a CMS.

From Catia V5 studies it was concluded that the field of view covered in conventional mirrors can be covered using a CMS without loss in spatial resolution. Camera and monitor resolutions needed to provide the driver with a high resolution image without any perception of poor level of detail were calculated and the results showed that these specifications are possible to realize with today’s technology.

Image quality and real time factors that originate from the limitations of the technical solution of a CMS must be further studied and their effect on driver behavior, risk assessment and quality feeling must be investigated.

Senior drivers

Special requirements that senior drivers may have on a CMS is something that was not explicitly investigated. Presbyopia, decreased night vision ability and decreased visual acuity are effects that can be seen with increased age and can influence rear-view perception in a CMS.

Presbyopia which is the eyes decreased ability to focus on nearby objects may influence the design of a CMS due to the fact that monitors should not be placed too close to the drivers eyes. In our evaluation of monitor-eye distances it was seen that the concepts found to be the most promising all were positioned relatively far away from the closest eye-monitor distance recommended in the ergonomics standard used. This makes these concepts less sensitive for effects from presbyopia but when positioning monitors in the cab in future concepts these recommendations will have to be validated for senior drivers as well.

Reduced visual acuity with age is an effect that can decrease the drivers’ ability to detect and identify objects located at a small distance from each other. Corrective aids such as glasses and contact lenses can be used to compensate for this to a certain extent and because the resolution in monitors is adjusted to meet the demands from drivers with perfect visual acuity it should not be influenced this. When positioning monitors inside the cab presbyopia will probably be a more influencing factor than reduced visual acuity. Reduced visual acuity also affects the performance in today's mirrors to the same extent as it would in a CMS.

Impaired night vision with increased age may be a problem that can influence the performance and perception of a CMS negatively. As evaluated and discussed the effect of surrounding light sources close to the drivers line of sight may be a problem even for the average driver and senior drivers that have impaired night vision may experience this even more. In future studies of how night vision is affected and driver perception is influenced by different monitor setups it is important to include how senior drivers with impaired night vision are affected.

Availability of the CMS

A topic that was briefly investigated in the thesis was availability of the CMS since it cannot be constantly turned on due to its power consumption. A way of doing this was presented which was based on vehicle modes and CMS states. Since trucks are used for other purposes than only driving and the CMS may have to be used in situations when the vehicle is not moving the availability of the CMS will differ from what is needed in passenger cars. When the CMS should be turned on and off will have to be further investigated in a driver study to ensure that its functionality is available to the driver when needed.

Availability of the extended view obtained through head movements

The field of view seen in conventional rear-view mirrors when the driver moves the head can be covered with a CMS by using increased camera lens opening angles and image processing. An increased camera lens opening angle is used to increase the area covered by the camera and image processing is used to either simulate head movements by cropping and moving the field of view shown to the driver, or by simulating an aspherical mirror by introducing a squeezed outer area of the field of view. By utilizing image processing the view presented to the driver can be altered depending on certain triggers which automatically provide the driver with the view needed in different situation.

Driver acceptance and system change implications

A very important factor when making the change from conventional mirrors to a CMS is the driver acceptance. Truck drivers and purchasers are generally considered as being fairly conservative and drastic changes to features or functions in a truck should be handled with care. Mirrors are today an important design feature and removing them would have a major effect on the exterior of the cab and placing monitors inside the cab will have complications as mentioned earlier. For a system change from mirrors to a CMS to be successful a plan for how to phase out mirrors will have to be laid out. The period should probably include a phase where mirrors and a CMS exist alongside each other for drivers to become accustomed to the new system as illustrated in Figure 71. A way of doing this middle step may be by incorporating cameras into today's mirror housing.

Figure 71 : System change from mirrors to a CMS

Scalability and active safety integration

When digitalizing the indirect visibility by introducing cameras and ECUs the possibility to integrate the system with other electrical systems in a truck emerges. An interesting possibility is the introduction of active safety functions in the CMS. Object detection and warning functions could be used with the cameras of the CMS and displayed in the monitors. The driver could be alerted if objects are present next to the vehicle in case of changing lanes, turning or vehicles are approaching at high speeds. The area of active safety is rapidly growing and at the place in time when a CMS may replace conventional rear-view mirrors it will probably be an important part of automotive safety systems. This makes it important to design a CMS with the possibilities of including potential active safety features. How the interfaces between a CMS and other systems should be designed to facilitate this is something that has to be further investigated.

Image processing can also aids the driver by reducing optical distortions originating from wide-angle camera lenses and be used for other image enhancing purposes to improve indirect visibility.

Functional safety and robustness

A CMS has many different electrical components compared to today's mirrors and if not designed in a proper way the robustness of the system might decrease. There is an ISO-standard regarding functional safety called ISO 26262 with methodologies and process steps that shall be taken to ensure the robustness and safety of an electronic and/or electrical system. Today's mirrors can last as long as the lifetime of the truck, which depends on the level of usage. This can be a challenge when changing from mirrors to CMS since monitors might not last that long without major decline in performance. These issues needs to be further investigated to ensure a robust system, but also to have an action plan for what to do if there is a CMS failure.

Validity of evaluation method

The Kesselring matrix used for evaluation of both camera and monitor concepts is a method for objectively ranking concepts against an ideal one as described in chapter 2.2.5. Normally there are only weights for each criterion, but in this project also feature area weights were added to rank the areas against each other. This feature area ranking was done by us based on internal Volvo GTT documents, and should in future be done by feature leaders so that the Kesselring results better reflects Volvos feature prioritizes, which also goes for the criteria weights.

Recommendations for further work

To be able to make full use of the work conducted a number of recommendations have been made for future projects in the area. In Chapter 9 these were discussed and a summarized list of proposals regarding how to continue the work for developing a CMS for replacing class II and IV rear-view mirrors can be seen below;

- Image quality and real time factors that originate from the limitations of the technical solution of a CMS must be further studied and their effect on driver behavior, risk assessment and quality feeling must be investigated.

- The effects on driver behavior and risk assessment when positioning a camera on different places on the truck needs to be further investigated.

- How perception and acceptance of monitors used for replacing rear-view mirrors is affected by different monitor locations and set-ups in the cab will have to be further investigated in a driver study with physical prototypes.

- The effects of self-soiling of the camera lens and how to actively and passively avoid this will have to be further investigated.

- When the CMS should be turned on and off will have to be further investigated in a driver study to ensure that its functionality is available to the driver when needed.

- For a system change from mirrors to a CMS to be successful a plan for how to phase out mirrors will have to be laid out.

APPENDIX A - REQUIREMENTS SPECIFICATION LIST

Cover field of view

Cover legal demands on field of view

Requirement	D/W	Level	Data/ reference
The field of view according to the ECE directive concerning a class II mirror shall be covered.	D	See chapter 5.2	(ECE 46-02, 2010): §15.2.4.2.1, 15.2.4.2.2
The field of view according to the ECE directive concerning a class IV mirror shall be covered.	D	See chapter 5.2	(ECE 46-02, 2010): §15.2.4.4.1, 15.2.4.4.2

Cover additional field of view

Requirement	D/W	Level	Data/ reference
The field of view obtained in FH truck mirrors shall be covered.	D	See chapter 5.2.1.1.2	(GTT, Mirror Drawing 20735623, 2010)
The horizontally extended field of view which with the conventional class II mirror is covered when the driver moves his head shall be covered.	D	See chapter 5.2.1.1.3	(Blomdahl, 2012)
The upper forward corners of the trailer and the rear trailer axle of the vehicle shall be covered.	D	See chapter 5.2.1.2	(GTT, Technical Requirement Mirrors 82374493_05_1_TR, 2012)
Parts of the cab body and the trailer shall be covered to provide a reference object for distance estimation.	W	See chapter 5.2.1.2	
Blind spots around the truck where objects aren't detected should be reduced	W	See chapter 5.2.1.6	

Display field of view

Display field of view ergonomically

Requirement	D/W	Level	Data/reference
The line of sight between the eye-point and the middle point normal to the display shall not be shorter than 400 mm. (ISO	D	400mm, see chapter 5.2.2.1.2	(International Organization for Standardization, 2008)

9241-3)			
The CMS shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in horizontal plane.	W	See chapter 5.2.2.1	(International Organization for Standardization, 2008)
The CMS shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in vertical plane.	W	See chapter 5.2.2.1	(International Organization for Standardization, 2008)

Display field of view comprehensibly

Image size and resolution

Requirement	D/W	Level	Data/reference
The camera shall have the same or smaller angular resolution as conventional mirrors and the same or better resolution as the monitor.	D+W	$\sigma_{camera} \leq \sigma_{mirrors}$	See chapter 5.2.2.2
The camera shall have the same or better resolution as the monitor.	D+W	$N_{pixels\_camera} \geq N_{pixels\_monitor}$	See chapter 5.2.2.2
The pixel density of the monitor shall be at least ≥30 pixels/degree visual angle which corresponds to an angular resolution of 2 arc-mins at the minimal viewing distance ergonomically acceptable.	D+W	$\sigma_{monitor\_400mm} \leq 2$	See chapter 5.2.2.2
For the minimum normal viewing distance the angular resolution requirement of 1 arc-min must be fulfilled.	D+W	$\sigma_{monitor\_F50} \leq 1$	See chapter 5.2.2.2
The angular size of objects of a certain size and at a certain distance displayed to the driver shall have an equal or larger angular size compared to what is seen in mirrors.	D+W	$\alpha'_{obj\_hor\_CMS} \geq \alpha'_{obj\_hor\_mirror}$	See chapter 5.2.2.2
The angular size of the field of view displayed to the driver shall be of the same or larger angular size compared to mirrors.	D+W	$\alpha'_{hor\_CMS} \geq \alpha'_{hor\_mirror}$	See chapter 5.2.2.2
As many depth cues as possible available in conventional mirrors should be provided	W	See chapter 5.2.2.2	

Image quality

Requirement	D/W	Level	Data/reference
The objects displayed to the driver in the monitor shall have as little optical distortions as possible vertically and horizontally	W	See chapter 5.2.2.2	
The displayed field of view shall not be deteriorated by self-soiling.	W	See chapter 5.2.2.2	
The effect on image quality from surrounding light sources such as headlights of other vehicles, the sun, street lighting etcetera shall be minimized	W	See chapter 5.2.2.2	

Display field of view when needed

Availability

Requirement	D/W	Level	Data/reference
The CMS shall be manually and/or automatically turned on when needed by the driver.	D	See chapter 5.2.2.3	
The extended class II field of view shall be manually and/or automatically shown when needed by the driver.	D	See chapter 5.2.2.3	

Reduce aerodynamic effects

Reduce noise

Requirement	D/W	Level	Data/reference
The rear-view vision system shall not influence the interior cabin noise negatively compared to today's mirrors	D	See chapter 5.2.3	
The rear-view vision system shall not influence the exterior noise negatively compared to today's mirrors.	D	See chapter 5.2.3	
The interior and exterior noise originating from the CMS shall be minimized	W	See chapter 5.2.3	

Reduce soiling

Requirement	D/W	Level	Data/reference
The CMS shall minimize the soiling of the cab and its windows.	W	See chapter 5.2.3	

Reduce fuel consumption

Requirement	D/W	Level	Data/reference
The rear-view vision system shall decrease the fuel consumption.	W	See chapter 5.2.3	

Improve direct visibility

Requirement	D/W	Level	Data/ reference
The legal requirements found in German legislation for direct field of view shall be fulfilled.	D	See chapter 5.2.4	(InterRegs, 2006)
The direct field of view should be improved compared to today’s mirrors.	W	See chapter 5.2.4	

APPENDIX B - KESSELRING EVALUATION MATRIX

Camera position, Class II camera

	Criteria	W/D	Criteria weight	Concept solution rating (1-5)													
				IDEAL		1		2		3		4		5		6	
				w	t	w	t	w	t	w	t	w	t	w	t	w	t
1	**Physical ergonomics**		**3**														
1.1	The CMS system shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in horizontal plane.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1.2	The CMS system shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in vertical plane.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	**Cognitive ergonomics**		**4**														
2.1	Objects seen in the CMS shall be displayed with a larger angular size and have a better angular resolution compared to conventional mirrors.	W	4	5	4,7	4	3,8	3	2,8	3	2,8	1	0,9	3	2,8	5	4,7
2.2	Parts of the cab body and the trailer shall be covered to provide a reference object for distance estimation.	W	3	5	3,5	5	3,5	4	2,8	5	3,5	4	2,8	5	3,5	5	3,5
2.3	Blind spots around the truck where objects aren't detected should be reduced	W	5	5	5,9	4	4,7	3	3,5	5	5,9	3	3,5	5	5,9	4	4,7
2.4	As many depth cues as possible available in conventional mirrors should be provided	W	3	5	3,5	5	3,5	5	3,5	4	2,8	4	2,8	3	2,1	5	3,5
2.5	The objects displayed to the driver in the monitor shall have as little optical distortions as possible vertically and horizontally	W	4	5	4,7	4	3,8	3	2,8	3	2,8	1	0,9	3	2,8	5	4,7
2.6	The displayed field of view shall not be deteriorated by self-soiling	W	4	5	4,7	4	3,8	4	3,8	3	2,8	2	1,9	1	0,9	5	4,7
2.7	The displayed field of view shall be positioned in such way that direct and indirect view can be used simultaneously to detect and identify objects when so needed.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.8	The effect on image quality from surrounding light sources such as headlights of other vehicles, the sun, street lighting etc. shall be minimized	W	4	5	4,7	5	4,7	5	4,7	4	3,8	4	3,8	3	2,8	5	4,7
2.9	Decrase brightness and movement in monitors close do drivers line of sight.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	**Noise**		**2**														
3.1	The interior and exterior noise originating from the CMS shall be minimized	W	3	5	1,8	2	0,7	4	1,4	3	1,1	5	1,8	3	1,1	2	0,7
4	**Soiling**		**3**														
4.1	The CMS shall minimize the soiling of the cab and its windows.	W	3	5	2,6	4	2,1	4	2,1	3	1,6	2	1,1	1	0,5	5	2,6
5	**Direct visibility**		**5**														
5.1	The direct field of view should be improved compared to today's mirrors.	W	5	5	7,4	5	7,4	5	7,4	2	2,9	5	7,4	5	7,4	5	7,4
	Total				43,5		37,9		34,9		30,06		26,9		29,88		41,3
	Relative total				100%		87%		80%		69%		62%		69%		95%
	Ranking			-		2		3		5		6		4		1	

N/A: Not Applicable

Camera position, Class IV camera

	Criteria	W/D	Criteria weight	IDEAL		1		2		3		4		5		6	
				Concept solution rating (1-5)													
				w	t	w	t	w	t	w	t	w	t	w	t	w	t
1	**Physical ergonomics**		**3**														
1.1	The CMS system shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in horizontal plane.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1.2	The CMS system shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in vertical plane.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	**Cognitive ergonomics**		**4**														
2.1	Objects seen in the CMS shall be displayed with a larger angular size and have a better angular resolution compared to conventional mirrors.	W	4	5	4,7	4	3,8	2	1,9	4	3,8	1	0,9	4	3,8	5	4,7
2.2	Parts of the cab body and the trailer shall be covered to provide a reference object for distance estimation.	W	3	5	3,5	5	3,5	4	2,8	5	3,5	4	2,8	5	3,5	5	3,5
2.3	Blind spots around the truck where objects aren't detected should be reduced	W	5	5	5,9	4	4,7	3	3,5	5	5,9	3	3,5	5	5,9	4	4,7
2.4	As many depth cues as possible available in conventional mirrors should be provided	W	3	5	3,5	5	3,5	5	3,5	4	2,8	4	2,8	3	2,1	5	3,5
2.5	The objects displayed to the driver in the monitor shall have as little optical distortions as possible vertically and horizontally	W	4	5	4,7	4	3,8	2	1,9	4	3,8	1	0,9	4	3,8	5	4,7
2.6	The displayed field of view shall not be deteriorated by self-soiling	W	4	5	4,7	4	3,8	4	3,8	3	2,8	2	1,9	1	0,9	5	4,7
2.7	The displayed field of view shall be positioned in such way that direct and indirect view can be used simultaneously to detect and identify objects when so needed.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.8	The effect on image quality from surrounding light sources such as headlights of other vehicles, the sun, street lighting etc. shall be minimized	W	4	5	4,7	5	4,7	5	4,7	4	3,8	4	3,8	3	2,8	5	4,7
2.9	Decrase brightness and movement in monitors close do drivers line of sight.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3	**Noise**		**2**														
3.1	The interior and exterior noise originating from the CMS shall be minimized	W	3	5	1,8	2	0,7	4	1,4	3	1,1	5	1,8	3	1,1	2	0,7
4	**Soiling**		**3**														
4.1	The CMS shall minimize the soiling of the cab and its windows.	W	3	5	2,6	4	2,1	4	2,1	3	1,6	2	1,1	1	0,5	5	2,6
5	**Direct visibility**		**5**														
5.1	The direct field of view should be improved compared to today's mirrors.	W	5	5	7,4	5	7,4	5	7,4	2,0	2,9	5	7,4	5	7,4	5	7,4
	Total				43,53		37,9		33,0		31,9		26,9		31,8		41,3
	Relative total				100%		87%		76%		73%		62%		73%		95%
	Ranking			-		2		3		4		6		5		1	

Monitor position

	Criteria	W/D	Criteria weight	Concept solution rating (1-5)											
				IDEAL		1		2		4		5		6	
				w	t	w	t	w	t	w	t	w	t	w	t
1	**Physical ergonomics**		**3**												
1.1	The CMS system shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in horizontal plane.	W	3	5	3,5	2	1,4	4	2,8	3	2,1	3	2,1	3	2,1
1.2	The CMS system shall strive to fulfill the demands set in ISO 9335-2:1999 on monitoring in vertical plane.	W	4	5	4,7	5	4,7	4	3,8	4	3,8	5	4,7	4	3,8
2	**Cognitive ergonomics**		**4**												
2.1	Objects seen in the CMS shall be displayed with a larger angular size and have a better angular resolution compared to conventional mirrors.	W	4	5	4,7	3	2,8	5	4,7	5	4,7	3	2,8	5	4,7
2.2	Parts of the cab body and the trailer shall be covered to provide a reference object for distance estimation.	W	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.3	Blind spots around the truck where objects aren't detected should be reduced	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.4	As many depth cues as possible available in conventional mirrors should be provided	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.5	The objects displayed to the driver in the monitor shall have as little optical distortions as possible vertically and horizontally	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.6	The displayed field of view shall not be deteriorated by self-soiling	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.7	The displayed field of view shall be positioned in such way that direct and indirect view can be used simultaneously to detect and identify objects when so needed.	W	4	5	4,7	4	3,8	1	0,9	3	2,8	3	2,8	2	1,9
2.8	The effect on image quality from surrounding light sources such as headlights of other vehicles, the sun, street lighting etc. shall be minimized	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2.9	Decrase brightness and movement in monitors close do drivers line of sight.	W	4	5	5	3	2,8	1	0,9	2	1,9	2	1,9	2	1,9
3	**Noise**		**2**												
3.1	The interior and exterior noise originating from the CMS shall be minimized	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4	**Soiling**		**3**												
4.1	The CMS shall minimize the soiling of the cab and its windows.	W	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5	**Direct visibility**		**5**												
5.1	The direct field of view should be improved compared to today's mirrors.	W	5	5	7,35	4	5,9	3	4,4	4	5,9	4	5,9	3	4,4
	Total				30		21,4		17,6		21,2		20,2		18,8
	Relative total				100%		71,4%		59%		70,6%		67%		63%
	Ranking			-		1		5		2		3		4	

APPENDIX C - MONITOR SIZE CALCULATIONS

Horizontal size of monitor

If combining Equation 8 and Equation 15:

$$D'_{hor} = \frac{\tan\left(\frac{\alpha'_{hor}}{2}\right)\cdot 2r'_d}{\cos(\alpha_{tilt\_hor})} = \left\{\frac{\alpha_{obj\_hor}}{\alpha_{hor}} = \frac{\alpha'_{obj\_hor}}{\alpha'_{hor}}\right\}$$

$$= \frac{\tan\left(\left(\left(\frac{\alpha'_{obj\_hor}}{\alpha_{obj\_hor}/\alpha_{hor}}\right)/2\right)\right)\cdot 2r'_d}{\cos(\alpha_{tilt\_hor})}$$

$$= \frac{\tan\left(\frac{\alpha'_{obj\_hor}\cdot\alpha_{hor}}{2\alpha_{obj\_hor}}\right)\cdot 2r'_d}{\cos(\alpha_{tilt\_hor})}$$

$\alpha'_{obj\_hor} = (16'/60)$ [°]

$\alpha_{obj\_hor} = \left(2\tan^{-1}\left(\frac{D_{obj\_hor}}{2r_d}\right)\right) = \left(2\tan^{-1}\left(\frac{0{,}8}{2r_d}\right)\right)$ [°]

$\alpha_{hor} = camera\ horisontal\ opening\ angle\ in\ degrees$ [°]

$\alpha_{tilt\_hor} = degrees\ tilting\ of\ monitor\ around\ the\ vertical\ axis$ [°]

Vertical size of monitor

If combining Equation 8 and Equation 15, but change hor for ver:

$$D'_{ver} = \frac{\tan\left(\frac{\alpha'_{ver}}{2}\right)\cdot 2r'_d}{\cos(\alpha_{tilt\_ver})} = \left\{\frac{\alpha_{obj_{ver}}}{\alpha_{ver}} = \frac{\alpha'_{obj_{ver}}}{\alpha'_{ver}}\right\}$$

$$= \frac{\tan\left(\left(\left(\frac{\alpha'_{obj_{ver}}}{\alpha_{obj_{ver}}/\alpha_{ver}}\right)/2\right)\right)\cdot 2r'_d}{\cos(\alpha_{tilt\_ver})} = \frac{\tan\left(\frac{\alpha'_{obj\_ver}\cdot\alpha_{ver}}{2\alpha_{obj\_ver}}\right)\cdot 2r'_d}{\cos(\alpha_{tilt\_ver})}$$

$\alpha'_{obj\_ver} = (28'/60)$ [°]

$\alpha_{obj\_ver} = \left(2\tan^{-1}\left(\frac{D_{obj\_ver}}{2r_d}\right)\right) = \left(2\tan^{-1}\left(\frac{1{,}4}{2r_d}\right)\right)$ [°]

$\alpha_{ver} = camera\ vertical\ opening\ angle\ in\ degrees$ [°]

$\alpha_{tilt\_ver} = degrees\ tilting\ of\ monitor\ around\ the\ horizontal\ axis$ [°]

Table 28: Detection distances for each mirror

Monitor	r_d [m]
Driver side, ClII	63,1
Driver side, ClIV	19,9
Passenger side, ClII	28,8
Passenger side, ClIV	8,3

Table 29: Distances between eye-point and the different monitor positions

	r_d' [m]					
Monitor	Concept 1	Concept 2	Concept 3*	Concept 4	Concept 5	Concept 6
Driver side, ClII	0,751	0,907	0,803	0,751	0,802	0,803
Driver side, ClIV	0,869	0,889		0,869	0,728	0,92
Passenger side, ClII	1,866	0,92	1,886	0,939	1,773	0,939
Passenger side, ClIV	1,917	0,898		0,927	1,54	0,935

At calculation of the monitor sizes the tilt angles are set to $\alpha_{tilt\_ver} = \alpha_{tilt\_hor} = 0$ [°]. From calculation sheets the tilt-angle did not have large effect on monitor sizes for tilting angles between 0-5°, which is normal tilting angles in Volvo trucks.

For monitor evaluation

The sizes of the monitors in the concept evaluation carried out in chapter 7.2 are based on the following presumptions:

- The distances between eye-point and monitors are as stated in Table 29
- There is no tilting angle
- The detection distance are as in Table 28
- The critical objects sizes are as stated in the draft version of ISO 16505: $D_{obj\_ver} = 1{,}4\ [m]$
  $D_{obj\_hor} = 0{,}8\ [m]$
- The camera opening angle is as for camera concept 6 (with NOT extended view for class II). Concept 6 won the Kesselring matrix in an early phase when the monitor evaluation started.

APPENDIX D - FOV DRAWINGS ON GROUND LEVEL

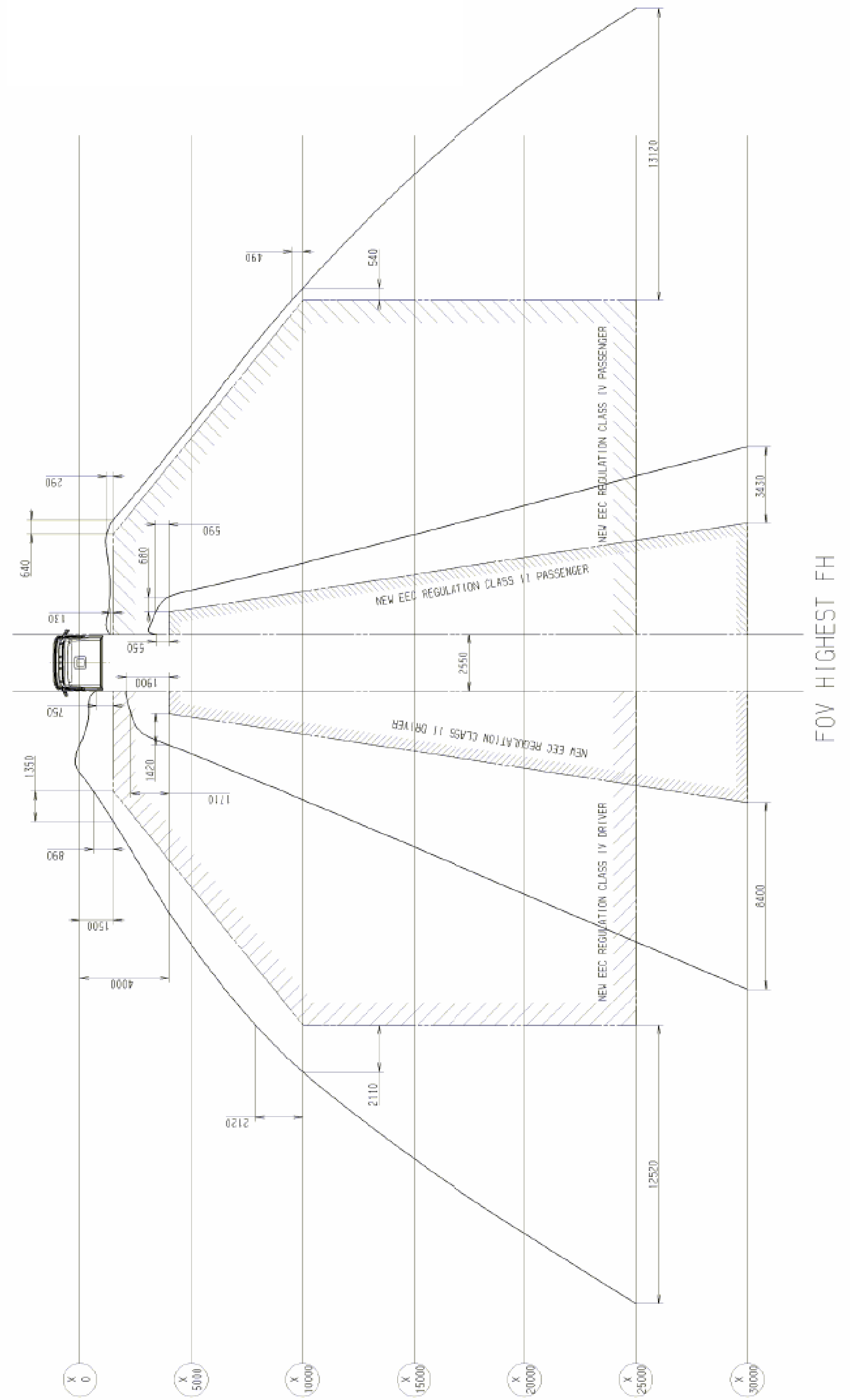

Figure 72 : Indirect field of view provided by class II and IV rear-view mirrors in Volvo FH truck (Volvo GTT, 2012)

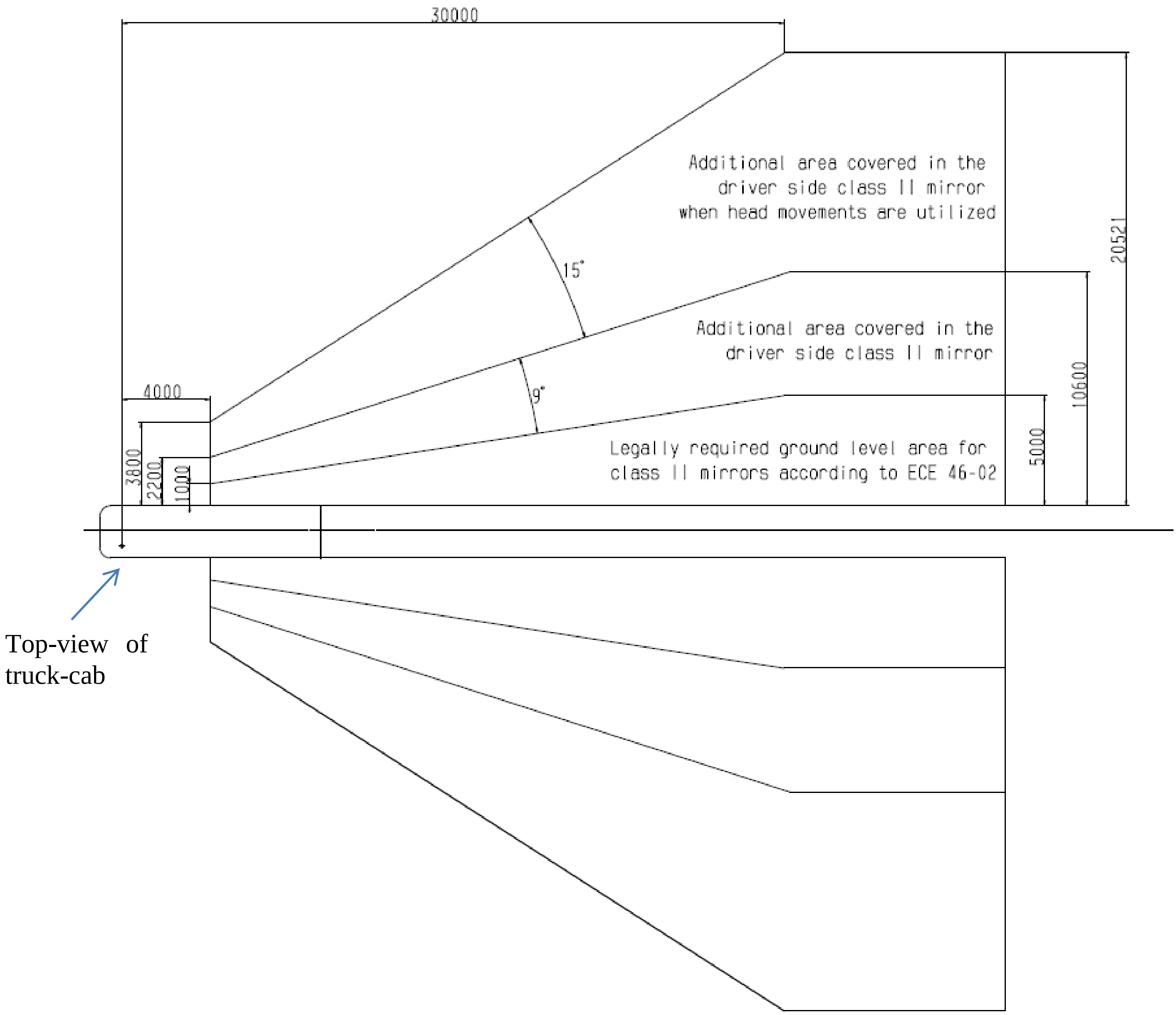

Figure 73 : Resulting class II field of view on ground

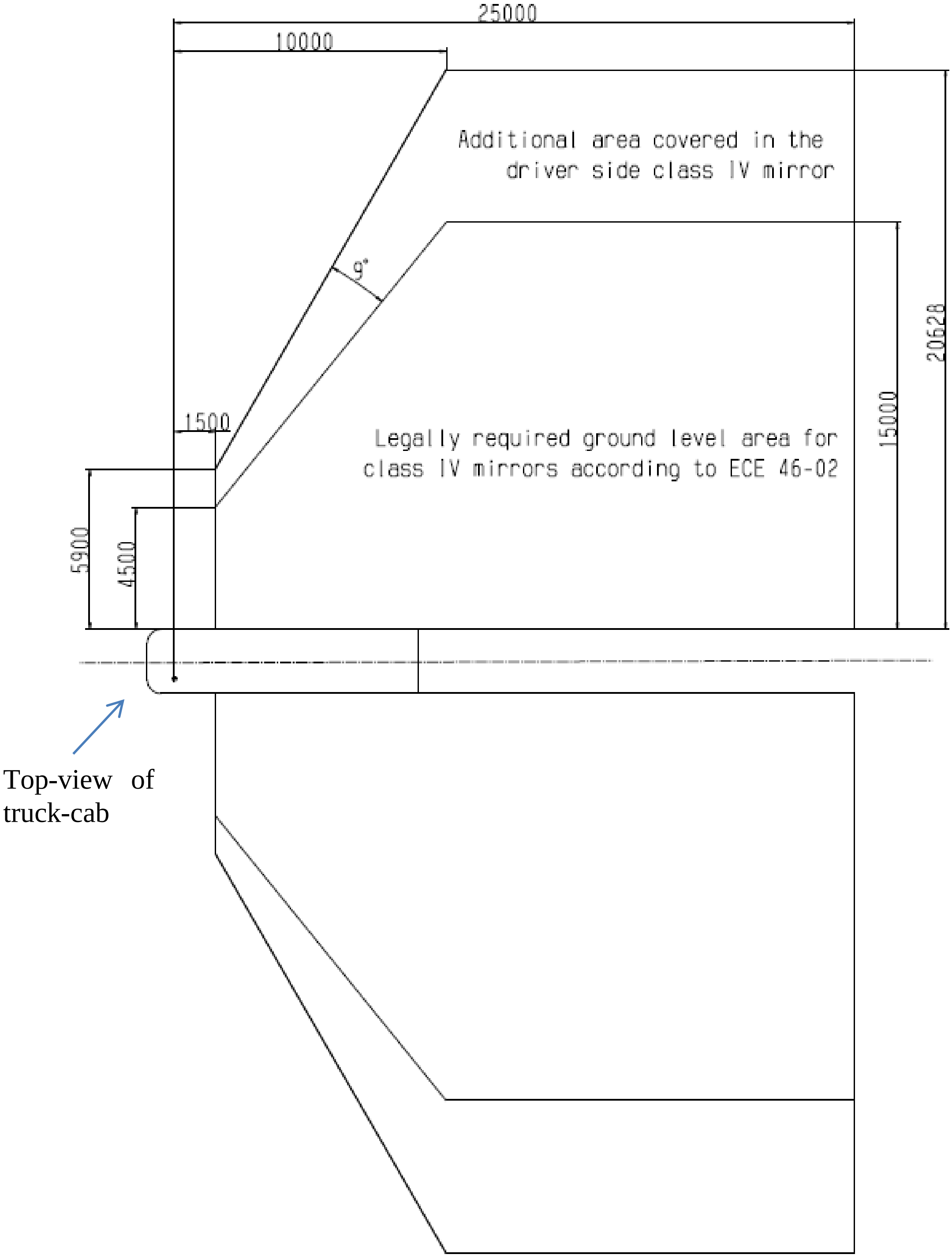

Figure 74 : Resulting class IV field of view on ground

APPENDIX E - GERMAN SIGHT REGULATION

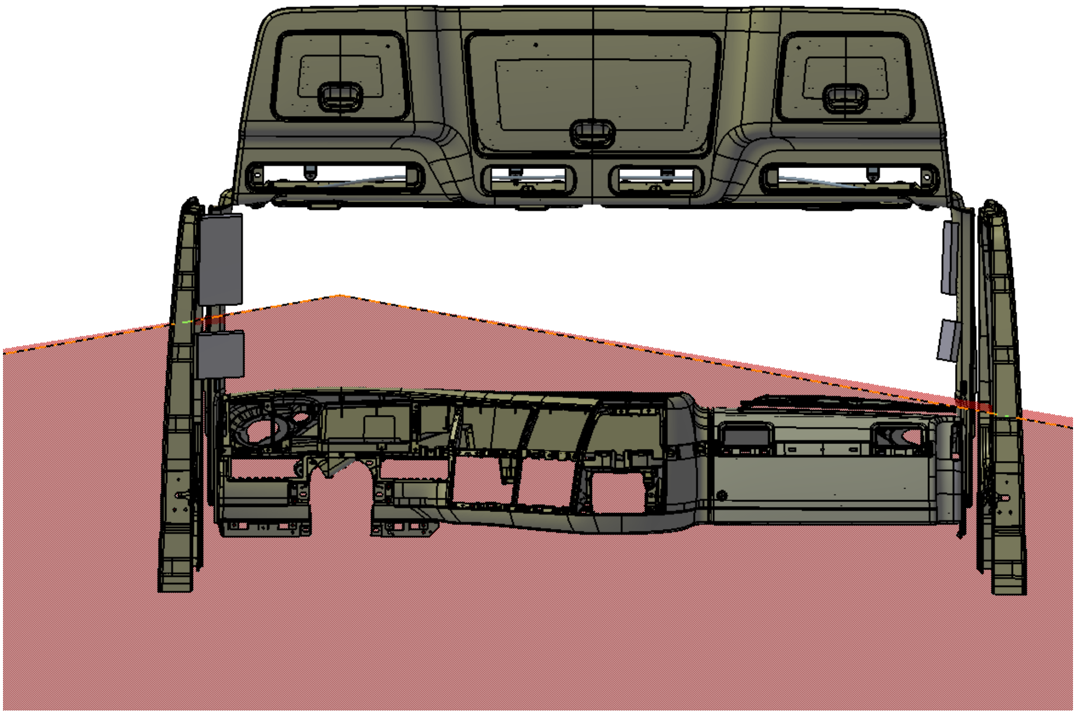

Figure 75: German regulation cone for monitor concept 1

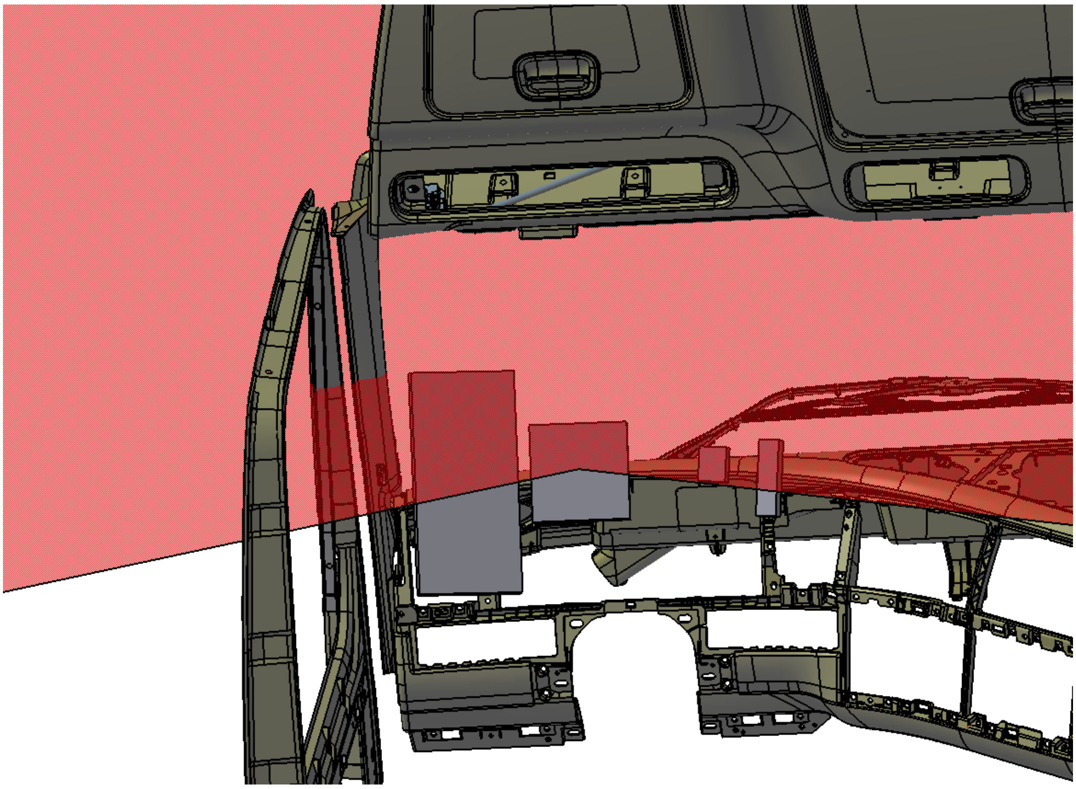

Figure 76: German regulation cone for monitor concept 2

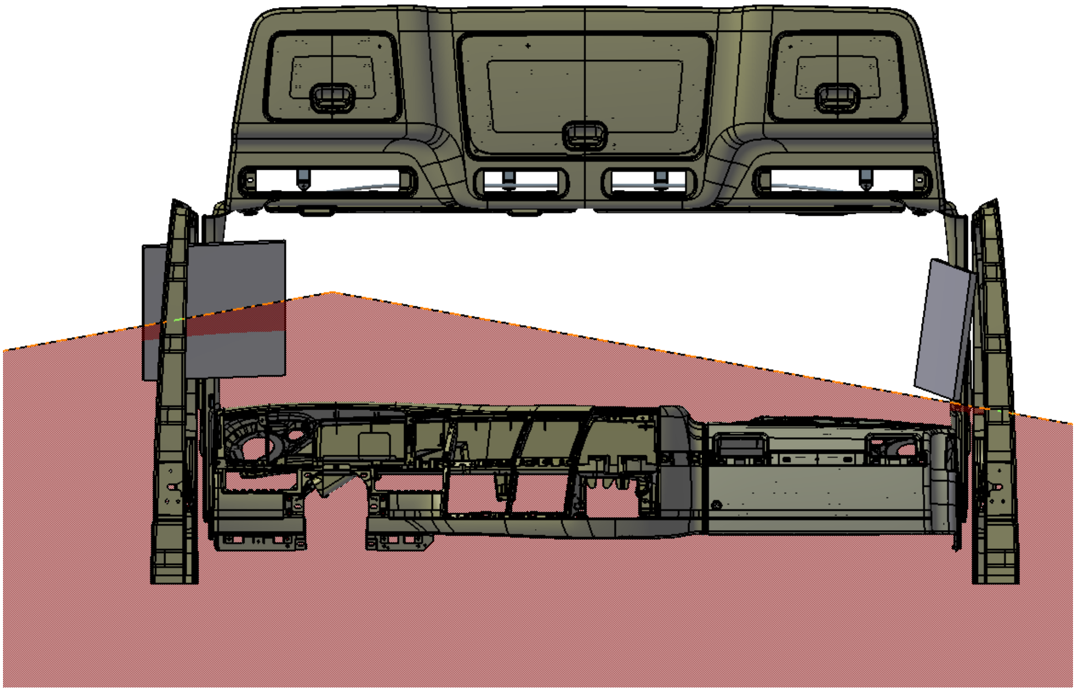

Figure 77: German regulation cone for monitor concept 3

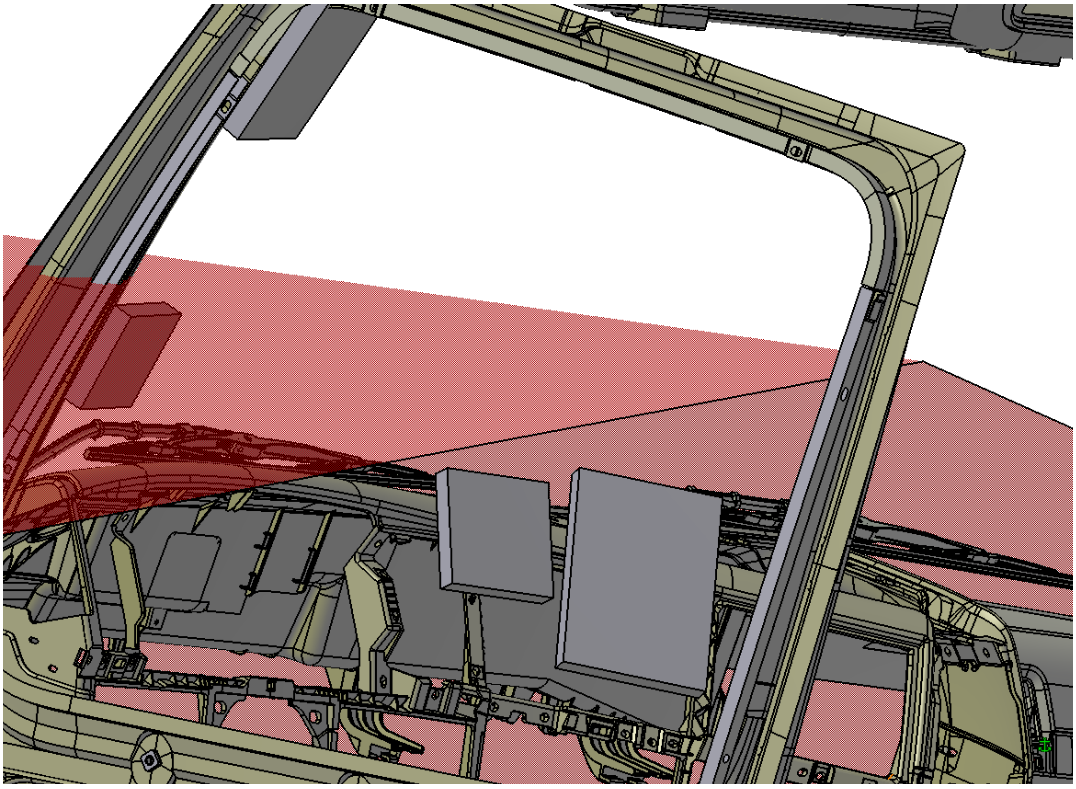

Figure 78: German regulation cone for monitor concept 4

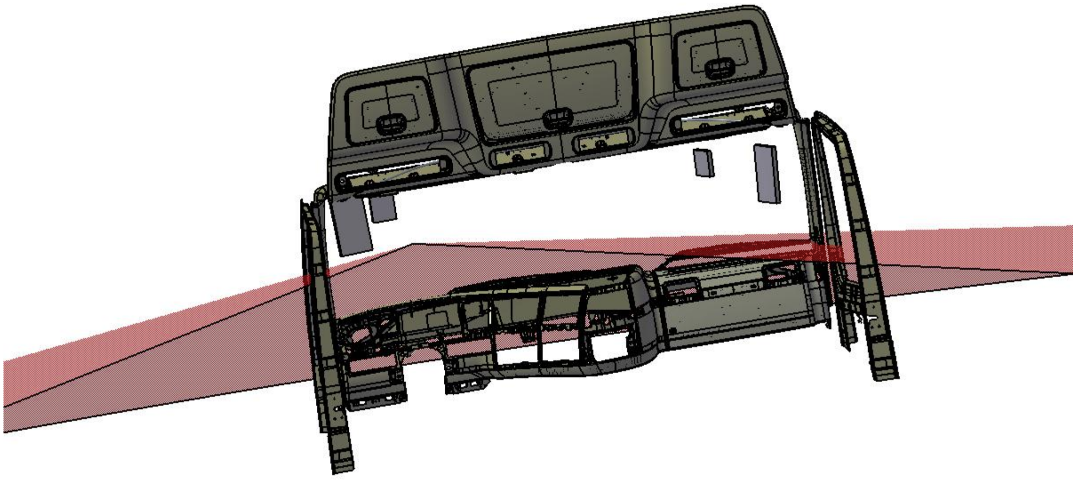

Figure 79: German regulation cone for monitor concept 5

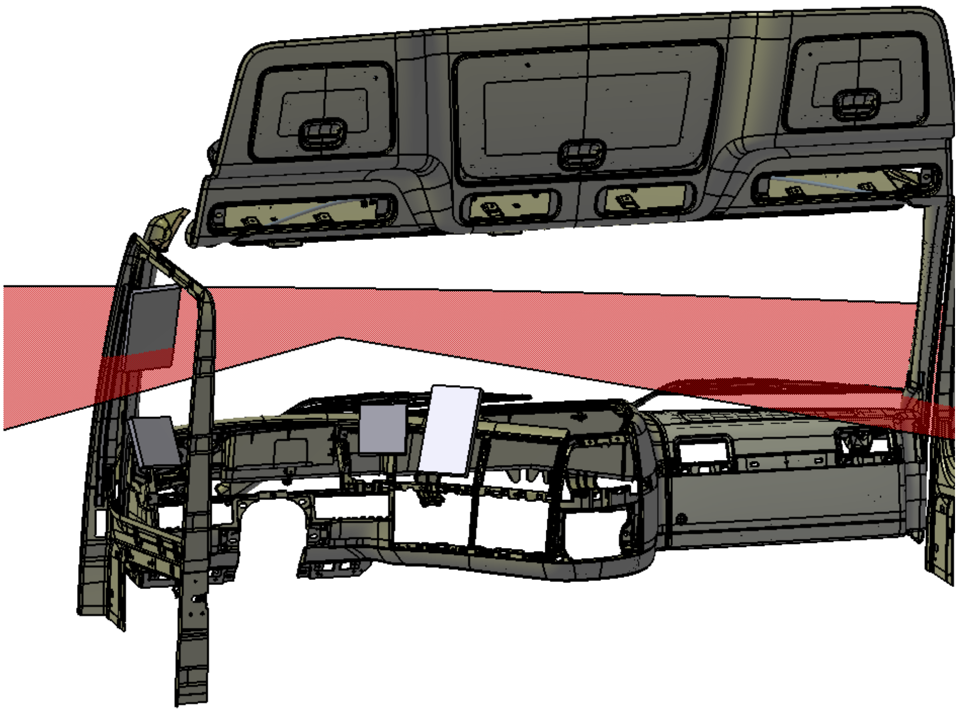

Figure 80: German regulation cone for monitor concept 6

APPENDIX F - MONITOR PIXEL CALCULATIONS

Monitor size

		Concept 1	Concept 4	
Class II	Hor (width)	150	130	[mm]
	Ver (height)	270	240	[mm]
Class IV	Hor (width)	130	130	[mm]
	Ver (height)	140	140	[mm]

Distance eye-point—monitor

M97,5

		D2	D4	P2	P4	[mm]
Monitor concept	1	751	869	1866	1917	
	4	751	869	939	927	

Distance eye-point—monitor

F05

		D2	D4	P2	P4	[mm]
Monitor concept	1	572	620	1801	1816	
	4	572	620	701	650	

Here one can see that all monitors lie closer to driver for F05.

<u>Angular monitor resolution:</u>

$$\beta\_hor = \tan^{-1}\left(\frac{Width\_monitor}{D\_F05}\right) [°]$$

$$\beta\_ver = \tan^{-1}\left(\frac{Height\_monitor}{D\_F05}\right) [°]$$

<u>Pixels per monitor (PpM):</u>

$$PpM = \beta \cdot PAR \text{ [pixels]}$$

Where PAR = Pixel angular resolution (TCO: 30 pixel/degrees, for a person with perfect vision: 60 pixels/degree)

<u>Pixel density (PD):</u>

$$PD\_hor = \frac{PpM}{Width\_monitor \cdot 10} \text{ [pixels/cm]}$$

$$PD\_ver = \frac{PpM}{Height\_monitor \cdot 10} \text{ [pixels/cm]}$$

APPENDIX G - QUESTIONNAIRE REGARDING CAMERA AND MONITOR POSITIONING ON THE EXTERIOR AND INTERIOR OF THE CAB

Presentation material

Presentation material with a project background, three camera position concepts and three monitor position concepts were sent to six feature leaders within Visibility, HMI and Driver Interface at global truck sites within the Volvo Group. The camera positions 1, 4 and 5 and the view gained in these camera positions were used in the material and the monitor concepts 1,4 and 5 were used. These were chosen because they included the aspects that we wanted to investigate and including all of the concept solutions developed would make the material too extensive.

Questionnaire

A questionnaire was sent along with the presentation material which was answered and returned by all six survey participants. The questions and compiled answers can be found below.

Answers concerning camera positions 1, 4 and 5

1. **What did you think of the view gained from the three different camera positions?**

   Four of the participants ranked the views with regards to which one they preferred and as seen in Figure 81 camera position 1 was top rated by all participants.

		Participant							
Cameras		1	2	3	4	5	6		**Rank**
Position	1		1	1	1		1	1,0	1
Position	4		2	2	2		2	2,0	2
Position	5		3	3	3		3	3,0	3

Figure 81 : Questionnaire grading for camera position

   One participant commented the following for all of the camera views and provided no ranking;

   - Class 4 is superior. It displays much more information than class 2. However far away objects may be hard to see due to small displays.

2. **Which view do you think would facilitate the detection of vehicles and other objects around the vehicle the most? (please elaborate)**

   These opinions were put forward;

1. Class 4. Class 4 provides the driver with a much broader view. The red car is obviously not viewable from in class 2.
2. Camera position 1 – motorcyclist is not hidden
3. *(camera position 1)* Offers a high perspective to help the driver understand the traffic situation.
4. For the camera position 5, it is easy to see the surrounding road condition and has more visible area than others. It is also easy to check the upper rear portion of the van. The lower the position of the camera, the more the blind spot would be by surrounding vehicles.
5. –
6. I think the best is camera position 1 for to see the maximum of vehicles or other objects (pedestrian, bicycle,…) and to appreciate distance between all things around the vehicle.

3. **Do you see any other problems with the camera positions presented?**

1. *(camera position)* 5 is too low for both classes. Class 4 view *(camera position)*1 is the most superior view. It provides the driver with the most information on his or her surroundings.
2. There will be design challenges to hold the cameras away from the vehicle and maintain a stiff support without creating aerodynamic problems, i.e. vibration, soiling.
3. –
4. For the camera position 1, affected by vibration of a vehicle if the camera is installed on bumper and also easy to get hit by surrounding obstacles. For the camera position 1 and 4, it would be easy to get splashes.
5. –
6. We must put it on no direct field of view (to not have a blank), protect from shock and various soiling. Be careful for vibration, foreign soiling (on side window).

4. **Additional comments, thoughts or remarks?**

1. This wide angle lens configuration used in class 4 might construe the actual distances of faraway objects and make closer objects appear closer than what they are.
2. In the US we have different requirements - Flat glass and a different radius convex. My opinion is that the advantage of the cameras, while greatly improving indirect visibility, will require enormous work / time to be accepted in the marketplace.
3. –
4. It is better to layout the camera same as eye-point height. Drivers feel like they are seeing by their own eyes.
5. –
6. Regulation will need to accept this new technology.

Answers concerning monitor set-ups 1,4 and 5

5. **Which monitor set-up do you think would facilitate the detection of vehicles and other objects around the vehicle the most? (please elaborate)**

As seen in Figure 82 monitor concept 1 was ranked the highest by the participants.

		Participant							
Monitors		1	2	3	4	5	6		**Rank**
Concept	1	1	1	2	2	1	1	1,3	1
Concept	4	2	1	3	1	2	2	1,8	2
Concept	5	2	2	1	3	2	2	2,0	3

Figure 82 : Questionnaire grading for monitor concepts

These comments were put forward;

1. Setup 1 is the most superior setup. It is the most logical and intuitive setup. Their setup mimics an actual mirror configuration.
2. I struggle between the traditional place to look to the right for mirrors, concept 1 and the already crowded dash space, concept 4.
3. *(concept 5)* It keeps the head elevated, so that peripheral vision is still centered on the road. It moves the screens closer to the drivers forward vision so there is less time loss during head movements than you will find in option 1.
4. –
5. Concept 1, is the best for me, as for concept 4, it's not the same head movement to see the similar information and both concept 4 & 5, the fact to not have the 2 mirrors not in the same vertical line is not easy to understand.
6. And is natural to turn you head on right by to know what we have on this direction, and on dashboard we have so much monitors.

6. **Do you see any other problems with the monitor set-ups presented?**

1. 4 and 5's setups are not logically setup to the way an actual mirror would be. They also occupy too much cab space.
2. Concept 5 does not make sense if there is a passenger.
3. Option 1 is good because it does not add an additional vision obstruction but instead just goes with the A-pillar. I have concerns with someone looking down like is shown in Option 4, but truck dashes are typically pretty high, so they will not be looking far down.
4. Direct vision would be obstructed if monitors are placed on windshield. Also, it is burdensome for passenger at assistant driver's seat.
5. In the concept 4, the central area is always needed for a lot of functions… then it could be good if it was mixed with other display, but not good as we do not know when the driver want to look at the screen. A possibility could be to have automatic even detection.
6. On concept 5, we create some blank. Not good for direct vision.

7. **Additional comments, thoughts or remarks?**

1. –
2. The size of the monitor could be compromised, made smaller, if this is feature was in addition to the current mirrors. Recently during a ride along on a refuse collection vehicle with a camera for backing, the complaint was lodged that sunshine at the horizon completely wiped out the image displayed – another technological challenge….
3. –
4. It is better to layout the assist side monitors above B cluster. The layout would shorten the time for recognition and driver's head movement angle would be smaller (concept 4).
5. Why do not you have solutions with screens in the bottom of the dashboard (more easy to look under the horizon and then imagine a full large display (currently crazy solution), where we could display all the information.
6. The size of the monitor could be compromised, not so smaller for to see correctly and not so bigger (in compare to A pillar) to not have blank for direct vision.

APPENDIX H - FINAL SYSTEM SPECIFICATION LIST

The position for cameras covering class II and class IV will both be located at the area around the attachment point for the sun visor above the door as seen in Figure 83

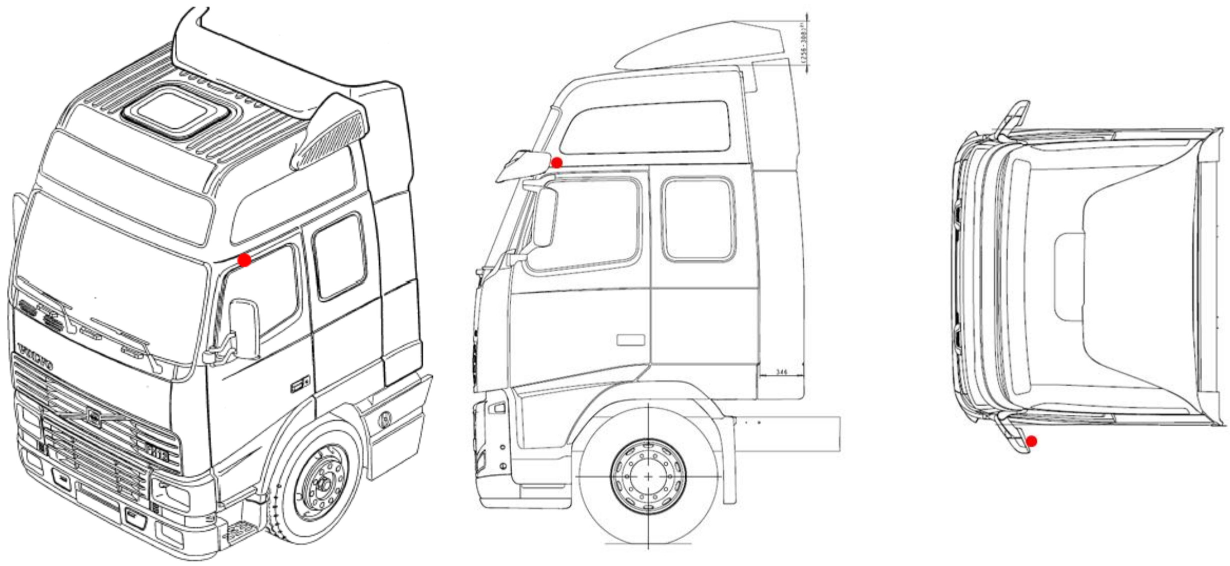

Figure 83 : Position for cameras covering class II and class IV

The specifications for the camera can be seen below in Table 30.

Table 30 : Final specifications for class II and IV cameras

	Lens opening angle [°]		Resolution [pixels]	
Camera	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
Class II	40,3°	50,6°	1349	1635
Class IV	69,5°	77,7°	722	778

The monitors will be positioned according to Figure 84 for the two monitor concepts found most interesting for further development.

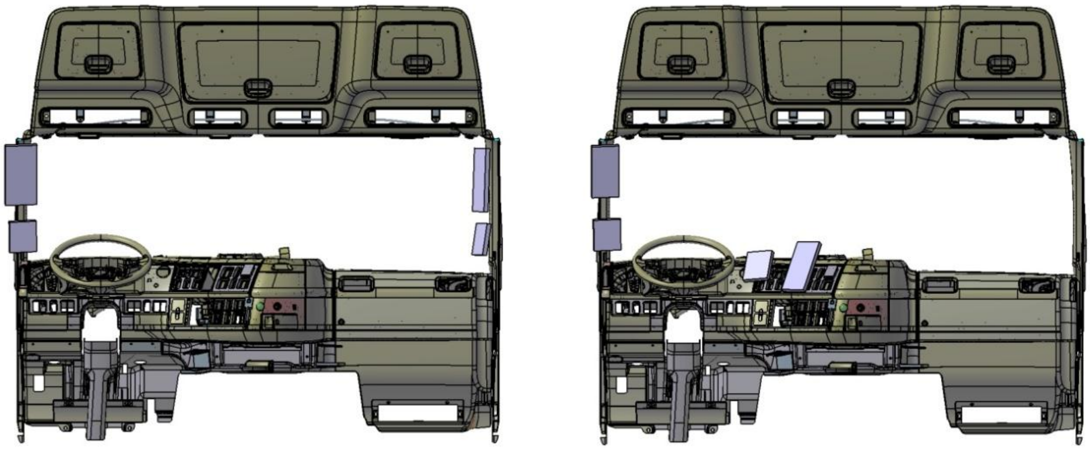

Figure 84 : Monitor set-up concepts interesting for further development

The specifications for the monitors showing the class II and IV field of view can be seen in Table 31.

Table 31 : Final specifications for class II and IV monitors

		Dimensions [mm]		Resolution [pixels]	
	Monitor	**Horizontal**	**Vertical**	**Horizontal**	**Vertical**
Concept 1	Class II	150	270	897	1595
	Class IV	130	140	722	778
Concept 4	Class II	130	240	779	1423
	Class IV	130	140	704	758

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