Linköping University | IEI – Department of Management and Engineering
Master thesis report 30 HP | Civilingenjör - Design and Product Development
Fall term 2015 |LIU-IEI-TEK-A--16/02437—SE

Planning Interior Lighting in a Truck Cab

A thesis in visual ergonomics

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Preface

This thesis was written at the department for physical vehicle ergonomics at Scania CV AB in Södertälje. We are very thankful for the opportunity to write this thesis at Scania and all the help we got, especially at the department of physical vehicle ergonomics, but also from other departments at Scania.

We would like to give a special thanks to our supervisor Stefan Uddholm, who has been a great support while writing this thesis. He has always been willing to answer questions and guide us at Scania.

We would like to thank our supervisor David Eklöf at Linköping University for good discussions and feedback on our thesis. Also our examiner Kerstin Johansen for great feedback.

We would like to thank Per Nylén, at Arbetsmilöverket for sharing his knowledge in visual ergonomics and lending us a luminance meter.

We would like to thank Michael Hallbert for inspiration and teaching us about lighting design.

Abstract

A long-haulage truck cab from Scania is an environment that involves various activities and combines a working place with compact living which sets different requirements on the lighting environment depending on the activity. Truck drivers have different requirements in means of visual ergonomics and preference on the lighting design. A conclusion in this thesis is that different user in various activities sets different requirements on lighting design in a truck cab.

Lighting planning in a truck cab with new lighting technologies such as LED (Light Emitting Diode) and OLED (Organic Light Emitting Diode) stands for a paradigm shift in lighting planning and lighting design. The new technologies enables more integration in the interior, more diverse lighting which means more effort is needed to succeed in good visual ergonomics, light distribution, aesthetic expression and branding.

Studies have shown that by blue enriched light can be used as a tool to affect the humans' sleep-awake rhythm. With the new paradigm shift with LED and OLED comes an opportunity to change the colour temperature of the lighting and use blue-enriched light as a tool to possibly create a better working environment for shift working truck drivers using warmer light at night and colder light in the morning.

In this thesis two main studies has been conducted, the first was regarding product and user knowledge and the second was a lighting study. From these studies we have concluded three analyses and suggested a lighting planning guide for Scania that takes into account future lighting planning with new technology for a better working environment for long-haulage truck drivers.

Terminology

Some useful terms for this thesis are explained in this chapter.

Accommodation – The lens adjustment of focal length

Candela – The SI-unit for luminous intensity (cd)

Circadian rhythm – Processen in biological organism with the duration of approximately for 24 hours

Colour rendering - Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant

Colour rendering index (CRI) - CRI is a quantitative measure of the ability of a light source to reveal the colours of various objects faithfully in comparison with an ideal or natural light source (Unit=Ra)

Direct lighting – The light source illuminates the motive directly

Directional lighting – Lighting directed in a certain direction

Disability glare – Disability glare impairs the vision of objects

Discomfort glare – Instinctive desire to look away from a bright light or making it difficult to perform a task

Flicker – Visible quick changes in luminious intensity

Glare – Difficulty seeing due to bright light

Illuminance (at a point of a surface)

Incandescent (electric) lamp - Glödlampa

Indirect lighting – Lighting not directed towards the motive

Luminous flux – Amount of light from a light source. Unit: Lumen (lm)

Luminous intensity – Amount of light in a given direction (cd)

Monochromatic light – Light exhibiting one colour

Polychromatic light – Light exhibiting more than one colour

Reflectance – A surface effectiveness in reflecting radiant energy

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1 Introduction

This chapter explains the problematization, purpose and research questions in this thesis. The objective of the thesis will be achieved by literature study and through gained knowledge of the product and the user. The delimitations of the thesis are also explained.

1.1 Scania CV AB

Scania CV AB, hereafter called Scania, is a company with sales and service organisation in more than 100 countries and with its production in Europe and Latin America. The Head Office and research and development operations is located in Södertälje, Sweden. In total approximately 42000 employees work at Scania and out of these about 3500 work with research and development. (Scania, 2013)

The company's objective is to provide the best profitability for its customers throughout the product life cycle by delivering optimised heavy trucks and buses, engines and services. All off Scania's operations are based on the company's core values; *customer first*, *respect for the individual*, and *quality* and is applied as a unified concept. (Scania, 2013)

1.2 Department of Physical Vehicle Ergonomics (RCDE)

This thesis was written at the department of physical vehicle ergonomics at Scania in Södertälje.

1.3 Long-haulage truck

The long-haulage truck (see Figure 1-1) is used to move different types of cargo, often long distances which can take several days. This is why long-haulage trucks often are equipped for compact living inside the truck cab. The

truck cab is an environment where the truck driver both works, rests and sleeps.

Figure 1-1, one of Scania's long-haulage trucks and one of the authors.

1.4 Problematization

Light affects our senses every day, from the moment we wake up we experience countless sets of lightings. Every individual perceive the element of light different, in the way that the eye physically reacts and how it consequently affects the psychological and physical well-being of the human body. Light is also what creates visual experiences for indoor and outdoor environments.

The way light affect the human is an important factor in the everyday work of many. Several big companies use some set of requirements regarding ergonomics, where physical load on the human body is in focus. It is important to provide employees with a safe and ergonomic work environment but also a satisfying environment to maintain efficiency and to empower their will to work. For many truck drivers the majority of the time spend is often limited to the inside of the truck cab and is therefore also a place for resting and living. The cab is provided with equipment for, e.g., cooking and sleeping and one might consider it a minimalistic and compact living. With the truck driver's well-being in mind it is important as a cab designer to help facilitate low physical and psychological load in every sense possible. The truck driver experience several sources of light during working hours and it is therefore in the users and the company's interest to create the best lighting possible.

Incandescent lights is common in over-head installations in e.g. long-haulage trucks or cars. The LED technology is rapidly gaining foothold in interior

lighting and many preferred qualities can be extracted from that. In Scania's interest, LED along with newer technology is the future of interior lighting both from an economic and also competitive perspective.

1.5 Purpose

The purpose of this study is to explore the needs and opportunities to improve the working environment in a truck cab with lighting design when planning for interior lighting in a truck cab by using LED (Light Emitting Diode) and/or OLED (Organic Light Emitting Diode) and how it could affect the working environment for truck drivers.

1.6 Objective

The objective with this study is to create a planning guide plan for lighting design in a truck cab.

1.7 Research questions

The research questions that will be answered in this study are:

- Is there a need for personalized lighting in a truck cab?
- How can lighting planning and LED/and or OLED improve the lighting environment in a truck cab?

1.8 Approach

The approach for this study is to gain knowledge in the subject of visual ergonomics and lighting design by studying literature, interview experts in visual ergonomics and lighting design. Knowledge about the user, truck drivers, and the product, the truck cab, will be gained with a user study and benchmark of existing interior lighting in long haulage trucks. The knowledge is supposed to aid in further development and research in the area studied.

1.9 Literature

The base of the literature study shall include studies and reports regarding visual ergonomics, the technology of LED (Light Emitting Diode) and OLED (Organic Light Emitting Diode), also traditional lighting planning. The

literature will be used as a tool to build knowledge and to bring substance to the research and to aid in answering the research questions.

1.10 Delimitations

The following delimitation will be made in the study:

Production - The conclusions of this thesis will not consider production nor construction of light installations.

Financial - The conclusions of this thesis will not consider financial aspects of new technology or light installations.

Only interior lighting - The thesis covers only the interior lighting inside the cab of a truck. Furthermore, light from indication lights or instrument panel will not be regarded.

Long-haulage - The study is limited to long-haulage trucks.

2 Theoretical framework

This chapter contains the theoretical framework of this study. The theoretical framework is divided into six sections; Visual ergonomics, Light, Technology, Lighting planning, Product development process and Driving and rest periods for truck drivers.

2.1 Visual ergonomics

Visual ergonomics is the knowledge about how our eyes and vision is affected of the things we see and its consequences on our health and performance (Renström & Håkansson, 2013). According to International Ergonomics Association (IEA, u.d.) the definition of visual ergonomics is as following:

> *"Visual ergonomics is the multidisciplinary science concerned with understanding human visual processes and the interactions between humans and other elements of a system. Visual ergonomics applies theories, knowledge and methods to the design and assessment of systems, optimizing human well-being and overall system performance. Relevant topics include, among others: the visual environment, such as lighting; visually demanding work and other tasks; visual function and performance; visual comfort and safety; optical corrections and other assistive tools."*

Within visual ergonomics there are four main subjects, the vision, the lighting, the work piece and the impact from the surroundings (Nylén, 2012). Many benefits can be found with successful visual ergonomics in a working environment, both for the employer and the employee. It doesn´t take a lot of effort or investment to create a good visual environment. With only common sense and know-how, problems as being blinded by lighting, contrast between working pieces and the background, and also sufficient lighting in a workspace can be corrected. Good visual ergonomics can be achieved with correct directional lighting, no blinding lights, good colouring and evenly distributed light (Renström & Håkansson, 2013). Important parameters when processing light are; contrast, colour- and night vision, depth perception and detection of movement (Bohgard, et al., 2010).

2.1.1 The Eye

The knowledge about the human eye's function and its anatomy is of interest when trying to understand how lighting in a working environment affects the user and how the lighting should be designed (Nylén, 2012).

Out of all our senses, sight has the most impression on our brain with 80% of the total impression from our senses (Nylén, 2012). The eye detects the visual light of the spectra (see Figure 2-1). Humans rely mostly on the visual sense and is very effective to see movement (Bohgard, et al., 2010). The visual sense is actively looking for pattern and structures.

The first thing the light hits is the cornea where most of the focusing is done (Nylén, 2012). The refractions in the cornea is 2/3 of the total refraction in the eye (Hemphälä, 2008). After the light has passed the cornea the lens refracts the remaining 1/3 and the light travels through the vitreous and hits the retina. In the retina there are two kinds of photoreceptors, cones and rods that transform the light energy into nerve signals that through nerve cells ends up in the brain. The rods detects all kinds of light no matter the colour of the light (Nylén, 2012). They are more sensitive to light than the cones and signals only in a grayscale from black to white. At dusk, when there is not much light, only the rods gives signals to the brain. Also the rods are few in the central part of the field of view, which makes the night vision less detailed as in an environment with daylight. In the retina there are 10 billion photoreceptors, but the distribution of photoreceptors is uneven. Only in a little region of between 1-2% is the vision sharpest. In this region the vision is roughly similar as the resolution of a 200-500 megapixel camera. The amount of light that is projected onto the retina is adjusted with the pupil (Renström & Håkansson, 2013).

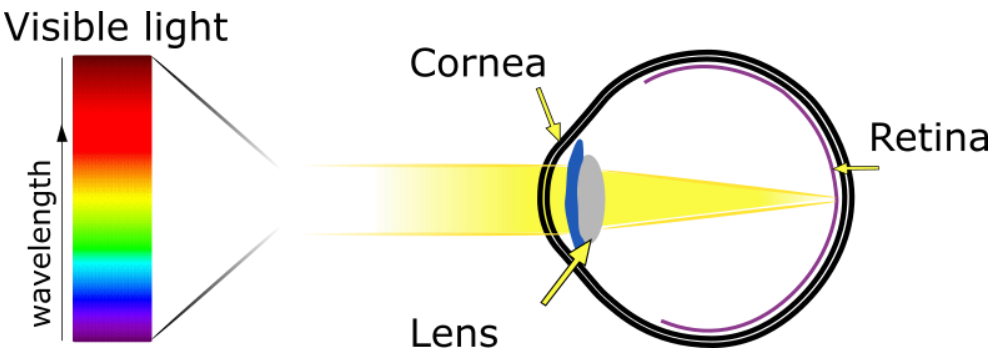

Figure 2-1, light within the visible spectra is detected by the eye which helps us form coloured images (adopted from Renström & Håkansson, 2013 p.11 and Nylén, 2012 p.17).

The eyes ability to adjust the focus on objects in different distances to the eye is called accommodation (Renström & Håkansson, 2013). A transition in the size of the lens occurs instantly when the lens changes its elasticity on the inside and outside. An object that is closer to the eye needs more convergence than an object that is further away (Nylén, 2012).

2.1.2 Circadian system

The human among many living organisms possess the ability to adapt to phase shifting light conditions, meaning our biological clock is mainly steered by the presence and absence of sunlight. The biological phenomena is called the circadian clock which refers to the internal timing of a 24 h rhythm, which would refer to a "daily rhythm" in common language. The circadian clock is the reason for shifting between sleep and alertness. (Fuhr, et al., 2015)

Several studies has been made about the issues with altering the circadian rhythm and how it affects us (Boyce & Hopwood, 2013) (Cajochen, 2007) (Holzman, 2011) (Kramer & Martha, 2013) (LeGates, et al., 2014), this thesis include a handful of these studies. Changes in routines can influence our sleep and consequently change our mood and cognitive function negatively, this is agreed by most without an exact reference. The idea of the connection between light and the circadian clock would explain why e.g. shift workers experience negative physical and cognitive effects due to shifting lighting environment. Disturbance of circadian rhythm is closely connected to depression and effects from light therapy have been detected as a positive factor regarding e.g. sleep deprivation or seasonal affective disorder (Boyce & Hopwood, 2013).

2.1.3 Non-visual effects

The eye and the retina not only helps us form images but work as a detector of light which consequently regulates numerous behavioural and physiological functions. This group of functions is called non-image-forming visual functions (NIF visual functions). These NIF visual functions are major contributors of the regulation of the circadian clock where the periodical changes in light confine our activity-rest rhythm (LeGates, et al., 2014). When the retina of the eye is exposed to certain wavelengths of bright light, melatonin secretion is suppressed (Boyce & Hopwood, 2013). Melatonin is a hormone and should peak in level during night when we should be the most tired. Beside this, light might affect humans independently of the circadian rhythm, basically meaning that the eye responses to light during exposure and stops responding after exposure. In order to alter the attention, alertness and emotional processes, short wavelengths of blue light are preferred (LeGates, et al., 2014).

Studies in the past decades show that light has a strong influence on a human's state of alertness from the brain's non-visual detection of light (Cajochen, 2007). Blue light at a certain wavelength suppresses the melatonin secretion causing us to think that we should be awake, due to alertness and the circadian rhythm. Most of us are frequently subjected to blue light at night when we are using our computers, TVs, tablets or smartphones. Blue light affects our biological clock most negatively at night, and at the same time affects us in the most positive way during the day, it keeps us alert (Holzman, 2011).

Cajochen (2007) stresses the importance of reliability of test results on suppression of melatonin secretion and the importance of the difference between laboratory testing and a real life setting. To measure alertness one

might, according to Cajochen (2007) use subjective or objective ratings where subjective ratings may be misleading due to intuitive answers from test subjects. To measure alertness or fatigue on a test subject in a real life setting, e.g. truck driving, the nature of interference needs to be taken into account. Electroencephalographic (EEG) and electrooculography (EOG) monitoring will measure brain activity and eye movement. Such measures can be used to verify levels of alertness or fatigue while their nature of interaction is a big disadvantage.

Cajochen (2007) also mentions that past research mainly uses bright light (>1000 lux) while a normal lighting in a room is about 100-200 lux. However, Kozaki, et al. (2008) made a study on the suppression of melatonin secretion with illuminance (the amount of light) of 200 lux, which was meant to simulate a normal indoor environment. The result show that light at 5000K supress melatonin secretion considerably more than for light at 3000K. The result conform to at least three studies that has been done on suppression of melatonin secretion from light (Kozaki, et al., 2008).

Kuijsters, et al. (2015) made a study on elderly people where they exposed them to two sets of lighting in a closed environment. It is shown that light in a closed environment can create a cosy and an activating environment that affects elderly people in a state of an anxious or a sad mood. The study shows that a whiter and "active" environment will affect people in a sad mood positively and that a warmer and cosy environment will affect people in an anxious mood positively.

2.1.4 Sight changes with aging

Our sight changes with aging and it gets tougher to handle different visual tasks as we get older (Bohgard, et al., 2010). By the age of 40-50 years old it is noticeable that the lens in the eye gets stiffer and can't go back to its spherical shape as in a younger age. The term for this phenomenon is presbyopia.

The eyes ability to accommodate reduces with aging and it gets more difficult to get a clear view since the depth of focus reduces and the accommodation takes longer (Bohgard, et al., 2010). Increasing age means increased need of light significantly (Nylén, 2012). The author further explains that a 50-year old person needs 200% and a 60-year old 300% more than a 20-year old.

2.1.5 Sleeping disorders and shift working truck drivers

In 2013, SBU released a report about the correlation between the working environments and sleeping disorders (SBU - Swedish Council on Health Technology Assessment, 2013). One who suffers from disrupted sleep may encounter issues such as low energy during the day, mood swings and decreased concentration. A survey from 2008 with 1 550 Swedish participants 18 to 84 years old showed that roughly one in four experience some sort of sleeping disorder. One of many reasons, regarding sleep, for a Swedish worker to be negatively affected by work is to be thinking about work during free-

time. From SBU's report one in five from a study in 2011 indicated problems with sleeping due to this.

In 2002, VTI (Swedish institute for research of road and transport) made a police-report summary of road accidents caused by tiredness (Larsson & Anund, 2002). It is discussed that sleepiness behind the wheel contributes to 10-20% of all traffic accidents. The report shows that for tiredness, single-vehicle accidents at 90-110 km/h is the dominating relation, meaning it is likely to be on the highway.

In 2015 Pylkkönen, et al. made a study about sleepiness and sleep for shift-working long-haul truck driver's methods they used for counter measuring sleepiness. The study containing 54 long-haul truck drivers with at least 2 years corresponding work experience was conducted in Finland during the winter months from November to March. With four different shift-types studied the conclusion was that sleepiness and severe sleepiness at the wheel is widely common for shift working long-haul truck drivers. Depending on the type of shift different sleepiness countermeasures was used, such as intake of caffeine, taking a nap, having a light or heavy meal, smoke or take a walk outdoors (Pylkkönen, et al., 2015).

2.2 Light

Light is what we call the electromagnetic radiation that we can perceive when it hits our retina (Nylén, 2012). The human visual system reacts to wavelengths in the span of 380-780 nanometres (nm) (Boyce, 2014). Other creatures reacts to different spans of wavelengths. The different wavelengths for different colours of light are approximately for blue 430-500 nm, green 515-560 nm, yellow 565-585 nm and red 600-780 nm (Nylén, 2012). When we talk about light we usually refer to luminous flux, luminous intensity, illuminance and luminance (see Figure 2-2).

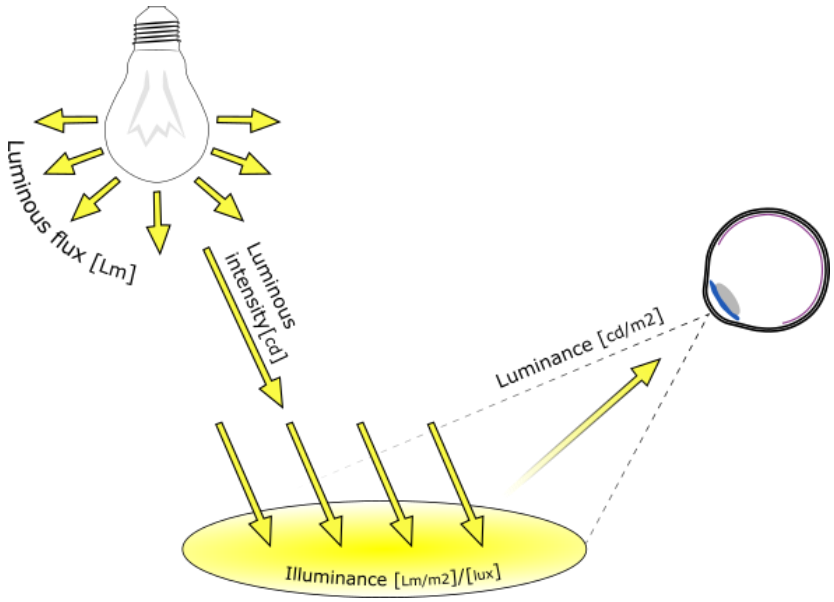

Figure 2-2, physical units of light (inspired from p.22 (Renström & Håkansson, 2013) and (Starby, 2003))

2.2.1 Luminous environment

The meaning of the term luminous environment is such which is affected of sources of light and their characteristics, the lights spectral composition and direction, how much light that hits different objects and the objects reflection. Not only is good lighting a presumption to get correct information, but has a esthetical dimension which can affect our well-being. Variations in lighting has an effect on biochemical processes in the body such as seasonal changes and variations during the day affects our circadian rhythms. (Bohgard, et al., 2010)

2.2.2 Luminous flux

Luminous flux is the term for the amount of light a light source emits. The unit for Luminous flux is lumen (Lm). Both the luminous flux and the lighting fixture is crucial to achieve the desired illuminance. (Renström & Håkansson, 2013)

2.2.3 Luminous intensity

Luminous intensity is a term for the intensity of the luminous flux in a certain direction (Renström & Håkansson, 2013). The unit for Luminous intensity is Candela (cd). Luminous intensity is displayed in a light distribution curve, which shows how the light varies around the fixture, see Figure 2-3. The graph represent a cross section of a lamp or fixture's luminous intensity in every angle. If the curve reaches above the horizontal centreline it indicates that light is distributed above the fixture. As for the picture on the left the luminous intensity is approximately 680 candela [cd] and is only distributed

downwards. The light distribution curve ease the planning of a new lighting project (Renström & Håkansson, 2013).

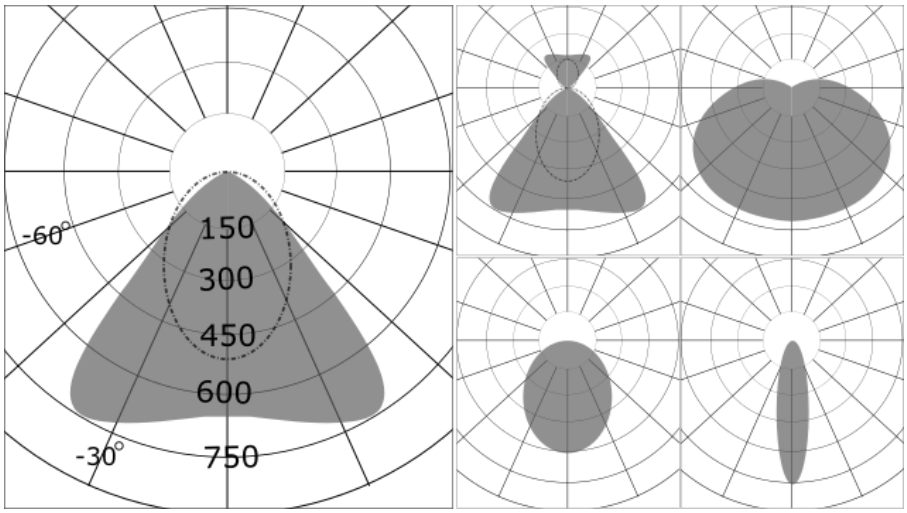

Figure 2-3, the light distribution curve shows how light is distributed from a lamp or a fixture (inspired by (Renström & Håkansson, 2013)).

2.2.4 Illuminance

Illuminance is the term for the amount of flux that strikes a surface (Renström & Håkansson, 2013). The unit for illuminance is Lux (lx) and 1 Lux is when a luminous flux of 1 lumen illuminates evenly an area of 1 m2. Different types of work require different amount of illuminance (Nylén, 2012). Illuminance is not a measurement of lighting quality, which is often misinterpreted, since it doesn't describes the experience of the lighting environment. Illuminance is measured with a lux-meter (Renström & Håkansson, 2013).

2.2.5 Luminance

Luminance is the term for the amount of luminous flux reflected on a surface (Renström & Håkansson, 2013). The unit for luminance is candela per m2 (cd/m2). Two surfaces with the same amount of illuminance can differ in the amount of luminance, depending on their reflectance (Nylén, 2012). A dark surface has less reflectance than a white surface. The visual experience between the dark surface and the white is called brightness difference and what is measured is called luminous difference (Renström & Håkansson, 2013). It is important to consider recommended limits of luminance, when planning new lighting, but it doesn't ensure a good visual experience (Renström & Håkansson, 2013). The perception of luminance differs among people due to how well the eye is adjusted to light (Nylén, 2012). A general recommendation of comfort reasons is not levels over 2000 cd/m2 and definitely not levels over 10000 cd/m2. Luminance at this level can do damage to the retina. Other symptoms caused of the experience of great luminance differences are stress, tiredness and glare (Renström & Håkansson, 2013). The luminance level of some none-covered fluorescent lighting is sometimes over

10000 cd/m2 and therefore needs to be foreclosed or not appear in the viewing field (Nylén, 2012).

Luminance is measured by a luminous meter which is pointed to a surface like a camera. It is quite complicated but important knowledge can be gained. (Renström & Håkansson, 2013)

2.2.6 Colour temperature

Objects only have an ability to reflect colours from the light spectra that is why it is so important to choose the right light source to accentuate the visual expression of an object or environment. Regarding artificial light, colour temperature and colour rendering index are the factors that separate one light source from another. Colour temperature is measured in Kelvin (K) and is often divided into warm (yellow) and cold (blue). (Wall, 2009)

The character of the lighting are described as the apparent colour of the light and is also called chromaticity. The correlation between the colour characteristics and the colour temperature of the artificial light (T_{cp}), can be seen below in Table 2-1. Daylight is always changing its intensity and colour temperature. Research shows that lighting not only have a visual impact on humans, but also a biological and emotional impact. (Ljuskultur, 2013)

Table 2-1, a description of relation between how colour often is perceived in terms of temperature (inspired by (Ljuskultur, 2013)).

Colour characteristics	**Correlated colour temperature T_{cp}**
Warm	Below 3300K
Neutral	3300-5300K
Cold	Over 5300K

It is a balance of psychology, aesthetics and the perception of what's natural when deciding the colour temperature of lighting. Colder light is often preferred in warmer climate and warmer lighting in colder climate (Ljuskultur, 2013). Basically, a regular 60 W light bulb has the colour

temperature 2700K, a cloudy sky 6500K and a blue sky 30 000K (Bohgard, et al., 2010).

2.2.7 Colour rendering index

The quality of colour rendering of a light source is expressed in colour rendering index (CRI), or also called R_a-index. Maximum value is 100 and comes from an ideal light source. A light source has excellent colour rendering if the Ra-value is above 90, good colour rendering above 80 and poor colour rendering if below 80. (Renström & Håkansson, 2013)

2.2.8 Rule of distance

When a light source is active and cause illuminance upon a surface perpendicular to the beam, the distance between the light source and surface cause different illumination. The rule (see Figure 2-4) says that the illumination changes due to changes of the square value of the distance (Starby, 2003).

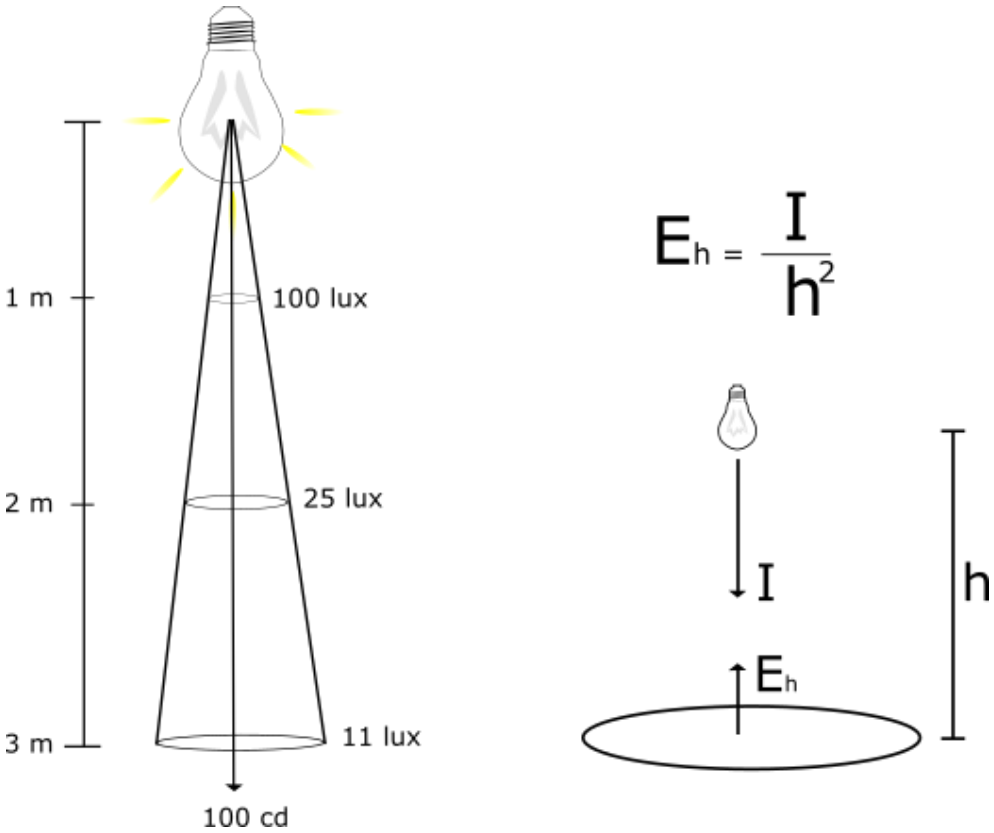

Figure 2-4, the rule of distance explains how much a surface at a distance from a light source is illuminated (inspired by (Starby, 2003)).

2.2.9 Light source efficiency

When comparing light sources it is common to refer to the light source efficiency -how much luminous flux (lumen) a light source emits relative its electrical power. This relation is expressed as lumen per watt (Lm/W). For a retailer of lamps it is most usual to express this specifically for the lamp, but in fact there may be a loss in effect due to different light fixtures. E.g. if a retailer sells a 36W light bulb that emits 3000 Lm the light efficiency is told to be 3024/36= 84 Lm/W, but if the loss from the fixture is 10W the efficiency is 3024/(36+10)=65,7 Lm/W. So the lighting designer should consider the so called system effect of the lamp. (Starby, 2003)

2.2.10 Shadows and Contrasts

Shadows makes it easier to estimate distances and to perceive shapes. Objects appearances change depending on the direction from which the light comes from. Directed light results in sharper shadows and light from several different light sources makes the light and the shadows soft. (Renström & Håkansson, 2013)

Contrast is perceivable differences in colour and brightness (Renström & Håkansson, 2013). Being blinded due to contrast of two adjacent surfaces with great difference in brightness can cause blinding and is called contrast blinding (Nylén, 2012). Preferably should the distribution of the luminance in the central part, the adjacent and the peripheral parts be in the ratio 5:3:1, see Figure 2-5. Contrast blinding occur when the difference of luminance is greater than 100 times as much as the other, but many factors affects contrast glare as distance between the surfaces and their sizes. To be able to see clearly the contrast need to be well balanced (Renström & Håkansson, 2013). Also factors such as genetics and age correlates to the perception of contrast blinding (Nylén, 2012).

Figure 2-5, principle sketch of desirable ratio, 5:3:1, central: near peripheral: far peripheral, between luminance in the viewing field (inspired by (Nylén, 2012)).

2.2.11 Reflectance

Reflectance is the term of the amount light a surface can reflect. A surface reflectance property is defined in percentage. As example, a black matte

surface reflects 5% of the incoming luminous flux whereas a white matte ceiling often reflect more than 85% of the incoming luminous flux. (Renström & Håkansson, 2013)

2.2.12 Glare

Glare occurs when the eye is exposed to brighter light than what the eye is adapted to (Ljuskultur, 2013). Also bright surfaces or intense reflection can have a glaring effect. Older people have more difficulty in adapting to different luminous environments and therefore get easier blinded by light. Glare can be prevented by shielding the light source and correct placement (Renström & Håkansson, 2013).

To quantify glare it is proper to use a luminance meter to assess the amount of discomfort blinding lights by using the UGR method (Unified Glare Rating). The UGR method is based upon a formula developed by the international commission on illumination. UGR refers to the measure of emitting luminance from a fixture to the eye when the eye has a fixed line of sight. How to measure UGR can also be seen in SS-EN 12464-1. According to Ljuskultur (2013) the formula is as follows:

$$UGR = 8log_{10}\left(\frac{0.25}{L_b}\sum\frac{L^2\omega}{p^2}\right)$$

$L_b = Luminance\ in\ the\ background\ (cd * m^2)$
$L = Luminance\ at\ the\ bright\ spots\ at\ each\ lighting\ fixture\ in\ the\ direction\ of\ the\ viewers\ eye.$
ω =Angle between the direction of sight and the centre of each light source.
$p = Guths\ position\ index$

Four different types of blinding lights can be avoided due to a well-planned lighting- and workplace design according to (Bohgard, et al., 2010):

1. *Direct glare*, due to blinding lights hitting the eye directly.
2. *Indirect glare,* due to reflection in reflecting materials.
3. *Contrast glare* - Being blinded due to great difference of luminance in the viewing field.
4. *Adaption glare* - Being blinded due to quick changes between a bright and dark environment.

To avoid being directly blinded from a light source, should it be placed with at least 45° angle from the direction of the view, see Figure 2-6.

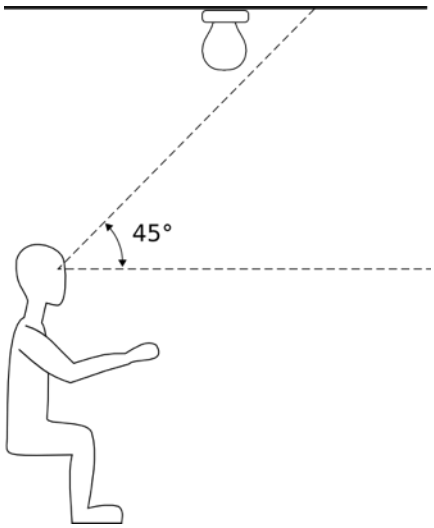

Figure 2-6, the angle between any light source and the direction of view should at least be 45 degrees to avoid direct glare (inspired from Bohgard, et al. (2010)).

Direct light from light sources can cause disability glare and if so should be shielded (Ljuskultur, 2013). The shielding angle is the angle between the horizontal line and the first line of sight where a light source can be seen, see Figure 2-7. The cut-off angle is the angle is from the vertical line and to the line where light from light sources or surfaces with high luminance is longer visible.

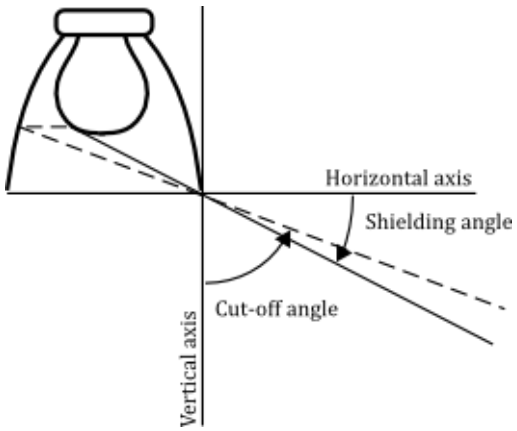

Figure 2-7, the cut-off angle and shielding angle are used to shield a light source from glare (inspired from Ljuskultur (2013)).

2.3 Lighting technology

In this chapter follows a brief descriptions of LED, what to think of when dimming LED and also OLED.

2.3.1 LED

Light emitting diode (LED) is a semiconductor activated by electrical current and emits light of different colours through electrical stimulation (Renström & Håkansson, 2013). LEDs differ from traditional light sources where emitting light is a secondary product from a heat source often mixed with gas. LED-technology has now progressed to compete and go beyond conventional light sources in matter of light output and colour characteristics (Khanna, 2014).

A LED doesn't emit UV- nor IR- radiation and are therefore suitable for sensitive environments (Renström & Håkansson, 2013). The LED lights up instantly when activated by electrical current and has extremely high luminous flux. It hasn't any sensitive parts and can therefore bare vibrations and mechanical stress. LED-lights can easily cause glare and needs to be combined with various forms of reflectors, optics or some diffusing material. LED technology changes traditional lighting standards and housings and conventional thinking is not applicable to this technology (Khanna, 2014). One factor that defines the quality of LED-lights is that the colour temperature doesn't change over time. White light from LEDs are blue LEDs with a layer of phosphorus on top. The phosphorus layer creates yellow light which combined with the blue light results in white light. The CRI-index for LED-lights can vary from 60 to 95 (Renström & Håkansson, 2013).

The characteristics of a LED is mostly its ability to control the light spectra and to direct light without having to use reflectors where light often is trapped in the fixture (Renström & Håkansson, 2013).

2.3.2 Dimming LED

Flicker is the term for quick luminous variations which can be perceived and is subjective. The physiological term, when the frequency of the flicker is greater than we can perceive, is amplitude modulated light variations. The impact amplitude modulated light has on people varies from no problems to, migraine, unconsciousness and epileptic seizures (Hemphälä & Nylén, 2013). Both flicker and amplitude modulated light variations should be avoided (Belysningsbranschens Tekniska Komitté, 2015).

There are two main types of techniques for regulating the luminous intensity in actuators for LED-lighting according to Belysningsbranschens Tekniska Komitté (2015):

Pulse Width Modulation (PWM), is an actuator with a modified voltage. The frequency shouldn't be below 300 Hz, due to eventual risk of flicker. A High-quality actuator with PWMs shouldn't flicker, but low-quality actuators might when not applying the existing recommendations. Many actuators combines PWM with amplitude modulation at low luminous intensity levels.

Amplitude Modulation (AM), is a technique which means current reduction to reduce the luminous intensity and can't cause flicker.

A concern from the lighting industry is that flicker from magnetic-ballasted fluorescent, metal balide and high pressure sodium lamps from 60 Hz possibly have a connection to headaches, distraction, fatigue, annoyance and lower productivity (Lehman, et al., 2011). Lehman, et al. further explains the concern about that an increasingly popularity of LED-lighting follows possible flicker, due to various forms of pulse width modulation in many products. LED-luminaires needs to be carefully matched with a compatible dimmer.

The reason pulse width modulation is used are due to less thermal load, longer life-time and it is a simple dim-technique. LED-light sources has potential, but when planning for new lighting design it is important to highlight the importance of choosing right actuator (Hemphälä & Nylén, 2013).

2.3.3 OLED

Organic Light-Emitting Diode (OLED) is a LED with an emissive electroluminescent layer of organic compound that emits light in response to electric current (European Commision; Joint Reasearch Centre, 2014). OLEDs emits a ”pleasant” UV-free light with a high CRI-index (European Commision; Joint Reasearch Centre, 2014). OLED-technology enables the creation of extremely flat panels, which emits light evenly over a surface (Khanna, 2014).

A manufacturing challenge with OLED-panels is integrating them into functional luminaires. It is no clear analogy for OLED luminaire manufacturing compared with LED luminaire manufacturing which is more similar to conventional luminaire manufacturing, consumer electronics manufacturing and semiconductor manufacturing (European Commision; Joint Reasearch Centre, 2014). OLED will pilot a paradigm shift, creating surface-emitting planar sources, in the lighting industry, together with LED-lighting (Khanna, 2014). OLED is the only lighting technology creating the possibility for an embedded light-emitting surface and functions as either a lamp or luminaire (Khanna, 2014). It is also possible to change the OLED in a range of colour temperatures. OLED- lighting enables a new way of design, personalize and create novel lighting concepts for living environments, offices, public places and vehicles such as cars, buses, railways and airplanes (Khanna, 2014).

Other benefits with OLED-Lighting are; *Less heat generation*, because of the capability to, instead of operating at a higher luminous intensity, enlarge the luminous surface and creating the same luminous flux (Khanna, 2014). The light source can be placed closer to the task surface without having a glaring effect, due to OLEDs low brightness (European Commision; Joint Reasearch Centre, 2014)

The ability to create the OLED-surface *transparent* enables the lighting to be mounted on windows and both work as a source of daylight and as a luminaire at night time. OLED-lighting will in the future be mounted in ceilings and on walls (Khanna, 2014). Transparent OLEDs improves contrast, which simplifies viewing displays in bright sunlight and can be used in head-up displays, smart windows or augmented reality (European Commision; Joint Reasearch Centre, 2014).

2.4 Lighting planning

An effective approach to find good lighting solutions is a structured analyse of the needs of an activity and the knowledge about good lighting (Nylén, 2012). According to Nylén (2012) should a structured analyse of the lighting environment include:

- Sufficient illuminance
- Harmonic brightness distribution
- No blinding lights
- Correct light direction
- Appropriate shadowing
- Good light colour and colour rendering
- Good room climate

Some aspects that should be taken into account when planning lighting according to Renström et.al (2013) are:

- Visual conditions for the user
- Esthetical conditions
- Technical conditions
- Architectural conditions
- Economical aspects
- Environmental aspects

It is important for the user's well-being and to be able to see that the visual conditions are well planned (Renström & Håkansson, 2013). Factors that enhance well-being are when the user is able to adjust the brightness in the lighting environment and a diverse lighting setting (Renström & Håkansson, 2013). Key is an appropriate colouring and that all surfaces are lighted (Renström & Håkansson, 2013).

It is important that the interior design, colours and the design of the lighting fixture have a harmonic impression together (Renström & Håkansson, 2013).

Different situations in the room requires different lighting environments. It is important with sufficient lighting, correct light sources and fixtures for all the situations in the room. (Renström & Håkansson, 2013)

Lighting have the ability to enhance and improve the design of the room (Renström & Håkansson, 2013). Good communication with the designer is important for the overall experience in the room (Renström & Håkansson, 2013).

Economical aspects needs to be taken into account in order to make the project realistic. The lighting environment should be both stimulating and energy efficient. (Renström & Håkansson, 2013)

The light sources and the fixtures are a part of our ecological system and needs to be environmental friendly (Renström & Håkansson, 2013).

Different working and living-environments need different sets of lighting. An important aspect when planning for lighting design is to determine the preferred level of quality. This could mean that only standards and requirements are important or that bringing a certain feeling to the environment is important. (Renström & Håkansson, 2013)

2.4.1 Lighting planning process

The lighting planning process according to Ljuskultur (2013) can be seen in Figure 2-8.

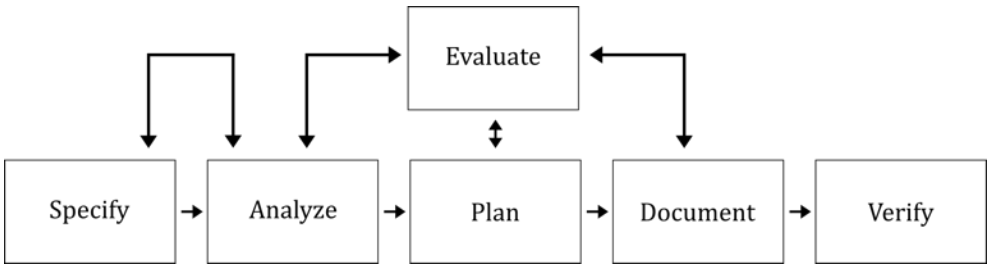

Figure 2-8, the Lighting planning process according to Ljuskultur (2013).

Specify

If nothing else is mentioned is the information in this chapter gathered from Ljuskultur (2013).

Initially when starting a lighting planning project it is important to define the stakeholders in the project, which can be people in several different working categories. Stakeholders can be; the client, project manager, lighting planner, architect, decorator, installer, electrician and the end-user. The tasks for each stakeholders is different and it is important with good communication (Renström & Håkansson, 2013). Initially in a lighting planning project the client together with lighting planner sets the goals and the requirements for the lighting.

Specify key activities and what the room is used for. If there is a need for an emergency lighting it should also be specified and which laws and regulations to follow.

The visual tasks should be specified and include information about in which planes, vertically, horizontally or angled they take place in. Also the visual

environment, with the working object, working area and the surroundings, should be planned to create the best visibility as possible.

Define working areas, their requirements and how they affect the rest of the room.

The visual experience should be specified to fulfil the client's desired result both in visual and nonvisual aspects. It is important the lighting is coordinated together with the interior, the materials and the colours in the room for the overall experience.

It is important that the interior design, colours and the design of the lighting fixture have a harmonic impression together (Renström & Håkansson, 2013).

Specify the environmental goals and energy efficiency for the lighting. Try to make the lighting system as energy efficient as possible without effecting the visual experience.

Specify a budget for installation, energy during use, controlling and maintenance.

Make a time plan for the project and specify the projects different phases; analyse of the conditions, planning of the lighting system, evaluation, documentation and installation.

Analyse

If nothing else is mentioned is the information in this chapter gathered from Ljuskultur (2013).

After the lighting planning have been specified an analysis of the forced conditions should be done. Define all laws, physical conditions, economical and historical conditions which needs to be taken into account in the lighting planning. Check how well they corresponds to the clients requirements.

Analyse the general conditions for the lighting planning. Define what is flexible and what is set in the design, interior, daylight, character and which type of screens is used. Check how well they corresponds to the clients requirements.

The list of requirements includes the clients- and legal requirements. Also lighting recommendations. All requirements should be weighed after importance. The list of requirements should include parameters such as; lighting intensity, lighting distribution, contrast between working area and the adjacent and the peripheral areas, lighting intensity in ceiling and on walls., cylindrical lighting intensity, reflectance of surface and their colours, size and position of windows, the colour temperature of the light sources and their CRI, limitations of luminance, luminance ratio within the viewing field and requirements to shield from glare, also energy consumption.

Aesthetical and architectural requirements can't be quantified but should be fulfilled as much as possible.

Plan

If nothing else is mentioned is the information in this chapter gathered from Ljuskultur (2013).

When all have been specified in the previous steps, it is time to evaluate the lighting conditions and decide light sources, fixtures and controlling of the lighting system in this phase in the lighting planning process. Calculations for the lighting and the energy consumption should be done together with evaluation of the design and an economical assessment of the project and a maintenance plan is created.

Document

If nothing else is mentioned is the information in this chapter gathered from Ljuskultur (2013).

The documentation from planning the lighting system, blueprints and maintenance plan is compiled when they are approved of the client. The documentation should be so extensive and can be used for inspection assessment.

Evaluation

If nothing else is mentioned is the information in this chapter gathered from Ljuskultur (2013).

New lighting should be evaluated to check if the lighting works accord to the lighting planning. Existing lighting should be evaluated to make sure requirements for good lighting is fulfilled. New lighting systems require more extensive evaluation than existing lighting.

When evaluating the visual environment in the truck cab the questions in Appendix 8 – Visual/Physical – Conditions, with inspiration from Renström & Håkansson (2013) and Ljuskultur (2013), can be used as a checklist. When evaluating the visual condition an advantage is to use a lux- and luminance meter, but first evaluating the overall experience by looking end being in the room (Renström & Håkansson, 2013).

2.5 Product development process

The Front-End process is an iterative process used during the concept development in a product development process and is developed by Ulrich & Eppinger (2008), see Figure 2-9. During all phases are also the result and

knowledge from an economic analysis, benchmark, prototypes and models input for all phases (Ulrich & Eppinger, 2008).

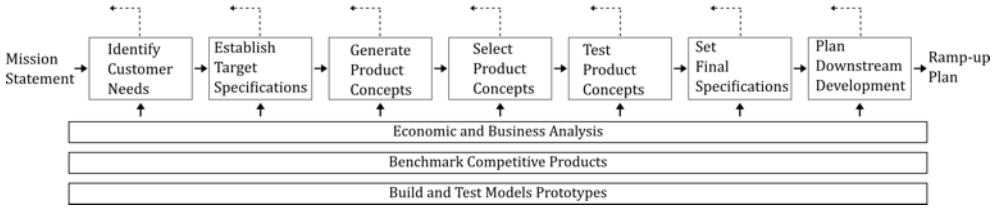

Figure 2-9, concept development process developed by Ulrich & Eppinger (2008).

The *mission statement* is the result from the planning phase of the project and contains specification for the targeted market, business goals, key assumptions and constraints. (Ulrich & Eppinger, 2008)

The first phase in the development process is to *identify customer needs* and to list them in a hierarchy of which statements are important or not. (Ulrich & Eppinger, 2008)

In the second phase the development team *establish a target specification,* which is a technical translation of the customer needs. The result is a target specification list and each specification has a metric, a marginal and ideal value. (Ulrich & Eppinger, 2008)

With the target specification in mind the product development team *generates product concepts* thoroughly. The concept generation begins with clarifying the problem and dividing it into sub problems. The search for solutions and can be both internally and externally. When searching for solutions externally can include interviewing lead users, consult experts, search for patents, benchmark. When searching for solutions internally can be either individual or in group sessions. A combination of individual work and group sessions are ideal. Group sessions are critical for creating consensus, communicating information and refining concepts. (Ulrich & Eppinger, 2008)

The number of solutions is narrowed down and promising *concepts are selected* in a structured way and the concepts are evaluated how well they fulfil the customer target specification. Some concepts may be further developed before being selected. (Ulrich & Eppinger, 2008)

The selected concepts are further refined and tested to ensure they fulfil the target specification. Iteration is possibly needed. (Ulrich & Eppinger, 2008)

After further refinement of the concepts the *final specification* are set for the product. (Ulrich & Eppinger, 2008)

In the last phase of the concept development process the *downstream development for the project are* planned. (Ulrich & Eppinger, 2008)

2.6 Driving and rest periods for truck drivers

There are several restrictions regarding the truck drivers driving and rest periods and are described in the following section. Examples of how the schedule during a week can look like can be seen in Figure 2-10. (Transportstyrelsen, 2015)

2.6.1 Daily rest

Each 24-hour period needs to have one daily rest. The duration of a normal daily rest is 11 hours. A reduced daily rest is 9 and the daily rest can be reduced maximum three times during a working week. A daily rest can also be divided into two periods the first period of 3 hours and the latter 9 hours (3+9hours). (Transportstyrelsen, 2015)

2.6.2 Driving time

Registered driving time is the time when the driver is driving the truck. The daily driving time is between two daily resting periods and is normally 9 hours, or maximum 10 hours two times a week. The maximum driving time during a week is 56 hours and during a two week period 90 hours. (Transportstyrelsen, 2015)

2.6.3 Resting time

During the resting time the driver is not allowed to do anything work related. After a 4.5 hour driving period a 45 minutes break is mandatory. The break can be divided into 15+30 minutes breaks and the latter break needs to be at least 30 minutes. When resting in the cab the truck needs to be still and equipped with suitable resting equipment. (Transportstyrelsen, 2015)

2.6.4 During a 24-hour period

A truck driver is allowed to drive for maximum 4.5 hours at a time, before taking minimum a 45 minutes break. The driver can choose to split the break during these 4.5 hours into two periods (15 min + 30 minutes). A new 4.5 hour period starts to count after the longer period, 45 minutes or 30 minutes. (Transportstyrelsen, 2015)

The truck driver can drive 9 hours before taking a daily rest. Each 24-hour period needs to have a daily rest. Additionally applies a rule which the driver can make an exception two times a week and drive for 10 hours before taking a daily rest. (Transportstyrelsen, 2015)

2.6.5 During a week

The working week for a truck driver can be maximum 6 days in a row, before a weekly rest is mandatory. A normal weekly rest is at least 45 hours long, but an option is a reduced weekly rest of 24 hours. When having a reduced weekly rest the driver needs to add the time missing during the reduced weekly rest to another daily rest (9hours+lost time during reduced weekly rest), before the end of the third week after the reduced weekly rest. (Transportstyrelsen, 2015)

2.6.6 Multi drivers

When driving with multiple drivers a daily rest of 9 hours needs to be taken during a 30 hours period. The 30 hour period begins when the first driver starts to drive after a daily- or a weekend-resting period. When driving as multiple drivers the co-driver must be on board during all hours except on hour in the beginning of the driving period. The co-drivers time is registered as available. (Transportstyrelsen, 2015)

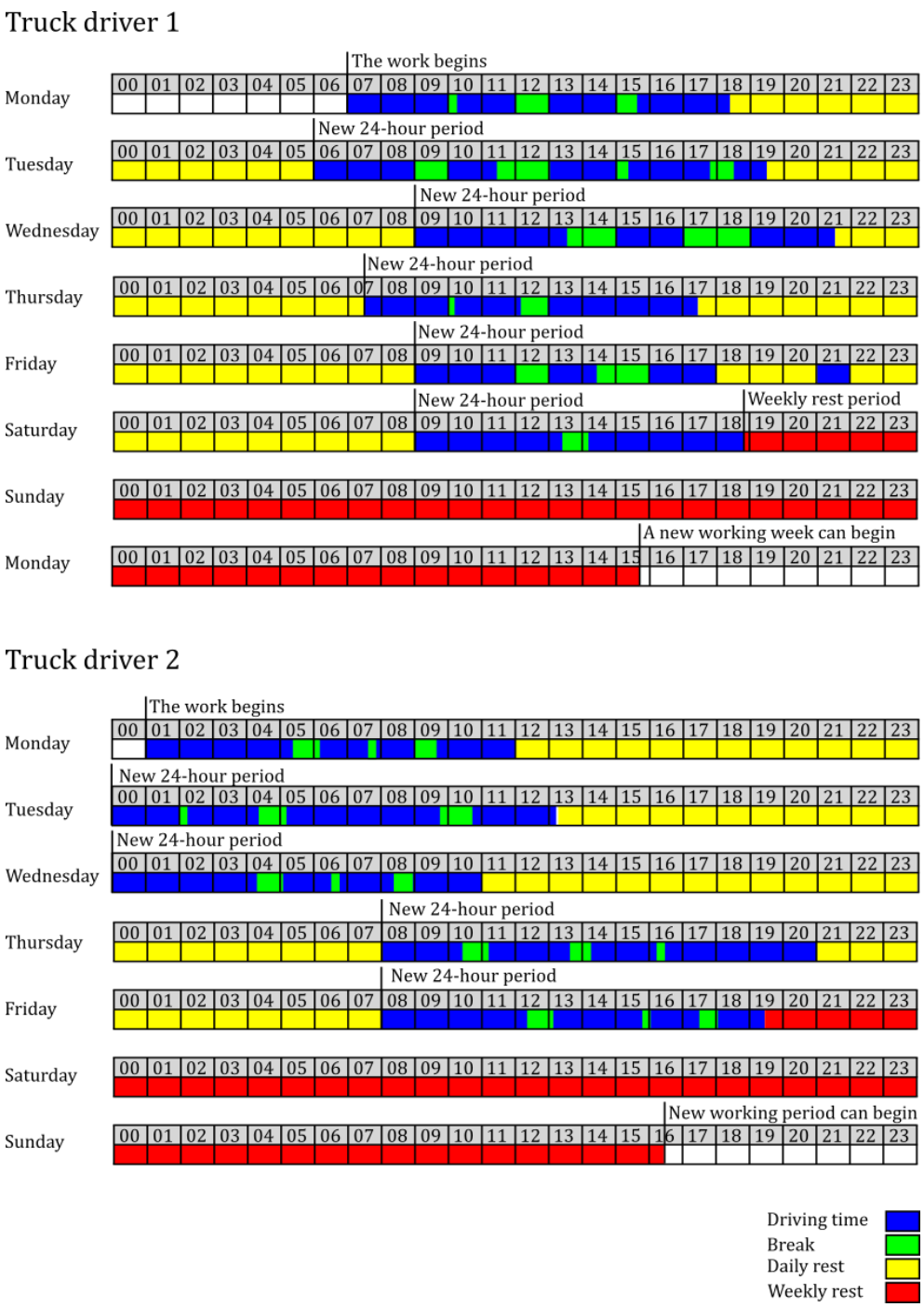

Figure 2-10, examples of truck driver schedules (inspired by the regulations on Transportstyrelsen (2015)).

3 Methodology

This chapter contains the methodology and the process of this thesis. The methodology is based on user-driven design. The process can be seen below in Figure 3-1*. In the first phase focus is planning and to gain knowledge about the user, the product and to study basic relevant literature. The first phase will result in an analysis. The second phase is the main which is an iterative process with the first analysis as input. The third phase is a ramp-up phase as a result of the final two analysis with a guide for lighting design (see* Figure 3-1*).*

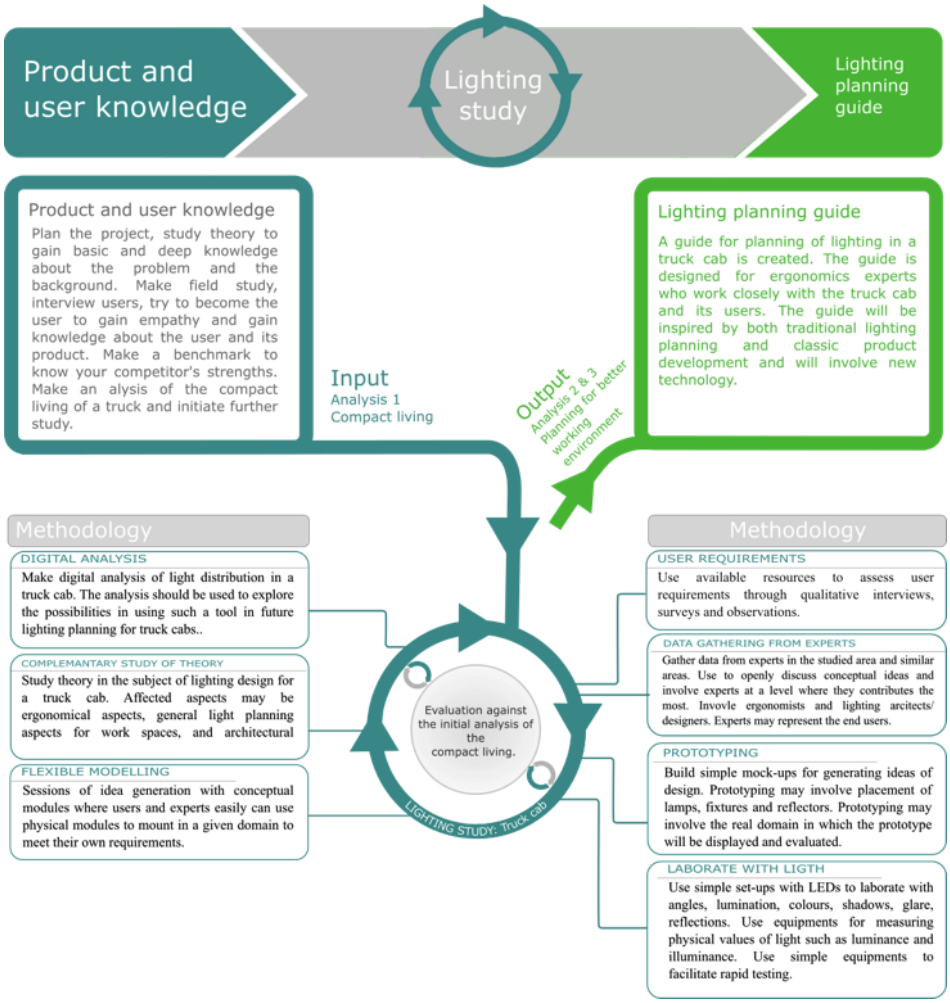

Figure 3-1, the work process of the thesis.

3.1 Product and user knowledge

The first aim was to get a better understanding of the product and the user; the Scania truck and its driver. To be able to understand the context in which the user interact and work, studies were made to widen product knowledge, i.e. learn more about the trucks, its environment and lighting design. Courage & Baxter (2005) stresses that the learning about a product and its domain and doing the "homework" before involving actual users is important for the researcher to know several basic facts: What are the available functions? Who are the competitors? Are there any known issues with the product? Who are the product's perceived users? These questions should be answered and are intended to aid in deciding what further research you want to perform.

3.1.1 Exploratory research

To be able to get an initial physical contact with the product and with no prior experience, a grab-and-test approach was used. An exploratory research is very flexible and spontaneous interactions and observations are encouraged (Hanington & Martin, 2012). This was done by first studying different truck's exterior and interior to get a feeling of basic measures and comfort, its expression etc. Studied trucks where from Scania's own existing product line such as the R, G and P-series. The study was performed at Scania, in daylight and in a free exploratory manner. Basic functions in the cab were tested such as control of light switches and visual comfort was discussed by sitting in the truck performing basic tasks.

3.1.2 Test drive at Scania demo centre

A test drive session was attended with trucks and busses at Scania's demo centre in Södertälje. The demo centre allows visitors to drive with Scania vehicles along a test road where you are challenged to handle vehicle and cargo through up- and downhill, sharp turns and parking. The authors test drove heavy cargo long-haulage trucks and also buss.

3.1.3 Living in the truck, an empathy study

An empathy study was performed in a Scania truck, a Scania R480 Long-haulage with accommodation for two people with cooking equipment, storage, fridge/freezer and bunk beds. The study was initiated through the authors need to empathise with truck drivers in a part of their daily life. The test was conducted from late afternoon until early morning. The purpose was not only to empathise with truck drivers but to understand issues with the existing interior lighting. The study was made in line with a method called AEIOU, which stands for Activity, Environment, Interactions, Objects and User (Hanington & Martin, 2012). The method AEIOU is an organizational framework of elements that needs to be coded during observations. The methods two primary functions are to analyse the objectives and issues of a client by developing elements and to code data (EthnoHub, 2015). Even though the method has a pre-set of elements, further analysing can be made (Hanington & Martin, 2012). It works as a guide during the observation and

helps the researcher to make sure nothing is forgotten. Elements which is coded during observations are; activities, environment, interactions, objects and users according to (EthnoHub, 2015):

- **Activities** are the actions and processes which is done to accomplish some sort of goal. Describe the pathway and specific actions and processes during these activities.
- **Environments** are the arena in which the activities takes place. Describe the atmosphere and the function of the context. Which spaces are shared and which spaces are individual are relevant questions.
- **Interactions** between elements are the building blocks for the activities. The elements could be between a person and someone or something else.
- **Objects** are the building blocks of the environment and relates to the activities somehow. Are the objects used as they are intended or are their function, meaning and context changed?
- **Users** are the people who are being observed. Who is the user? What are the user's preferences and needs and how is their behaviour? What values and prejudices do they have?

Prior to the study a protocol was made for several intended activities to be studied. The protocol is based on experience from the interview with a driver and the exploratory research where main focus was to study several possible activities. Also the lights that were used during each activities was notified. During observation for each activity the protocol was used, notes and photos were gathered.

3.1.4 Benchmark

Benchmarking is about learning about your competitors and their advantages/disadvantages regarding a similar product or a surrogate product. A benchmark can provide a rich source of ideas for the product and production design and successful positioning of a new product (Ulrich & Eppinger, 2008). The benchmarking was conducted by comparing lighting environments in trucks from other manufacturers. The trucks studied was long haulage trucks. The benchmark was conducted in an exploratory manner. The comparisons was made from unique features, design weaknesses and design strengths.

3.1.5 Interview

An interview was done with a truck driver in order to understand the user and to find key activities inside the cab.

Interview is a fundamental method to gain knowledge about not only people's thoughts and opinions, but their experiences, values, dreams and how they reason as well (Osvalder, et al., 2010). Interviews can be unstructured, semi-structured or structured. A semi-structured interview is a mix of a structured interview and an unstructured (Osvalder, et al., 2010). The interview has pre-set questions, but the interviewer doesn't have to ask the question in a certain order and can ask supplementary question. Semi-structured interviews have both predetermined questions and free questions resulting in the advantages such as easier analysed questions and enabling the interviewee to steer the discussion, but it is important the interviewer knows what's important so nothing important is left out. The interview should be divided in different topics in which the interviewer can ask supplementary questions. The questions can be both with alternative answers and more open questions, but the latter is preferable to get a better understanding. Semi-structured interviews can both result in qualitative and quantitative answers.

The interviews in this study were either semi-structured or unstructured. The interview with the driver was semi-structured, the questions can be seen in 13 Appendix 3 - Interview Questions. The data gathering from experts which can be seen in 3.2.2 Data gathering from experts was done with an unstructured interview. An unstructured interview is very flexible and doesn't have strict questions, which have several advantages such as the possibility to take detours, being more conversational and comfortable for participants (Hanington & Martin, 2012).

3.1.6 Personas

Personas is a tool to describe hypothetical archetypes of actual users (Cooper, 1999). It is better to focus on finding the best solution for a certain user instead of trying to fulfil the needs for several users, resulting in an "elastic user". The elastic users' needs is a compromise of several users' needs and a description of a user, which don't exist.

Personas was used as a tool to better describe the users and the scenarios when setting the guidelines. The personas are mainly based on the interview with a truck driver but also from the overall experience gained from exploratory research, empathy study and the benchmark. The personas was used initially as guidelines for the authors and along the way updated with newly gained experience from chapter 3.2 Lighting study. The information gained in this chapter was from the flexible modelling workshop, theory and data gathering from experts in visual ergonomics and lighting design.

The number of personas should be limited to around three to five (Hanington & Martin, 2012). If there are too many personas it is difficult to maintain the

design focus and a risk to target extreme outliers. Based on this three personas was made.

Three personas with various background, gender, age and preferences was made, see 14 Appendix 4 - Personas.

The following information was described in the personas:

- Name
- Quick facts (Age, Gender, Family, Location)
- Background
- Goals
- Pain points
- A day in life
- Key activities in cab
- Opinions in lighting

3.2 Lighting study

This is the first phase of the cycle where the process of developing concepts was initiated. Input from previous phase was a preliminary list of requirements.

3.2.1 User requirements

Previous survey from Scania: A questionnaire with answers from 600 truck drivers was compiled in 2014 with questions about what truck drivers do in their cab and what their personal preferences, issues and positive values are regarding their own truck. Questions regarding the different activities in the truck was studied to extract user requirements. A diversity in the driver's daily life, climate and preferences was concluded.

3.2.2 Data gathering from experts

Data was gather from experts in the studied area and similar areas. Unstructured interviews was used to openly discuss various aspects of visual ergonomics, lighting design. Also the authors attended at a light measurement seminar.

When data was gathered from the experts on both visual ergonomics and lighting design the advantages of an unstructured interview were used and the interviewee were able to highlight areas of interest.

Visual ergonomics: Per Nylén is a researcher and senior lecturer in visual ergonomics and lighting at 20% at KTH Royal Institute of Technology and works the remaining 80% at the Ministry of Employment as an expert in

visual ergonomics. An unstructured interview was made in his office at the Ministry of Employment.

Ergonomic experts: Experts at the ergonomic group RCDE consult in ergonomic questions regarding the cab of trucks. Each employee has expertise in different areas, the authors have been in close contact with the group with different questions and issues.

Lighting architecture: An unstructured interview was made with the lighting designer Michael Hallbert at his office in Stockholm. He is an expert in the subject of lighting design and has a lot of experience in both interior and exterior lighting design, many of his work can be seen in different places in Stockholm. The interview was held in Michael's office space and the topic of the interview was lighting planning and architectural aspects of lighting design.

Light measurement seminar: A seminar hosted by Konica Minolta was attended in Gothenburg. Konica Minolta, former developer of cameras is developing industrial measuring equipment and hosted a seminar about measuring equipment for light. The seminar contained presentations regarding spectrophotometers, luminance & illuminance meters and how to effectively set requirements for artificial light sources. A big topic was ways to measure colour in light, and the basic function of the problem is to take light and break it down to its spectral components which are calculated to different wavelengths of light.

3.2.3 Experiment with LED light

Simple set-ups with LEDs was used to experiment with angles, colours, shadows, glare, and reflections. Equipment was used for measuring physical values of flights such as luminance and illuminance. Simple equipment was used to facilitate rapid testing.

3.2.4 Prototyping

Simple mock-ups was built for generating ideas of design. Prototyping involved placement of lamps, fixtures and reflectors. The real domain in which the prototype would be displayed and evaluated was involved.

Before prototyping could be carried out, a preliminary test domain was decided. The authors had the privilege to book a prototype truck cab to use as domain. The truck was a model of Scania's construction vehicles with outer and inner dimension properties, such as roof height and interior design that differed from long haulage trucks. The roof height is considerable lower than for long haulage, and there is only a small resting bed in the back of the cab instead of two. The materials of the interior were different than in a real truck.

The prototypes were built from simple material, just enough to fit as fixtures for a lamps. Different kinds of LED light sources was purchased from a typical Swedish technology retailer. The light sources was low cost and no or little

consideration was taken regarding the quality of the light sources. The building of prototypes was carried out in a Scania workshop. Cables was soldered to properly provide the light sources with power.

The prototyping was divided into five different types of light sources (see Appendix 5 – Prototyping).

3.2.5 Flexible modelling

Flexible modelling was used during the concept generation phase to involve the user in the concept generation phase. Ten participants attended the session which was held in a Scania workshop. Flexible modelling is a good method to use when modules in a design are relatively set (Hanington & Martin, 2012). The method involves sessions of idea generation with conceptual modules where users and experts easily can use physical modules to mount in a given domain to meet their own requirements. During the modelling a discussion was held about design decision the user made. Different scenarios was described to the participant where their object was to design their own preferred lighting with available light sources. The compilation of answers can be found in 16 Appendix 6 - Flexible modelling. The users filled out a questionnaire about their preferences after the Flexible modelling workshop, see 17 Appendix 7 - Questionnaire.

Different modules with lighting were used for the flexible modelling workshop and can be seen in 15 Appendix 5 – Prototyping. The workshops took place in a prototype truck cab. All participants was employees at Scania. Seven of the participants of the workshops were employees at Scania RCDE who are experts in ergonomics and knows the users very well. Three of the participants came from electrics, construction and styling which are all departments connected to the lighting design in some way, more information about these departments will not be stated.

3.2.6 Digital analysis

A specific issue with lighting of a truck cab is the light distribution. The environment is rather complex and is not to be compared with any normal room in an office space. This is also an issue where it seems digital analysis is a reasonable solution. The authors created an analysis project in Dialux Evo 6.0, a software for lighting planning where an approximate re-creation of a truck cab was made (see Figure 3-2).

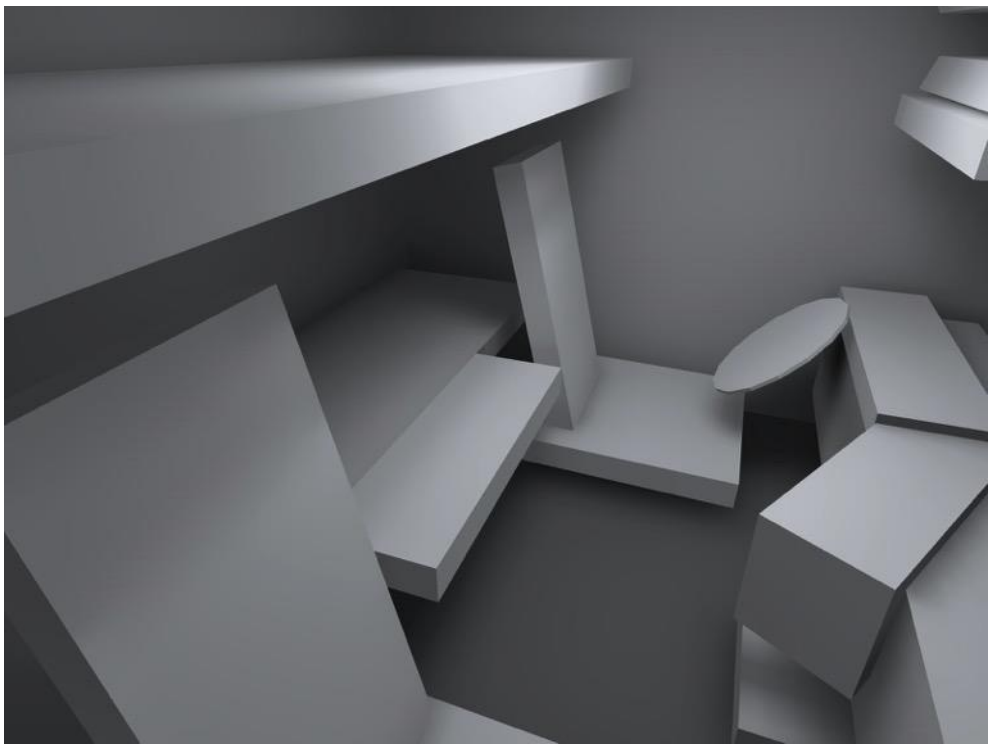

Figure 3-2, a capture from Diaux EVO 6.0 software of an approximate re-creation of a long-haulage truck cab.

3.2.7 Complemental Study of theory

During the lighting study several new aspects of the thesis has been identified and is also studied from books, guides and previous research in the specific area.

3.3 Lighting Planning in a Truck Cab

Lighting planning in a truck cab differs from traditional lighting planning for architecture. To illustrate the difference and analyse how a lighting planning process in a truck cab should look like literature for both traditional lighting and a concept development process was studied and analysed.

4 Empirical findings

The empirical findings in this study is presented in this chapter.

4.1 Empathy study

To better understand the user, the environment and the activities that takes place inside a truck an observation was made with the AEIOU framework in mind. During the observation notes and photos were taken, see Table 4-1.

The following activities was observed:

- Reading by the steering wheel.
- Working with computer in the passenger seat.
- Preparing food.
- Sleep and rest.
- Being in the truck in general.

Table 4-1 Empirical findings AEIOU

Activity	Lights used	Subjective analysis
Reading by steering wheel	Scenario 1 Reading lamp by steering wheel Scenario 2 Main lamps Floor lamp Upper storage lamp	Blinded by the main lights when taking folder from sitting position. Much shadows when searching for glasses. Steering wheel is reflecting light.
Working at computer	Main lamps Right reading lamp Left open storage lamp	Blinded by lights from storage when taking out the computer.
Preparing food	Main lamps Fridge lamp	Possible improvement of shielding the light in storage for microwave.
Sleeping/rest	Night lamps Main lamps	Sleeping lamps are preferably turned away to the wall (back of the cabin) for indirect light. From the view of the lower bed there are tiring effects from shifting lights. Softer light from several light sources are preferred. A need for a light that enhances vision of smaller objects to track before going to bed.
Being in the truck in general	All lights	A desire of having indirect lights. Too many shifts in contrast and too much shadows from the strong main light. A need for a central dimming controller for lights.

Figure 4-1, lights from storage spaces can have a glaring effect.

4.2 Benchmarking

The complete empirical findings from the benchmark can be seen in Appendix 2 – Benchmark. Below is a list of the strengths and weaknesses found from different competitors.

Strengths of different competitors

- Spacious impression of the environment
- Combined entry and floor light
- Gradually increasing light
- Aesthetics of the main lights
- Smart placement of storage lights in a non-blinding position
- Few shadows from artificial lights
- Blue LEDs good for visual enhancement
- None-glare reading lights

Weaknesses of different competitors

- Curtains makes the room smaller
- Curtains may partially block light sources

- Bad placement and limited intensity of reading lights in bed
- Limited lighting in storage spaces
- Limited or low quality light degrades feeling of interior material or spaces
- Shadows from artificial light
- Storage spaces that are not illuminated
- Several shadows from different light sources
- Too many light sources in one cab that draws attention

4.3 Interview and data gathering

The following chapter includes the result from the interview in this thesis.

4.3.1 Interview with a truck driver

A working day can be very different from the other and are depending on the type of shipment and how many deliveries are on the way. The driver continuously plans the route and the time for breaks to drive as efficient as possible. During working hours the drivers mind is occupied with planning and concerns for the expensive load he is driving. The laws are very strict on the time limit in driving too long and if they are exceeded the punishment is a fine, up to 3000 SEK, or even prison. Working hours and speed limit are logged in a meter above the driver. The meter prints a receipt of the driving on which, in case of a traffic jam etc., the driver can present the cause of the over time. It is a good system for the drivers who can't be pushed by the employer to work too long. The time limit for driving is 4.5 hours at a time. Thereafter a 45 minutes break is obliged. A working day normally is 9 hours and sometimes 10 hours long. The driver is on the road for five days in a week and normally sleeps in the cab during these says except the nights spent on the ferry.

A common working day is going from Örebro to Malmö to make it in time for the ferry. Unnecessary pauses is avoided to be as efficient as possible and to be able, due to the working time regulations, to arrive in Malmö in one day.

During the break the driver tries to get better blood circulation by walking around the truck, making sure the load is fine, stretching and get some fresh air. When the weather is bad it is more likely the driver stays in the cab, but stands and stretches in the cab and opens the window in order to get some fresh air. The driver stretches to reduce the risk of injuries to the back and knees. During the break the lighting is turned on to the max to get a better overview of the cab.

Sometimes during the break and the leisure time before going to bed the driver watches movies, checks his e-mail, text etc. on his tablet or smart phone. This was usually done while sitting in the bed. The driver explained that several drivers put in a TV on the wall just over the driver's seat. Also, some drivers had a rotatable passenger seat which was suitable when a TV was installed. It was not common to work with the computer by the passenger seat. The tablet was mounted on a rack by the instrument panel, which made

the driver's seat the natural place to sit while working with it. It was not common that he read a book, but sometimes he read a magazine.

The driver explained that he had made several adjustments of the lighting in another truck. He has put red LED strips as lighting under the instrument panel to light up the floor. This is because the floor is used as a storage surface for the cell phone and snacks while driving. Also because the driver likes to have an overview over the cab. This type of lighting was also used while sleeping and the driver explained he wanted this light in order not to step on his phone when waking up. The colour of the light was red. Secondly, the driver had put lighting in the back of the cab directed to the instrument panel. This type of lighting was used when a better overview was needed, e.g. while cleaning the cab. The colour of this light was explained as cold white.

Many drivers have a shelf over the instrument panel in the middle of the cab. The driver would like to have some sort of lighting to better see this shelf and the things, which are placed on it. A risk with the placement of this lamp is it can be blinding while driving and it's switched on.

The driver also explained it was several differences between younger and older drivers. The older didn't like as much styling, curtains and made modifications to their trucks, with the motivation it was distracting and the truck was a working environment. The younger driver was more educated in which type of modifications could be made and could spend a lot of money in order to get the cab as they wanted.

When it comes to steering the lighting the driver preferably uses a dim function, which is controlled with a screw button, the same way as you control the volume of the stereo. Some of the lamps should also have switches by the light source as well when needed.

4.3.2 Data gathering visual ergonomics

From the unstructured interview with Per Nylén: Bad visual ergonomics increases the risk of musculoskeletal injuries and it is important to emphasize the effect inadequate visual ergonomics has on people's health and well-being. Studies show that some workers tend to change to less ergonomically posture and position to compensate for the lacking sight, which possibly results in musculoskeletal symptoms and even injuries. Problems could be inadequate lighting, blinding lights, temporal blinding or visual defects.

The quality of sight changes with aging and is called presbyopia. When aging the lens gets stiffer and it gets more difficult for the eye to accommodate for different depths in the viewing field. Elderly people need more lighting than younger people to see clearly. Accommodation is easier in a brighter environment. It takes longer time for the eye to adjust to a darker environment than to a brighter. In seconds the eye adjusts to a brighter environment but to adjust to a darker environment can take several minutes. This is a problem for forklift truck drivers who drives in and out of warehouses or long haulage truck drivers when enter and exit tunnels.

Studies have been made of the working environment for locomotive drivers and the luminance level on the instrument panel, displays, windows have been measured. A problem in this environment is that the difference of luminance is great when looking through the window and at the instrument panel simultaneously, resulting in a strain for the eyes to keep adjusting for the different luminance levels. A good visual environment is when the luminance levels are not too far from each other, at most 10:1. The lighting environment for truck drivers is better than locomotive drivers since they sit closer to the window.

Different colours have different wavelengths. It is harder for the eye to adjust between colours far from each other in wavelength than colours that are closer.

Per uses two different lights in the bathroom. In the morning a cold white light and in the evening a warm white light. The cold white light to make him and his family more alert and the warm white light in the evening for a soothing effect before going to bed.

Flicker can occur when using pulse width modulation to dim LED-lights. LED shuts and lights up instantly. Flicker can be invisible to the eye and go unnoticed but has an effect on people's well-being. Instead of using pulse width modulation current control with continuous feed reduces the risk of flicker, but with a risk of change in colour as well. This shouldn't be a problem more than possibly changes in the aesthetics.

4.3.3 Data gathering from lighting architecture

From the unstructured interview with Michael Hallbert: The light from LED-luminaires is more directed compared to conventional light sources for ambient light, Michael mentions that developers are trying to overcome these challenges when designing ambient lights. Directed LED-luminaires can create great contrast in the luminous environment resulting in possible contrast glare. It is important to use diffusers to create smooth edges in the lighted areas when using LED-luminaires. Some of the total amount of light in conventional lighting and luminaires is directed and hits surfaces which from the beginning are not intended. The phenomenon is called stray light and is used by many lighting designers as a tool to create certain visual effects in the lighting design.

Michael mentions the importance of highlighting structural shapes, such as a tall brick chimney. When lighting the chimney with a cylindrical shape its shape can be enhanced by lighten the middle part of the chimney and let the light fade out at the sides creating shadows at the sides. When lighting the chimney with the same intensity all the way around there is a chance of perceiving the chimney as flat. The shadows is as important as the light when describing shapes in lighting design.

Michael talked about some tricks in creating lighting and also the future for LED. When working with interior lighting there are a few basic tips. Hidden lights in small spaces that are projected on a wall can create the illusion of

daylight coming in, which can be pleasant in mornings during winter times when the absence of daylight is extensive.

Michael believes OLED will be widely used in luminous lighting applications in the future and replace many lamp fixtures in e.g. office environments. Lighting by the wall, such as a wall-wash, is an effective way of hiding the light source and creating a spacious environment. He recommended tuneable white LED where it is possible to change colour temperature from a warmer more like incandescent light, to a clear and cold white LED light.

4.4 Flexible modelling

A short compilation of answers from the user study Flexible modelling can be found in Table 16-1 in 16 Appendix 6 - Flexible . Down follows four chapters concluding these answers in areas of particular interest which was found in the user study.

4.4.1 Light distribution

When reading by the steering wheel the overall opinion was to use bright light and especially the directed light above the head in the ceiling. At the same time have low ambient light to reduce contrast from other objects in the cab. In the same position but using a tablet the directed light was turned off since reflectance of the directed light was seen in the screen, and the lighting was redundant to be able to see the content on the backlighted screen. This was an opinion from several users. Several users wanted lighting hidden in small spaces in and under the dashboard. This type of lighting should also be dimmable.

4.4.2 Ambient light

Some of the user wanted low ambient lighting in the cab while driving at night. The chosen lighting was either monochromatic red or blue LED in the ceiling or the ambient white light in the ceiling, both at low intensity. All user liked indirect lighting on the walls, floor or the ceiling. It made the cab feel more spacious and perception of the surroundings.

4.4.3 Brightness

All participants have different preferences regarding brightness, meaning they need or prefer more or less light for their tasks in the cab. All tough there is no data on exact values, the most demanding tasks are reading, cleaning and preparing food. Reading requires brighter light but some prefer a larger light source rather than a spotlight. A higher brightness is often related to blinding lights, however during visual tasks such as reading, sufficient light is prioritized.

4.4.4 Shadows and Contrast

Through answers it is known that shadows can be highly disturbing as well as uplifting for the environment of the truck cab. Shadows and contrast can be used to create a cosy environment where demands on visual tasks are low. Big contrast are created easily with bright directional light e.g. from spotlights. There is a consensus about how shadows and contrast bring positive respectively negative values. It creates a more interesting and lively environment in the truck cab, however the subjective judgments differ between participants. During visual demanding tasks big contrast is preferably avoided, except for reading where it doesn't seem to be a problem to light up the book with a bright spotlight and let the surroundings be not at all or less bright.

4.4.5 Questionnaire

A questionnaire was given to all ten participants. The result of the questionnaire is presented in Figure 4-2. It is suggested that, from this result, certain areas are more important. Participants showed a consensus about the light being able to change the atmosphere and that this atmosphere should be different between activities. It is also suggested that dimming of the light and changing its colour temperature is important.

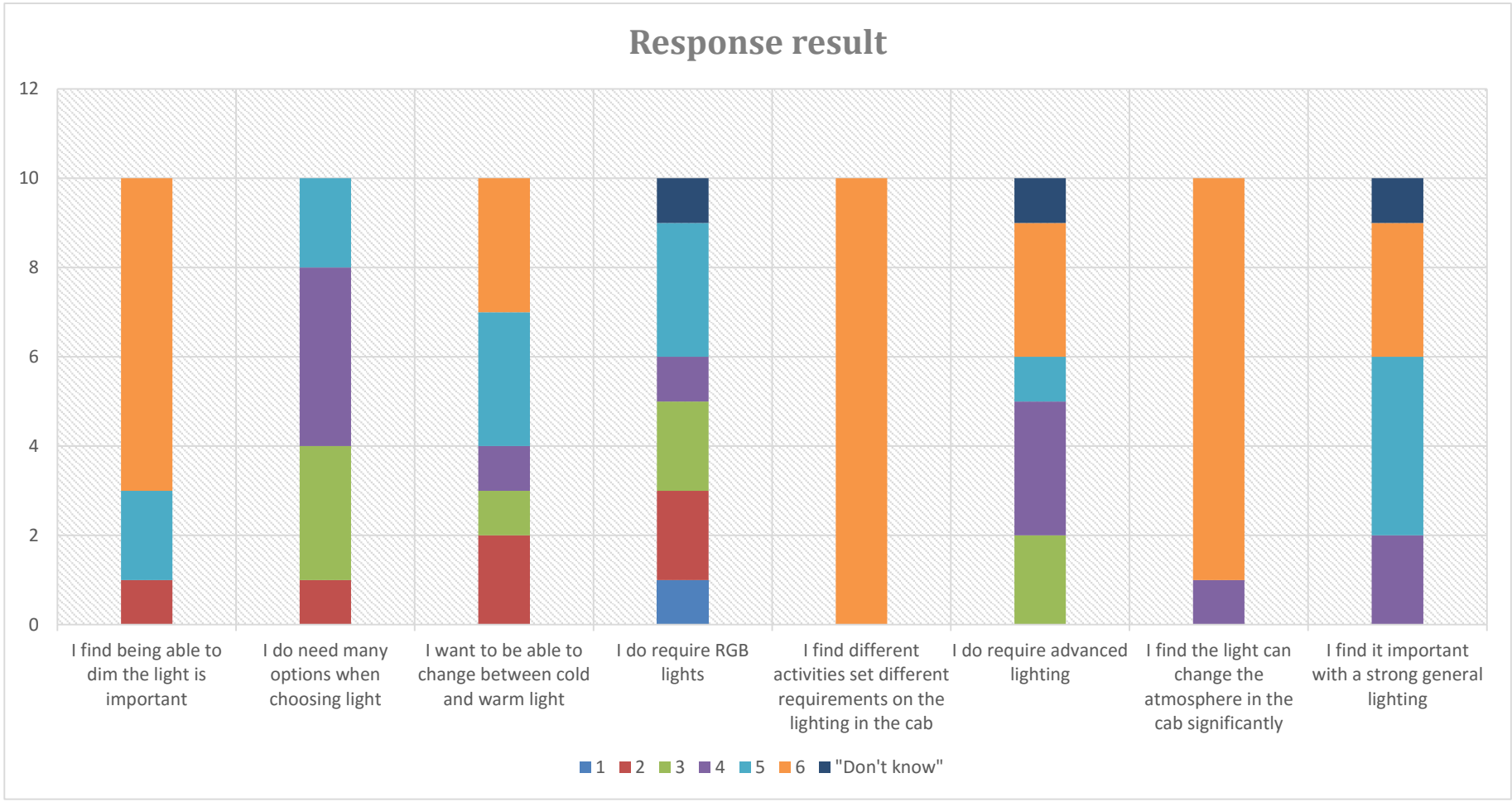

Figure 4-2, response results from questionnaire. Each participant asserted a value from 1-6 to each statement where 1 corresponds to "Not agreeing at all with the statement" and 6 to "Completely agree with the statement".

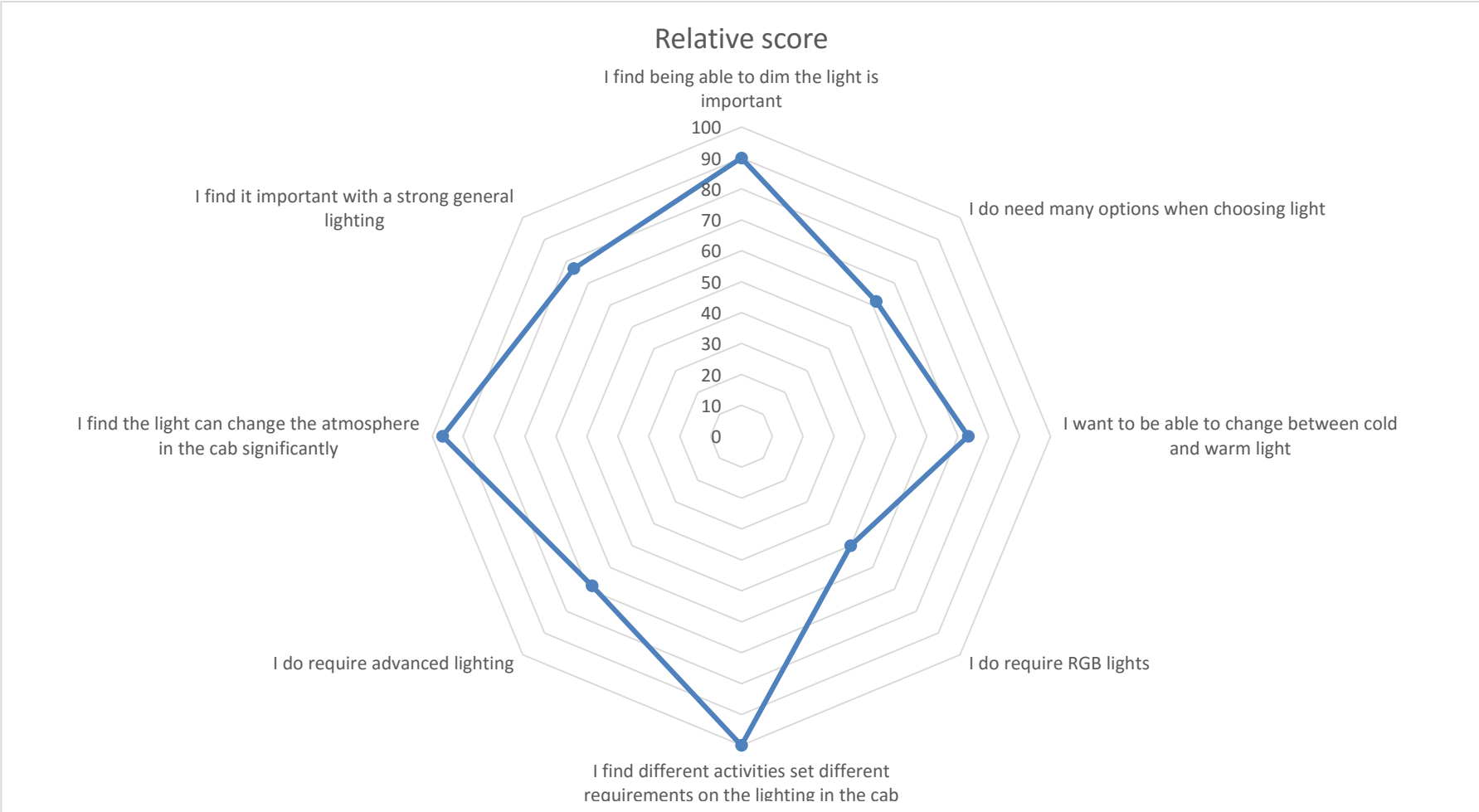

Figure 4-3, relative score for each correlated statement. Each score suggests their relative importance according to participants' answers.

5 Analysis 1- Truck compact living

An empathy study and an interview with a truck driver was done. The accommodation of the truck cab was the researched subject and from this, an experience was gained. The experience tells us that the truck cab compels a minimalistic living that can be booth cosy and appreciated in many ways, but also that it is too small and tiring in the long run. The truck cab needs to be seen partly as a workplace with higher demands on visual ergonomics and also as a small home with personal preferences to be satisfied.

5.1 The driver

It is obvious from the interview that the driver puts much pride in her or his work and that the truck cab is like a second home that needs to fit personal preferences and needs to be taken care of. Customization of the interior is widely common, consequently the interior lighting is often changed because it lacks in variety. Truck drivers tend to change traditional incandescent light to LED light and often included with coloured lighting. From the interview, benchmark and inspiration from customized trucks in the trucking community, the conclusion is that the market of trucks provide a small portion of variety and that customization is done to enhance both esthetical expression of the truck and also the personal comfort. It seems little is considered regarding the visual ergonomics when installing customized interior light, and undoubtedly, visual ergonomics is neither a topic of interest nor intuitive knowledge of truck drivers. On the other hand it is understood from the interview that there is a group, mostly represented by older truck drivers, which shows no or little interest in customization and are satisfied with what is given. The focus should be on new demands that satisfy a larger range of users and where visual ergonomics is in focus, to benefit all users in their daily work.

5.2 Current lighting

From the interview and the empathy study a set of critical issues has been identified. When the sun sets artificial lights will be used in the truck cab. There are several light sources that serve different purposes in the truck cab and the conclusion is that they do their job in terms of providing light for visual needs. However, some light sources may cause glare, and some causes unwanted shadows. The lights inside the storage areas causes blinding effects which is unpleasant and makes it difficult to see what is stored inside (see Figure 5-1).

Figure 5-1, placement and intensity of light sources in truck cab.

During the empathy study illumination were measured in planes where visual demands hypothetically occurs. The results showed that the illumination reached levels between 100 and 200 lux and these values somewhat conforms to recommendations about lighting in work places, meaning there is sufficient lighting in these areas. However, the light is insufficient in tight spaces (see Figure 5-2).

Figure 5-2, need of light is critical in tight spaces especially around the instrument panel where you would need light to find stored items.

The lighting is limited around the lower bed when the top bed is lowered, the main lamp is not sufficient to reach most of its area. However, the reading lamp is preferably used to create indirect lighting, which also creates depth to the environment (see Figure 5-3).

Figure 5-3, utilizing the flexibility of the reading lamps can create indirect light and cause depth and character to the interior environment of the truck cab.

5.3 Conclusion – Truck compact living

The lighting design should be planned for more than visual task and sufficient lighting. Aspects that need more attention are blinding lights, contrasts, shadows and light distribution. There is a need for variation of the lighting such as different colour and light intensity to satisfy a larger range of users.

5.4 Discussion – Truck compact living

The interview was done with one truck driver and does in fact only represent one user. However, one more truck driver was spoken to off record, one who had far more experience and showed us a different side of the profession. We reserve the right to express a professional opinion and do trust in the collected information gained from interviewing and talking to truck drivers and also physically exploring different trucks. One could argue that a broader study of truck drivers would give more substance, but it is our opinion that enough information has been collected to find improvement points, especially regarding visual ergonomics.

Several trucks have been explored and we do not regard the fact that a certain truck is the latest version, the light installation and interior can actually differ to the extent that comparison between the two is misleading. We have simply asserted issues and aspects of lighting that is representative for all and do feel confident in our opinion and judgement.

6 Analysis 2 – New technology for a better working environment

A user and theory study was done in order to address New technology provide different conditions for lighting planning regarding direction, distribution and colour of light. These conditions need to be accounted for when planning for lighting design, this chapter concludes the analysis of these conditions.

6.1 Lighting planning with LED and OLED

New technology change the way lighting planning have previously been done. The interviewed lighting designer explained under the interview that the light from LED-luminaires is more directed than the light from conventional light sources and many effects which lighting designers previously have used as a tool in lighting design. It is a must to have knowledge about the possibilities LED-lighting has but also the limitations when creating the desired luminous environment.

OLED stands for a paradigm shift when it comes to lighting design (Khanna, 2014). OLED-lighting changes lighting design and enables a new way to design, personalize and create novel lighting concepts for long haulage-trucks. Michael Hallbert also believes OLED will be widely used in the future. LED and OLED luminaires are possible to integrate in the interior in the truck in new ways which results in the need for cross-functional collaboration.

Both LED and OLED is light sources which enables the possibility to change the colour of the light. From the user study it was a variation in preference regarding the colour of the light and the brightness. It is also concluded from theory that warm and cold light can be used as a tool to change the perception of the cab to fit various activities. The controlling of the lighting between these activities needs to be simple and user-friendly.

The conclusion from this is; new technology demands new ways of planning interior lighting and has great opportunities to create novel lighting concepts.

6.2 Aspects of light

6.2.1 Light distribution

From the empathy study it was noticed that the light distributed from the two main lights in the ceiling was insufficient and did to some extent create too much dark spaces in the truck cab. Light distribution was also tested in the user study to compare a larger light source with the two traditional light sources (see Figure 6-1). From this study it was found that a large light emitting source which emits light direct and indirect in different directions does distribute light good meaning dark spaces can be avoided. However, if the light is distributed in all corners of the truck cab the environment seems flat and less appealing.

Figure 6-1, an installation of LED strips illustrating an OLED installation was used for flexible modelling.

A room with several bright spotlights can be perceived as dark, due to great contrast, even though the brightness of the light sources are sufficient to light up the room. The key is a well-planned lighting distribution and reduce contrast by lighting up the cab evenly. By directing light to the walls or in the ceiling creates the perception of a more spacious room.

When planning with new technology for new lighting design in a truck cab a digital analysis could be helpful. Since the truck cab is a complex environment to illuminate digital analysis will aid in finding critical areas of the truck where light does not reaches (see Figure 6-2). From interview with a lighting designer and the user study it is known that you need to find the right size, position, angle and intensity of a LED light source to get a good distribution of light that does not compromise the overall feeling of the environment. OLED can be used to emit light from a larger surface and distribute light evenly, but the intensity and size need to be calculated for to not compromise the feeling of the environment which can seem flat and less interesting.

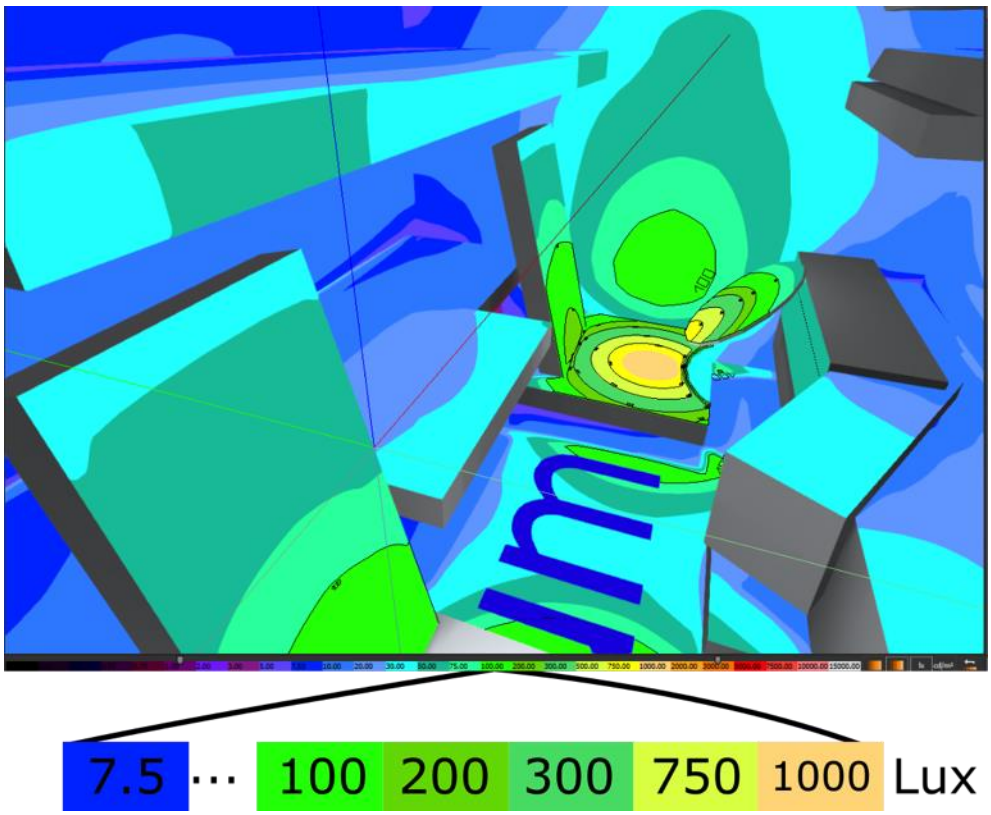

Figure 6-2, An example of an analysis of light distribution in Dialux Evo 6.0.

6.2.2 Ambient light

From the benchmark it is noticed that two out of four competitors have utilized monochromatic lights in the shape of single LEDs. These are either places in the ceiling, in storage spaces or to light up the floor. From the interview with a driver it is somehow confirmed that monochromatic lights are installed in different ways e.g. in the ceiling or in storage spaces, though people in the trucking community tend to use colours to express themselves. LEDs that provide monochromatic light can be placed in many places. The fixture of the diode will not take up much space and should be placed so that is not disturbing while driving. It is found from the user study that red monochromatic LED light can be used to enhance vision of objects, however to much red can be unpleasant (see Figure 6-3).

Figure 6-3, monochromatic red light is often used for ambient light while driving at night to get a general perception of the truck cab.

6.2.3 Brightness

From the benchmark it has been noticed that two out of four competitors use a dim-function to adjust brightness and that there is a good opportunity to be inspired and compete in this area. The need for a brighter environment increases with aging (see 2.1.4 Sight changes with aging) and sufficient brightness for all type of drivers is essential. The user study clearly showed how the user changed the brightness many times when adjusting the lighting for different activities in the cab. Nine out of ten found it important to be able to dim the lighting. From the user study and literature study it is noticed that younger truck drivers don't have the same need for a bright lighted cab and too much lighting can cause blinding lights. Blinding lights is basically an effect of a light source glowing in your eye, creating discomfort (see 2.2.12 Glare). To quantify glare it is proper to use a luminance meter to assess the amount of discomfort blinding lights by using the UGR method (see 2.2.12 Glare). When using a dimming-function on new technology it is important to keep in mind the effects of flicker from Pulse Width Modulation (PWM) (2.3.2 Dimming LED). The traditional main lamps in the ceiling are logically

positioned but they are sometimes blinding. The roof height in long-haulage trucks is high and therefore the need for bright lights occurs, which also results in blinding lights.

Adjustment of the brightness is essential. Personal preferences differ and age is a factor. It also takes longer time for the eye to adjust to a darker environment than to a brighter. This can be important when exiting or entering a lighted truck cab. The effect of flicker should be considered when using a dimmer-function to prevent tiredness.

6.2.4 Shadows and Contrast

By comparing different trucks, it is clear that a lot of projected shadows inside the cab is a weakness compared to those with less and also softer shadows. This attribute is related to interior material and contrasts. An even mix of light and dark interior materials is an enhancing factor when shadows are overrepresented. The best distribution of shadows occur during daylight passing through windows into the cab and the most critical area is the instrument panel and storage spaces. Several light sources that projects hard cast shadows in different angles is considered poor design or placement of fixtures.

Contrast is created from directional light and uneven light distribution. Since the eyes ability to adjust to different levels of luminance reduces with aging (see 2.1.4 Sight changes with aging) the truck cab should be illuminated enough to avoid such issues. The user study showed that there are many different preferences regarding shadows from artificial lighting. Some appreciate the occurrence of shadows more than others. The overall opinion is that hard shadows created by a single light source is tiring and unpleasant. The contrast between the shadow and the surrounding areas should not be too big, i.e. sharp shadows are to be avoided. The truck cab is partly a small space where you keep your belongings like clothes, food, keys etc. It is important that you don't have to "stumble" around and search for things that might be hidden in dark areas, where shadows are cast.

A critical area is the instrument panel. There are many tight spaces where the light does not reach the surfaces, due to either limited luminous flux from light source or limited luminous intensity in certain angles (see Figure 6-4).

Figure 6-4, angle and distance between lighted object and light source, and luminous flux are critical when shadows are generated.

Shadows creates depth, it is a fundamental source for the human eye to understand a three dimensional environment. Without shadows everything would seem flat. When light is emitted from a light source in a single direction it will cast single shadows, and when emitted from several or wider angles the shadows occur in increasing numbers or more soft.

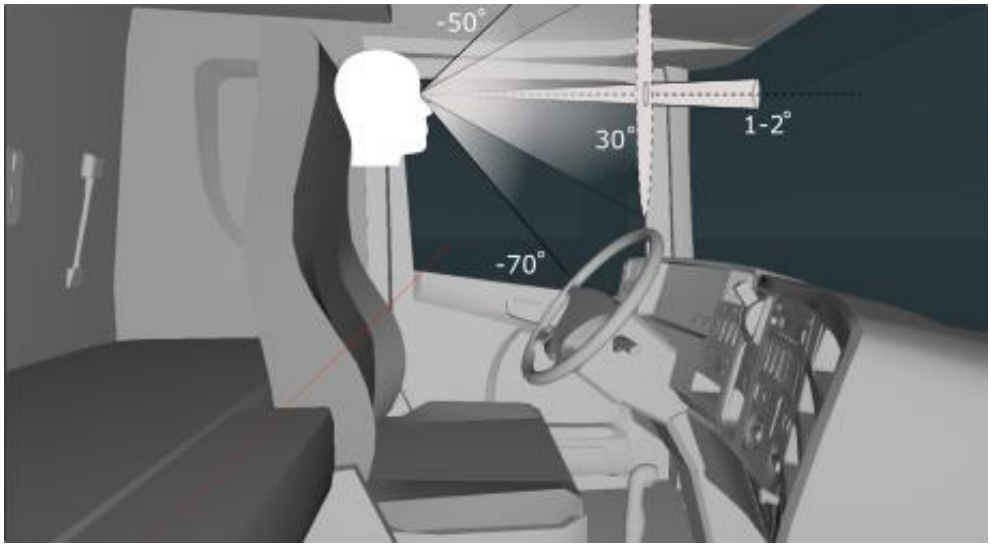

Figure 6-5, a humans field of view in a truck cab. The illustration is not an exact representation of a real life setting.

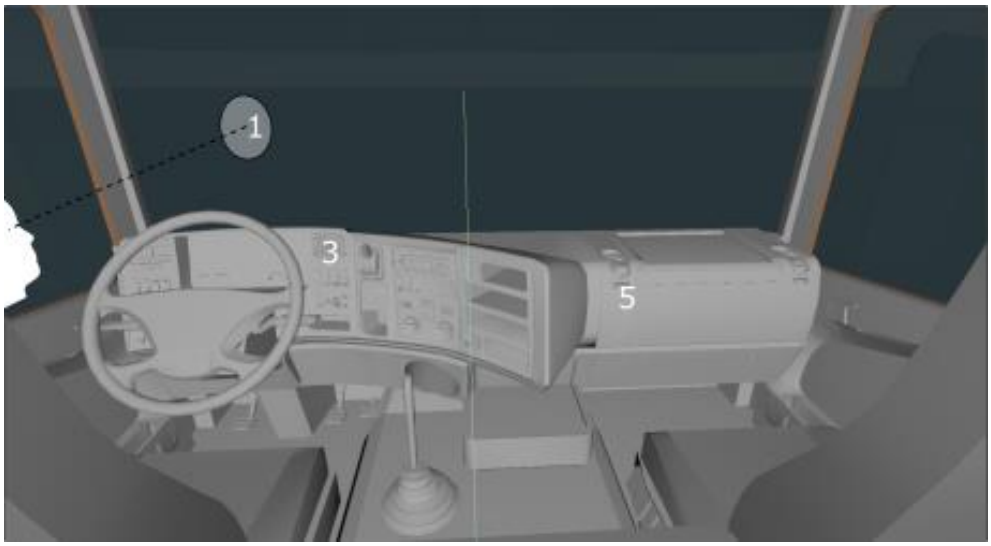

Figure 6-6, a typical scenario where differences in contrast would occur.

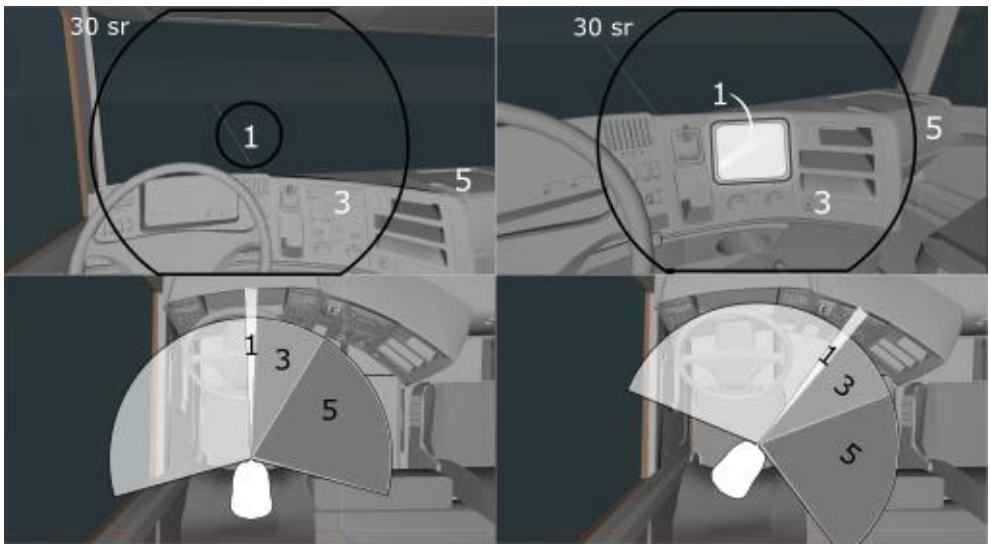

Figure 6-7, differences in contrast will occur in the truck cab, and it is important to address these issues and to avoid them in typical user scenarios, e.g. looking at a bright screen.

From an architectural perspective shadows is vital when creating outdoor and indoor environments such as lighting projects in a big city. Light sources has to be selected and carefully positioned so that projected shadows enhances the impression of illuminated objects. As well as shadows create depth it can be used to create visual effects. This is also strengthened by the user study where it is noticed that shadows have different meaning, however shadows contributes to a more interesting environment in the truck cab although they are preferably avoided during practical activities such as cleaning.

From an ergonomic perspective, in the visual field, the contrast between dark and bright reflections should not be of big difference. If the contrast is too big the eye will have trouble to adapt and you can get tired.

6.2.5 Control

During the flexible modelling session many choices in setting the lighting was available. The users had different preferences, especially regarding the brightness during different activities. They also felt the ability to change the perception of the room by changing the lighting. All users felt that the requirements differs in different activities.

In the result from the questionnaire it can be seen that the user wants to be able to control the brightness and the colour temperature of the lighting, see 4.4.5 Questionnaire.

It was understood by observing the users, during the flexible modelling sessions, that some of the choices was a bit confusing and unnecessary. In addition the controllers of the light sources used, was complicated to steer. The opinions regarding the ability to change the RGB-lighting in different

colours was very mixed. The users that used the RGB wanted to have it when driving at night and chose either blue or red light.

When comparing different solutions of controls to the lighting both strengths and weaknesses were found. By having a dim-function combined with different sets of modes to the lighting gave an easily manoeuvrable and understandable controlling of the lighting. None of the competitors had the ability to control the colour temperature of the lighting in the cab.

The coloured lighting in the cabs were blue, red and green LED lighting. The colours of these lamps were fixed.

All main controls of the lighting were positioned in the instrument panel or above the driver's seat. Some of the lamps which were out of range from the driving position also hade switches by the light source, such as the reading lamp by the bed or some of the lights under the storage spaces.

It was mentioned that the lighting should have a dim function which is controlled with a screw button, the same way as you control the volume on the stereo. In addition that some of the light sources should, when needed have switches by the light source as well.

To ease the controlling of the lighting in the cab a certain degree of freedom needs to be set. The controlling of the brightness is an essential function to create pleasant lighting for all users. The lights that not can be dimmed should have the possibility to direct in another direction to reduce the risk of creating blinding lights.

The possibility to change the colour temperature is a nice feature which can set different moods in the cab. There are several activities in the cab that require different sets of lighting. One parameter to either create a soothing environment or to create an environment that keeps you alert the need of controlling the colour temperature is needed. Further studies needs to be made on how to control the colour temperature.

6.3 Measuring light

When planning with new technology for lighting design requirements needs to be set. Some of these requirements are connected to the spectral distribution of a light source. Learnt from the light measurement seminar it is proper to use an instrument for assessment of CRI and dominant wavelengths of a light source in the truck cab. This instrument would preferably be used to measure new technology light sources such as LED and OLED. This provides a good tool for comparison between concepts of lighting design and light sources.

6.4 Daylight and blue enriched light

When exposing users to artificial light at a colour temperature of 5000K and above it showed that six out of ten felt discomfort. The discomfort was not mainly connected to colour temperature of the light but to the atmosphere of the room.

Truck drivers could possibly benefit from exposure of bright monochromatic light at short wavelengths. The interest lies in the alertness of truck drivers and safe driving, but also the physical and psychological wellbeing. Past research and documentation shows that disruption of the circadian rhythm is a critical issue, not least for shift workers and that blue enriched light is a central modulator (Boyce & Hopwood, 2013) (LeGates, et al., 2014) (Holzman, 2011) (Kozaki, et al., 2008) (Kramer & Martha, 2013).

Health aspects mostly concern blue light at night time (Holzman, 2011), present and future technology provide potential for more healthy lighting, such as OLED (see Figure 6-8).

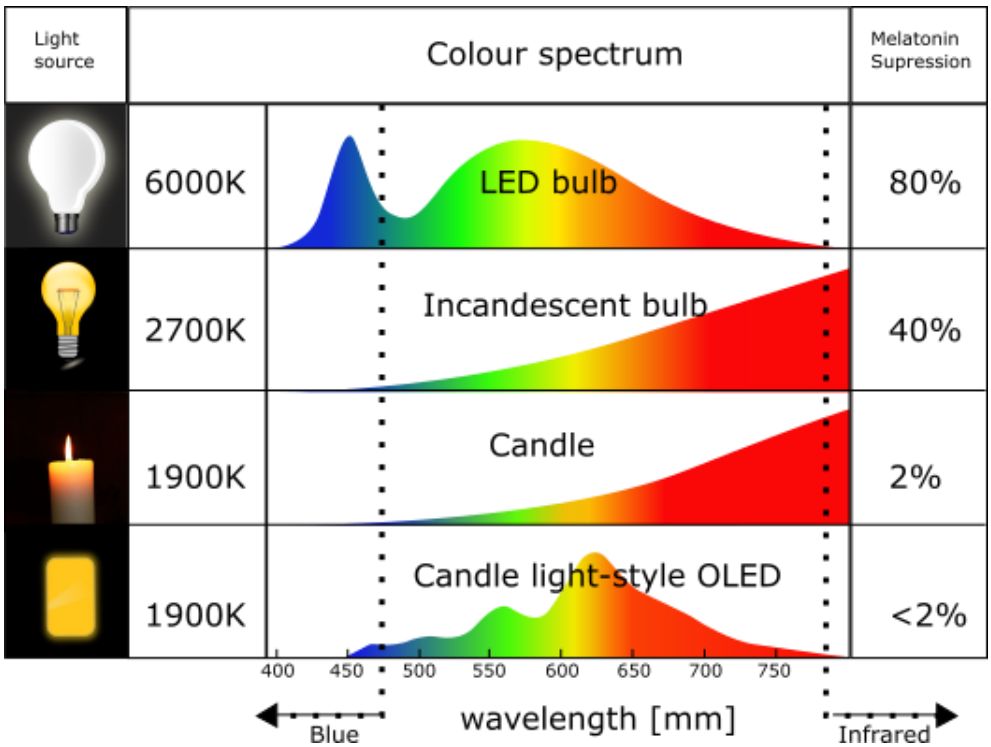

Figure 6-8, light sources and their power distribution, colour temperature and their effect on melatonin supression (inspired from an article about OLED and its potential for healthy light at night time (Jwo-Huei & Chun-Yu, 2013). The original figure is a compliation of studies).

6.5 Colour temperature and rendering

The user study showed that colour temperature is a major factor for the feeling of the environment. Users showed interest in cold LED light, warm LED light and ambient monochromatic LED light. The majority of participants would choose a warm light rather than cold. The result tells us that a warmer light is more pleasant but does not reject the opposite in a different scenario.

There is few situations when users feel that there is need for a light suited for a working environment such as an office. During activities which involves relaxing or effortless activities, a warmer light is preferred. Eight out of ten wants to wake up to and transition in to sleep mode with a warm light, those who disagree would prefer a colder light in mornings to separate wake up time and bed time. Light at 8000K is perceived as unpleasant whereas 5000K is seen as a good compliment to a warmer light at 3000K e.g. while reading a book or a document in sitting position. The need to alternate colour temperature is strongly linked to the simplicity and logic behind the control function. Only two out of ten strongly agrees that they need several options to choose between in their lighting.

RGB LED light is a common choice for ambient light, this is understood from the interview with a driver, benchmark and the user study. It is used while driving and drivers use ambient light to enhance vision of objects and the minimal perception of the surroundings, it should not be reflected in the windows or glossy objects. A colder light and a low amount of shadows creates a boring and flat environment.

From interviews with experts it is understood that LED is the future of interior lighting. LEDs are far more established in outdoor installations such as street lights and headlights for cars and not as preferred indoors. However, the advantages with LEDs exceeds those for traditional light installations. The dynamic properties of LED is an obvious advantage where it is possible to change colours. Tuneable white LEDs is growing more popular in home installations. This gives the option to control colour temperature from a warm to a cold light and thus control the feeling of the environment which can change the mood (Kuijsters, et al., 2015). Seen from the benchmark there is also a good opportunity to use the lighting to enhance the luminous environment to various activities of the cab since it is not common.

6.6 Conclusion – New technologies for a better working environment

New technology provides the right conditions for good lighting planning. There is new aspects to regard when the size and intensity of the light source changes regarding light distribution, glare and shadows.

A shift working truck driver in Sweden during winter season is likely to be subjected to night driving. Compared to many other shift jobs the truck driver

does not always have the privilege to have a lighted work space due to driving safety. Lights will reflect in the windows and interfere with the driver. A lighted truck cab will also create a contrast that makes the vision of the road worse.

It is during the breaks and free time in the accommodation of the truck light is possibly beneficial. Especially during wake up and night time when the light could help in transition from sleep to wake and vice versa (see Figure 6-9). It should be possible to alter the alertness through melatonin suppression with short wavelengths of polychromatic light at <200 lux (Kozaki, et al., 2008) (Holzman, 2011).

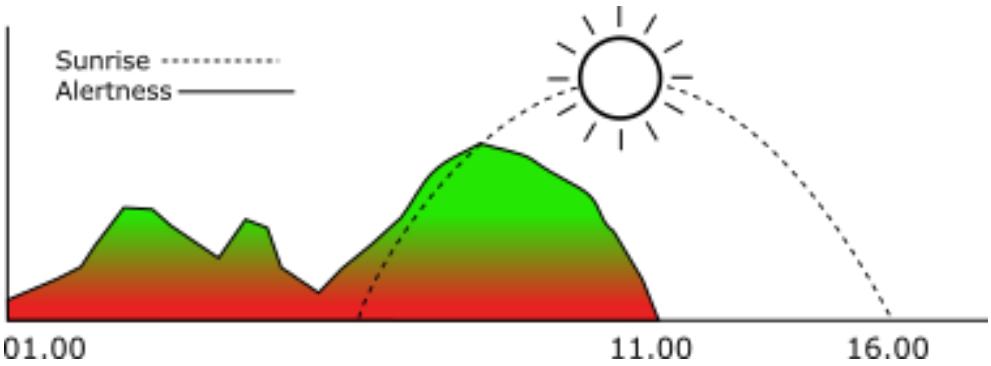

Figure 6-9, a schematic representation of a hypothetical relation between driver alertness and the presence of the sun in Sweden during the winter season.

Users want a logic and simple system for changing colour temperature. It is not obvious that users want to change between colour temperatures but ten out of ten think that light changes the atmosphere of the truck cab significantly. The colour rendering index is important to accentuate the intended colour of interior materials. Incandescent lights often have good colour rendering index and LED lights should be chosen with index so that it matches or exceeds current lights in the truck cab. This should be measured and compared against different light sources with a proper instrument.

6.7 Discussion – New technologies for a better working environment

The conclusion of this analysis is strongly dependent on literature study and a user study. We believe the theory studied has a strong connection to the subject of alertness of shift working truck drivers. The subject is yet to be analysed, and if so it will require extensive testing in a real life setting where driver fatigue or alertness is measured with and without blue enriched lights (Cajochen, 2007).

We see two possibilities, the first is a short term test on the effects of blue enriched light to heighten alertness with high blue content and low blue

content to lower alertness. This could be utilized when the driver needs to stay alert or when she or he needs to relax or go to sleep. Subjective test methods as explained in (Cajochen, 2007) could be used, but should be used on several drivers to get comparable results. The second possibility is to investigate the long term effects which means the awake-sleep rhythm of the driver. This would mean that a study is made over a longer period and the mood and changing rhythm is studied. This would also need further research to understand in depth.

Either way, blue enriched light affects the brain to different extent. A rule of thumb would be that a bigger portion of blue creates greater effect. The problem is that, as we have seen it from the user study, some blue lighting is perceived as unpleasant. A possibility is to test blue enriched light so that it main purpose is not to “boost” alertness but to be pleasant as well.

7 Analysis 3 – Lighting Planning in a Truck Cab

This chapter concludes the analysis of lighting planning in a truck cab regarding visual ergonomics with new technology. A traditional lighting planning guide has been used to be implemented in a traditional product development process.

7.1 Lighting planning and product development

Traditional lighting planning differs from traditional product development, of course. A traditional lighting planning for e.g. an office space roughly means to choose the best lamp fixture and lights for the visual tasks in the office. The lighting design of a truck cab should be in line with traditional product development with clear stages of product design and where different departments of the company is involved in different steps. The conclusion from this is: Lighting design for a truck cab should be rooted in product design and traditional planning.

7.2 Planning for flexibility

In the interview with a truck driver it was concluded that many, especially the younger, truck drivers made modifications to the interior lighting to get it customized after the drivers preferences. The truck driver further explained that the older generation used less styling, such as e.g. curtains, which can be perceived as more distracting. Older truck drivers has the need for more lighting to see clearly (Nylén, 2012). From the flexible modelling workshop it was also concluded that the preferences from the user varied in matter of brightness, colour temperature, position and direction. In the empathy study and from the questionnaire it was concluded that there are many activities, which set different requirements for the luminous environments. The conclusion from this is; there is a need for flexibility to create a good luminous environment for the user when planning lighting in a truck cab.

7.3 Conclusion – Lighting planning in a truck cab

Lighting planning with new technology in the future of truck cab will change. There is a clear potential to involve several functions of the company such as styling, construction and interaction design, to improve lighting design. The authors recommend that cross-functional collaboration is the first condition to succeed in planning for new technology such as OLED. As the technology of lighting becomes light emitting surfaces, the integration of lighting in the interior becomes more obvious. Windows as well as the sun roof will be able to emit light, and if this is the future of lighting there is a strong need for cross functional work. The recommendation is to use a traditional product development process inspired with traditional lighting planning, see 9 Interior Lighting Planning Guide.

7.4 Discussion – Lighting planning in a truck cab

A product development process can differ from product to product and to company. Our conclusions are anchored in the general complexity of designing lighting for a long-haulage truck cab. Because of this complexity and with new technology we have found several aspects of traditional technical design that is applicable in lighting design. The conclusions are also anchored in our own expert opinion, meaning we use experience from product development projects at the university and combine it with knowledge gathered in visual ergonomics for a truck cab. We have not controlled exactly in what direction the market of LED and OLED are moving nor the prediction of prices in the future. However, we have noticed the potential with the technology and it is our expert opinion that to both satisfy current users and to compete with other truck developers there is a process needed for a lighting design project. It is also difficult to predict what level such a project will obtain, we have neglected this and provided a basic process where any project of lighting design for a truck cab is useful.

8 Conclusion and discussion

8.1 Overall analysis

- Based on the analysis of the truck compact living we see that different users in various activities sets different requirements on lighting design in a truck cab.
- Based on the analysis of new technology for a better working environment and the analysis of lighting planning in a truck cab we see that new lighting technology provides the right conditions for good lighting planning. When planning for future light installations, cross-functional collaboration is needed to succeed in good visual ergonomics, light distribution, aesthetic expression, and branding.
- Based on the analysis of daylight and blue enriched light we see that light could be used as a tool to affect alertness and in best case sleep-awake rhythm for truck drivers.

Users of different age, size etc. have different preferences and work different shifts. A suggestion is that these preferences are addressed and considered in lighting design. Interesting aspects of personalization is colour temperature and brightness. Also there is an aspect of personalization where position angles and shading of light sources matter. A light source can be hidden and create indirect light and it can be the opposite. The final design of lighting should be of such that it provides a better workplace for all and satisfy a larger range of users. There is potentially a technological push from LED and OLED where the value for the company and its users must be addressed. There is potential to create a better working environment with new technology and also to gain even stronger foothold as one of the leading truck developers.

9 Interior Lighting Planning Guide

The following chapter describes the steps in the interior lighting planning guide. An overview of the process can be seen in Figure 9-1 Interior lighting planning guide.

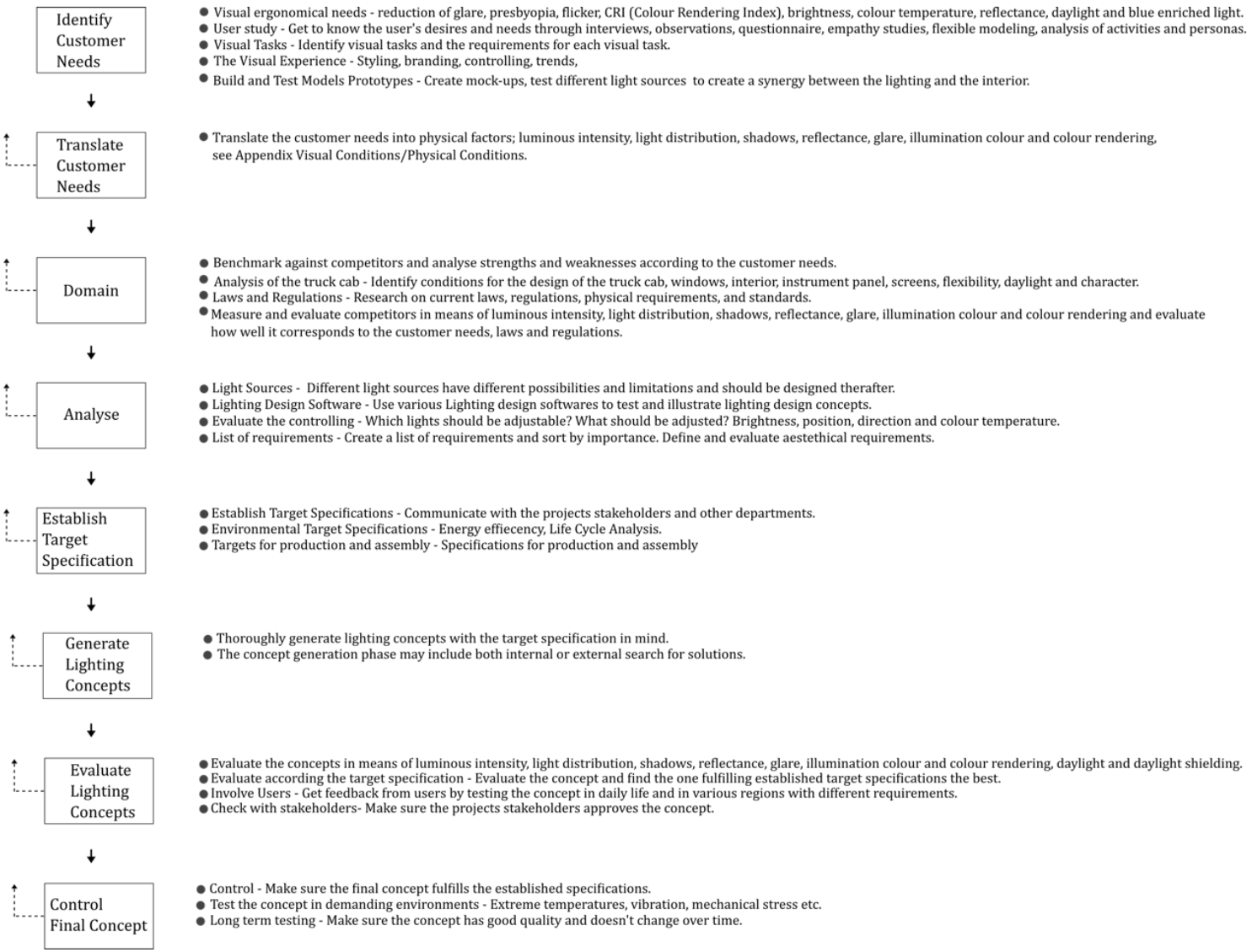

Figure 9-1 Interior lighting planning guide

9.1 Identify customer needs

Both a traditional lighting planning process and a product development process has many different stakeholders involved in respective projects. When planning lighting in a truck cab, the first thing is to target *the customer* and the *end-user*. The customer is the person or company who buys the truck and could either buy trucks for the company's fleet or the customer could buy the truck for himself and in that case be both the customer and the end-user. By identifying both the end-users needs and the costumers needs the project can be both realistic and fulfil the end-users needs.

To find the end-user needs the working environment should be assessed in aspects of user studies, visual ergonomics, visual tasks, the visual experience and could involve building simple prototypes which are tested on the user.

9.2 Translate customer needs

The customers' needs found in the first phase of the process should be translated into metrics and physical aspects of light such as; luminous intensity, light distribution, shadows, reflectance, glare, illumination colour and colour rendering. When translating the visual conditions to physical conditions see 18.

9.3 Identify domain requirements

The lighting in a truck cab both affect and is affected by many other requirements set on the truck. An analysis of the lighting conditions in the truck cab, domain, and which possibilities and limitations exist should be done.

In a product development process it is common to do a benchmark to see alternative solutions and to better understand the market and where to position the product. A benchmark can help with finding solutions, look for IP intrusion and evaluate by measuring how well competitors fulfils customer requirements.

9.4 Analyse

The result from gathering requirements and needs from both from the customer and the truck cab needs to be analysed to be able to set a final target specification.

After the lighting planning have been specified an analysis of the forced conditions should be done. Define all laws, physical conditions, economical and historical conditions which needs to be taken into account in the lighting planning. Check how well they correspond to the client's requirements.

Analyse the general conditions for the lighting planning. Define what is flexible and what is set in the design, interior, daylight, character and which type of screens is used. Check how well they correspond to the clients requirements.

The list of requirements includes the clients- and legal requirements. All requirements should be weighed after importance. The list of requirements should include parameters such as; lighting intensity, lighting distribution, contrast between working area and the adjacent and the peripheral areas, lighting intensity in ceiling and on walls, reflectance of surface and their colours, size and position of windows, the colour temperature of the light sources and their CRI, limitations of luminance, luminance ratio within the viewing field and requirements to shield from glare, also energy consumption.

Analyse the controlling of the lighting system. The lighting system should be easy to understand and to adjust to a good luminous environment.

9.5 Establish target specification

When establishing the target specification, all the specifications from various stakeholders in the project should be included. The requirements from the customer and the domain together with requirements, from other departments included in the project, is the basis for the target specification. The requirements should be weighed according importance.

In this stage all the laws, physical conditions, economical and aesthetics needs should be translated into a target specifications for the project. The specifications should be quantified and have a metric, a marginal and ideal value.

The target specification is a guiding document for further concept development.

9.6 Generate lighting concepts

Generating ideas for lighting concepts can be done both internally and externally. Searching for concepts externally can be done by interviewing truck drivers who are experts in their field and are those who spend the most time in a truck. External search can also include consulting experts in visual ergonomics, lighting design and electrical components. Also by searching for patents and study competitors or solutions in other products.

When searching for solutions internally group sessions with several departments involved can ease when coming to consensus and understanding the problem from different angles. Preferably is to both generate concepts individual and in groups.

9.7 Evaluate lighting concepts

When evaluating lighting concepts by measuring the luminous environment in means of luminous intensity, light distribution, shadows, reflectance, glare, illumination colour and colour rendering, daylight and daylight shielding.

Involve users and representative to evaluate the concepts. Check with the projects stakeholders if eventual changes needs to be done and which concepts fulfils their requirements the most.

9.8 Control final concept

Do long term testing to see if the lighting system changes over time and evaluate the concepts in demanding environments. Expose the lighting system for vibration, mechanical stress, extreme temperatures etc.

9.9 Further studies

In the closest future studies we see that some areas is of special interest for the company.

- Specify degree of freedom and design intuitive controlling for personalized lighting.
- Plan for collaboration between departments in lighting design with new technology.
- Decide the interest in truck drivers' alertness regarding blue light exposure.

The first interest for the company should be to specify the degree of freedom when designing for personalization. Both LED and OLED provides the right conditions to be able to change e.g. colour temperature and brightness. This thesis mean to conclude the need for personalization, however further study is needed to know how much a user should be able to change the lighting. It is a question of logic controlling of the lighting system and gained value for the user. When changes are made due to new technology, several departments should be involved to achieve in overall good lighting and truck cab design. New technology will also provide an opportunity in utilizing the blue wavelengths of light for the better regarding working environment. The blue light can possibly help in reducing tiredness of truck drivers. This is an issue of interest of course and there is other methods of countermeasures to prevent fatigue such as talking a short walk outside the truck or drinking

coffee. The company has to decide whether it brings new value to the user and if it is an advantage when competing with truck developers. It will take some thorough research in a live setting where truck drivers are evaluated day by day to determine the effect from blue light. If this is achieved it has potential to be a selling factor, along with overall good lighting and truck cab design.

9.10 Discussion of working methodology

In this thesis, an area of interest was studied from several different aspects meaning less time was allocated in each part. We noticed a potential for improvement and decided to dedicate the thesis to be a thoroughly made pilot study that would be enough to initiate involvement of stakeholders at the company.

The work was divided into two phases including several methods. The result is based on three different analyses with following conclusions. We wanted to provide value to the company and realized that several areas should be studied. It was obvious to allocate time in the first phase; product and user knowledge which has provided substance in our analysis and conclusions.

The study of theory has been the core of this thesis. The subject of visual ergonomics is wide and with many researchers involved. It has been a challenge to use information gathered to make an analysis of the working environment of a truck cab which differs from many other working environments. Late in the project we realized that we would not want to develop a light fixture as a product development project but rather involve different departments of the company to make a first approach at the future of lighting design in truck cabs. We did not consider the specific development aspects of a light fixture, this would not have provided the company with extra value. They need to later make a decision based on this thesis how to proceed in such a manner. We feel that this study has been done at a reasonable level, more work to develop the conclusions or the analysis of this thesis would not bring extra value. The thesis provides enough to initiate further work or at least a valuable discussion. It provides substance from both literature study and the analysis from the authors.

We understand that some different pathways along the study might have benefited the work. For example it could have been a good idea to provide the company with more tangible data such as measurement data from light intensity or power spectral distribution. However it is concluded in the analysis, conclusion and discussion that measurements will be valuable and it should be done in a real environment with real light fixtures to evaluate.

Some of our conclusions are based on personal preferences from answers in a user study. We discuss the possibility that the involvement of real truck drivers, instead of representatives, would have brought extra value and new points of view. However, the conclusions are well thought through with this in mind and we feel that the participants in this study work so closely to the users that they may represent them.

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11 Appendix 1 - Empathy study

Due to restrictions no pictures are shown in this chapter.

Table 11-1, protocol from the empathy study.

Activity	Environment	Interactions inside truck	Objects involved	User	Lights used	Physically data	Comments (subjective judgement)
Reading by steering wheel	Inside the cab of a truck at a lighted parkingspace	Turn on lights Pull out folder Find glasses Take notes Looking at LCD screen Looking at phone Change seat position	Light buttons Folder Glasses Pen Screen Phone Seat	Young male	**Scenario 1** Reading lamp by steering wheel **Scenario 2** Main lamp Floor Lamps Upper storage lamps	Scenario 1 Light button=80 Lux same angle as instrument panel, (0.6cd) Folder= 100 Lux Glasses=90 Lux Steering wheel=190 Lux (6.8cd, 2.7cd Floor=(1cd) Scenario 2 Steering wheel=300Lux (10cd folder, 3cd) Folder=190 Lux (1cd by folder, 2.5 cd by beige) Glasses=200 Lux (0.9cd) Light button=160 Lux (1cd) Window= (2cd)	Blinded by the main lights when taking folder. Much shadows when searching for glasses. Steering wheel is reflecting light.

Working at computer	"-"	Open hatch Pick out computer Performing regular task with computer	Hatch Computer	"-"	Main lamps Right reading lamp Left open storage lamp	Computer=22Lux(35cd, screen) Desk=25 Lux(0cd) Hatch Glove compartment=20 Lux Hatch over steering wheel=15 Lux(0.4cd) Open storage=15Lux(0.5) Vid lampan(1500 cd) Left upper storage= 20Lux(0cd) Vid lampan (1200cd)	Blinded by storage light and upper storage.
Preparing food	"-"	Open fridge Using the microwave	Fridge Microwave Shelf The food Silverware Cup Water container	"-"	Main lamps Fridge-lamp	Not measured	Possible improvement of shielding the light source in storage for microwave.

Sleep/rest	Inside the cab of a truck at a lighted parkingspace with curtains closed.	Make the bed Clean away things Put away your clothes and belongings Search for belongings	Sheets Phone Glasses Clothes	"-"	Sleep lamps Main lamps	"-"	Sleeping lamps are preferably turned away to the wall (back of the cabin) for indirect light and reduced contrast. A need for a light that helps you find articles in the cab to control your belongings before going to bed.
Being in the truck in general	Inside the cab of a truck at a lighted parkingspace	Moving from chair to chair Sitting in the bed Open the fridge Using your phone while lying in the bed Using control panel for lights		"-"	All lights	"-"	A desire of indirect lights. Perceived high contrast and shadows from the strong main light. A desire of a dim-function.

12 Appendix 2 – Benchmark

Tabell 12-1, conclusion of subjective judgement on each competitor regarding Unique features, Design strengths and Design weaknesses.

Researched trucks	**Truck 1**	**Truck 2**	**Truck 3**	**Truck 4**
Description	A spacious interior, only one bed. Light interior material and a well-controlled admission of daylight through sun roof and windows. Elegant prismatic lens for main lights and well placed light sources in storage spaces above driver and passenger. Red detection and background lights on the floor and other places.	A large cab with a lot of sunlight passing through the big front window and extra side windows above the doors. Relatively design of instrument panel. Many instances of orange lights such as backlight for buttons and night light. Main lights angled and not directed down.	A tight interior that gives a feeling of luxury. Separate controlling and dimming of lights. Light interior materials. Much space at passenger seats and a nice combination of LED diodes with main lights. Design over function.	Interior design that expresses function and not luxury. Functional entry and many orange lights for functional purpose. Heavy construction around sun roof. Several adjustable light sources that uses a half sphere which is direct able.

Unique features	- Angled light direction towards the bed - Long and flexible reading light, combined for reading in bed and while in driver seat. - Large sun roof with good light distribution. Smooth shadows from daylight through sun roof. - Light source on the side-walls in storage. - A handle for dimming and setting modes of lighting placed above driver seat. - Cold white light	- Large front window and extra windows on the sides, much light passing through. - Two big and strong lights directed towards the bed from level of storage. - Solely orange backlights for buttons. - "Un-centred" drivers panel - "Pink-ish" night lights in the ceiling with dimmer function from 1 to 10.	- Separate controlling of the light above driver seat. - Gradually increasing light intensity. - Three blue LED diodes mounted with some space around both the main lights. - Green LEDs inside the main lights for limited lamination. - A light interior. - Four blue LEDs above and front of the steering feel along with the whole front window. - Electrical adjustable sun screens. - Warm white light - Light interior at passenger side and dark at driver side.	- Reading lights are able to change direction. - Single orange night light in the ceiling. - Light fixture in the middle of the cab, in level below storage that you press to light the lamp. - Orange lights to emit storage surface. - "White-ish" light. - Spreading of main lights towards the walls. - High intensity of main lights.

Design strengths	-Seems spacious looking up towards the storage area. - Combined entry and floor light. - The room seems larger with the combination of daylight from sun roof and main lights. Gradually increasing light intensity.	- Cab seems large during daylight. - Cosy feeling from the dimmed version of the two main lights. - Smart placement of storage lights. - Combined entry and floor lights.	- Light from the sunroof. - Gradually increasing light intensity. - Few and little shadows created from daylight. - Blue LEDs enhance visual ability when searching for objects. - No glare from lights in the ceiling of storage spaces.	- Few shadows from reading lights above the driver seat because of the angle. The flexibility can create indirect light for background lighting. - No glare effect from reading lights.

Design weaknesses	-Curtains makes the room seem smaller. - Lights above the doors are blocked by the curtain.	- Reading light is covered by head when sitting in the bed. - Light passes through curtains during daylight. - Limited lighting in storage.	- Shiny curtains reflect lights. - Limited reading lights. - Uncomfortable back support while sitting and reading. - Ridged pattern on the walls created by the main lights. - The storage light degrades the impression of nice looking storage space and hatches. Also limited spread of lights. - Much shadows created by reading lights. - Limited use of the green LEDs in the ceiling. - Small storage at passenger side without lighting.	- Double and hard shadows from reading lights and reading lights in the middle of the cab both in level under storage. - No reading light in upper bed. - Too much pattern in interior, e.g. in curtains. - Limited intensity of reading lights. - Too many light sources.

13 Appendix 3 - Interview Questions

Before the interview starts: Brief summary of what we do and why we do this interview. (2min)

13.1 Opening questions (5 min)

- For how long have you been working as a truck driver?
- For which company do you work?
- In what way does your current job differ from your previous jobs?
- What do you feel about your job as a truck driver?

13.2 An ordinary day (15 min)

- How does an ordinary route look like?
- How does a working day look like?
- What and where do you usually eat?

13.2.1 Sleep and leisure time

- Describe a break?
- Describe the environment where you park tour truck before spending a night in the cab?
- How many times have you slept in the cab?
- Is it difficult to fall asleep in the cab, if so why?
- Do you feel well rested after a night in the cab?
- If you feel sleepy, do you do anything to prevent sleepiness during the break like a powernap, smoke, eat, drink coffee etc.?
- What do you do the time after you have parked the truck and before it is time to go to sleep?
- Do you eat breakfast in the truck?

13.3 The truck cab (10 min)

- How do you find the environment in the truck cab?

- Have you done any modifications, if so what and why?
- Do you miss anything in the cab?

13.3.1 Activities in the truck cab

- What do you do in the cab except driving?
- When do you need extra lighting in the cab?
- Have we missed any activities in the truck cab?

13.4 Lighting (15 min)

- How do you find the lighting today?
- What's missing in the existing lighting?
- Which type of lighting do you often use?
- How do you find the controlling of the lighting?
- How would you like to control the lighting?
- What's your experience of lighting inside other trucks?
- How do you do and which type of lighting do you use when...?
    - Reading by the steering wheel?
    - Brewing coffee/Tea
    - Reading a book
    - Watching a movie
    - Cleaning
    - Sleeping
- What kind of lighting do you use in your bedroom at home?

13.5 Final Question (5 min)

- Do you want to add something we haven't mentioned?

14 Appendix 4 - Personas

Helena

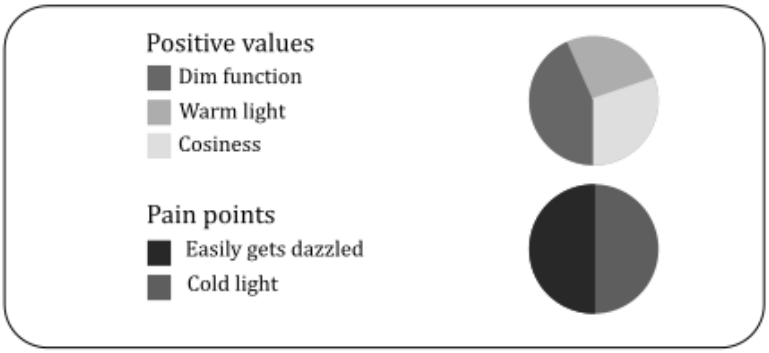
Status: 35 Female with husband and two children

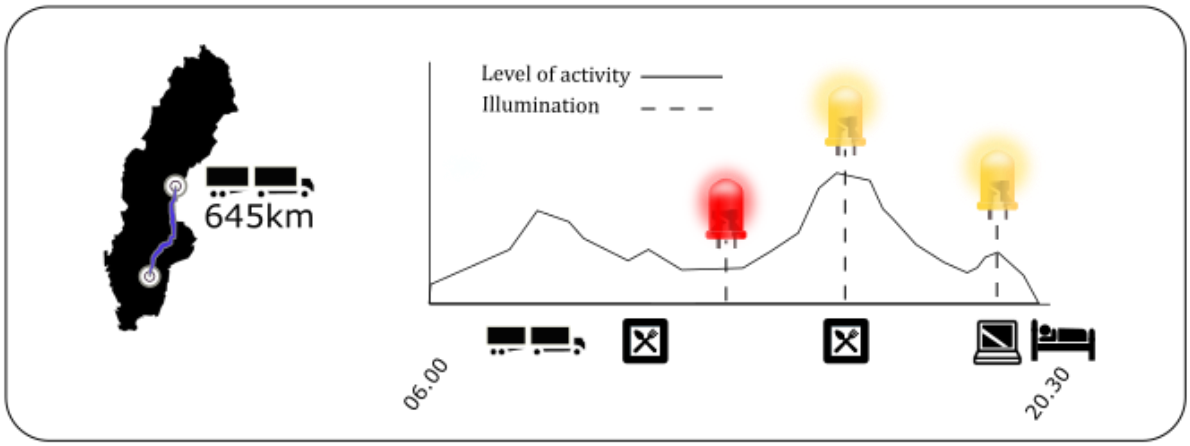
Route: Eksjö - Sundsvall

When i video chat with my family, i feel comfort and i try to imagine being home

Background

Helena is a truck driver from Eksjö, Småland. She has been working as a truck driver from the age 20 and have always been interested in trucks since her father and her uncle works as haulage contractors.The family is very important for her. She has great knowledge about the haulage industry and is often recognised in the long haulage community. It is a family business and in the future she believes she will take over the company and work with more administrative work than she does today. At the moment she is driving 4 days in a week between Eksjö and Sundsvall and works with administrative tasks in Eksjö at Fridays. She drives from Eksjö to Sundsvall on Mondays and spends one night in the cab. The day after she goes back to Eksjö the same route and spends the night at home. On Wednesdays she has the route Eksjö-Sundsvall and Thursdays Sundsvall-Eksjö. It is a stimulating job with a lot of planning and time pressure, which on the downside is a bit stressful





Prefered lighting

To compensate for the stressful working environment Helena needs to relax on her breaks and has modified her truck cab to fulfil her needs. She has similar lighting as she has at home in Eksjö. It is a lot of indirect lighting directed to the walls and ceiling. During a break in her cab she uses a dimmed warm white lighting, which makes her feel warm and cozy, compared to the cold and dark environment outside the cab. You can't really see any of the light sources, but the indirect lighting directed up in the ceiling and the walls and hidden in small spaces in and under the dashboard. The only directed light she has is the main lamps in the ceiling and the reading lamp by the bed. She rarely uses the main lighting except when she finds it really difficult to find something or when she cleans the cab. She doesn't like bright light and gets easily dazzled by lighting.

A day in life

06:00 Helena arrives to the warehouse and goes in to the office for a quick cup of coffee. Her uncle is already there and they talk a briefly about the weekend and what's happening at work this week. She is a bit tired because she had problems getting to sleep last night.

07:00 Helena is on her way to Uppsala and a gas station she is familiar to and where she knows the staff. She really wants to make it to Uppsala before lunch, which sometimes can be a problem because of the traffic jams in Stockholm. Unnecessary breaks are avoided, but sometimes she stops for a quick break to go to the toilet.

11:20 At the stop in Uppsala she takes a 45 minutes break in which she eats at the restaurant and walks around the truck for a few minutes before hitting the road again.

12:05 It starts to get dark outside when she continues her journey north. She likes to have a better overview in the cab and turns on the red subtle red lighting in the cab.

15:30 When she arrives in Sundsvall she unloads the truck at a warehouse.

17:00 After the truck has been unloaded and loaded she has parks at a compound with a fence and surveillance cameras together with other long haulage trucks. She makes the truck cosy by dimming the lighting and eats her dinner which is some leftovers from the dinner with her.

19:00 She usually video chat with her husband and her two children for half an hour before her children is going to bed. 19:30 She continues reading a crime novel she has been reading from time to time the past two weeks. She thinks it is really thrilling.

20:30 She eats some snacks and sandwich before going to sleep.

Lars

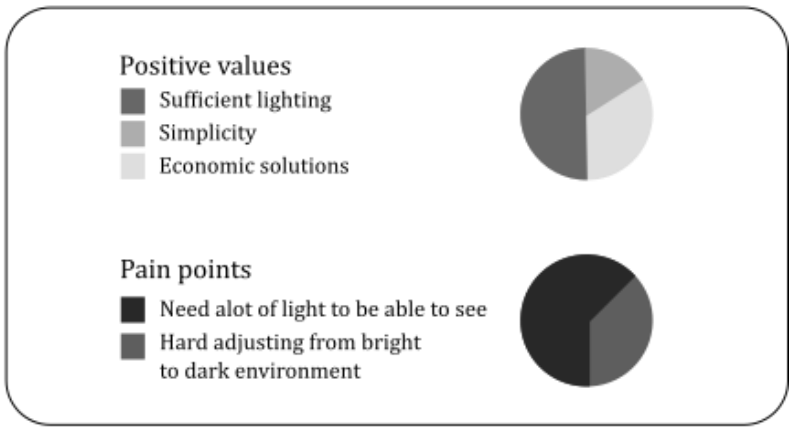
Status: 55 Male with wife and three children

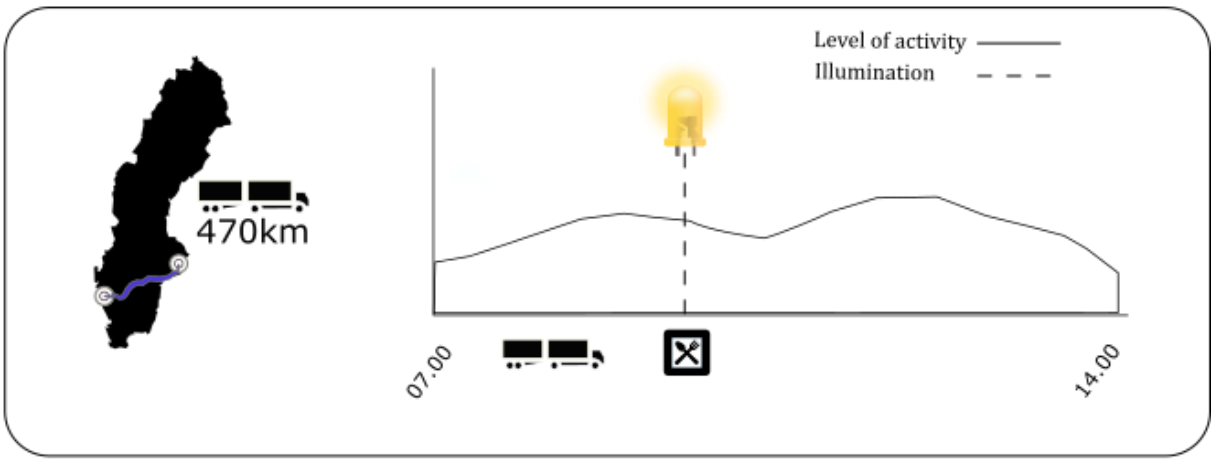
Route: Gothenburg - Stockholm

I like strong light to see clearly, also i am happy with the lights in the truck today.

Background

Lars lives in Gothenburg with his wife and his son who recently graduated high school. His other children has moved out some years ago. He delivers packages mostly between Gothenburg and Jönköping between his company's warehouses. Occasionally he has to drive between Gothenburg and Stockholm and spends a night in his truck. He likes to spend time with his family and grill, or go out fishing in Gothenburgs archipelago with his boat, in his spare time. He has an old mustang which he is really proud of and spends a lot of money and time on. He likes old cars especially the ones from the 50's. Leif has worked as a truck driver for 30 years and have a lot of experience.





Prefered lighting

Lars hasn't made any changes to the lighting in his cab. He likes the cab as it is and always keep his cab very clean and doesn't want to have anything that could distract him laying around in the truck. He is well aware of the younger generations interest in tuning the trucks but finds many of them a bit too much. Leif doesn't feel the need to prove himself, he too old for that and knows he is a very good driver. He uses mostly the main lighting in the ceiling when he reads by the steering wheel, making coffe or tries to find something in the cab. He turns mostly the lighting on full because he wants to be able to see. Sometimes when he gets dazzled by the lighting he has problem to adjust to a darker environment The only time he uses any other lighting is just before he goes to sleep the times when he sleeps in his cab during his trips to Stockholm. At that time he uses the reading lamp by the bed.

A day in life

07:00 Lars wakes up, eats his breakfast and drives to his work. He doesn't have any problem getting out of bed.

08:00 Arrives at his works and gets the truck filled with cargo.

09:00 Lars is leaving the warehouse in Gothenburg and is heading to Stockholm.

13:30 Lars stops by the side of a road and eats his food he brought from home in the truck. He sits in the passenger seat while he eats and continues to listening to the program on the radio he has been listening to on the road. He has turned on the lighting to see clearly while he prepared and eats the food. He walks around the truck for some minutes to get some fresh air. He turns of the lights and rests in the bed during the last 10 minutes before continuing to drive.

14:00 He arrives to his destination, unloads and loads the truck.

15:00 He starts heading back to Gothenburg.

Simon

Status: 25 Male, single

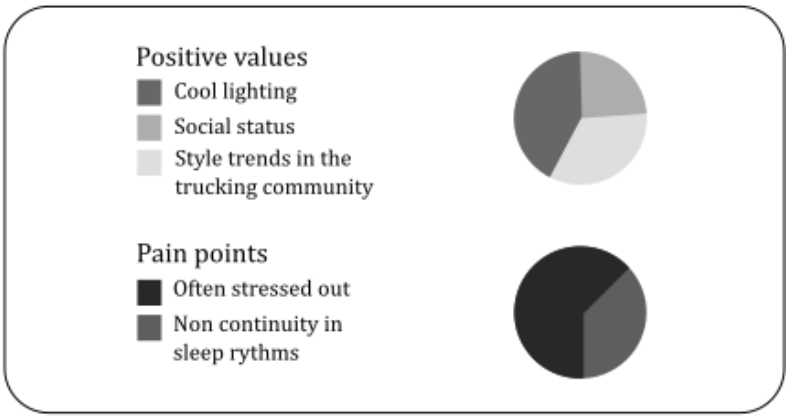
Route: Sweden - France

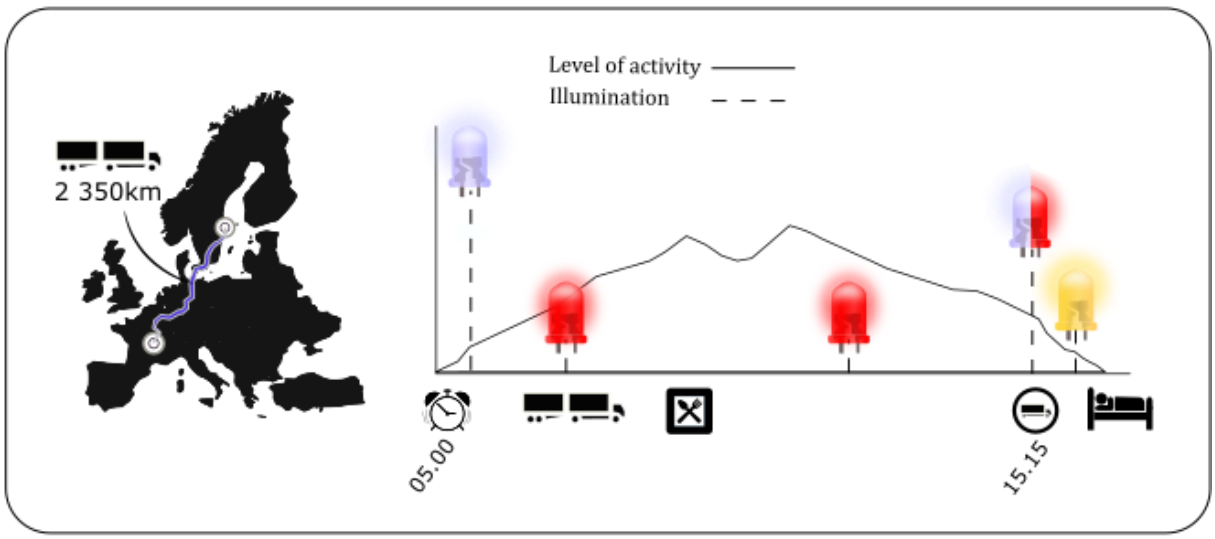
If you have a nice looking truck, other truck drivers are likely to talk to you at the parking lot

Background

A day in life

Simon is born and raised in Örebro and has been working as a truck driver since he turned 20. He has always been interested in vehicles and styling. It started with him getting a moped when he was 15, which he tuned to impress his friends. The moped was later replaced by a light motorcycle by the time he was 16. By the age of 18 he bought his first car in which his styling interest continued. He had several adjustments to the interior made such as red LED-strips new carpets and two dices hanging by the rear mirror. He works five days a week on the road delivering goods between Sweden and France. He drives at daytime on the way down to France on Mondays and Tuesdays. Unloads and loads on Wednesdays and drives back at night time to Sweden on Wednesday night and Thursday night. Simon finds the shift work a bit difficult but likes his work because it's exiting and he gets to see interesting places.





Prefered lighting

05:00 Simon wakes up in

Simon has changed the main lighting in the ceiling to a cold white LED-lighting. He has also put in extra lighting over the bed to get a better overview in the cab and red LED-lighting under the dashboard. He likes to eat in the passenger seat and turns off the lighting over the steering wheel in order to mentally let go of his work and where he sits the most of the day.

Paris in France to eat breakfast in the cab. He arrived in Paris at 19:00 the day before and went to sleep as soon as he could. He wasn't that tired but he knew he had to get up early this day and tried to sleep as much as he could.

05:30 Simon is driving to load goods from three different places around Paris.

10:00 Simon is in a hurry and has one more loading to do in Paris but is obliged to take a 45 minutes break. He stops at a gas station and gets something to eat and walks around the truck to get some blood circulation.

10:45 Simon continues his journey to the last warehouse, finishes loading the truck and starts heading back to Sweden.

15:15 He makes it to a gas station outside Aachen in Germany before he needs to sleep for 9 hours. He tries to sleep and have difficulty since he has to change his daily rhythm.

- 00:15 (The day after) He wakes up and continues his journey back to Sweden. To wake up a bit he turns on bright cold lighting, also goes outside to get some fresh air before hitting the road. When he drives he has a very subtle red light on to get an overview what's in the cab and where he had put stuff like his cell phone, wallet, keys and some snacks.

15 Appendix 5 – Prototyping

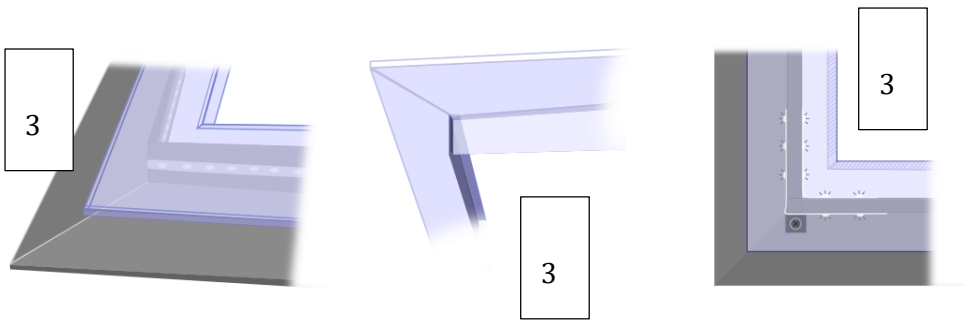
1 Existing fixture with LEDs replacing incandescent lights: From the existing fixture the incandescent lights was replaced with LEDs (1) and used in a similar installation and positioned above driver and passenger.

2 Adjustable spotlights: LED spotlights with reflectors and no prismatic lens was mounted in cubes for easy fixture in the cab (2). Double-sided tape was mounted on the back of the cube enabling them to be mounted on the walls or in the ceiling inside the cab.

3 LED strip with diffusor: Two types of LED strips with a diffuser was used, (3). One LED-strip with white light in the colour temperature range 3000K to 8500K. The other LED-strip was a RGB-strip. Both was mounted in the ceiling and controlled with remote controls.

4 LED-list: Two LED-lists with warm-white light were used (4). One list was fixed and the other was flexible.

5 Small LED spots: Simple LED-spots powered with batteries was used (5). The tape on the back of the spots enabled them to be mounted on the walls and in the ceiling.



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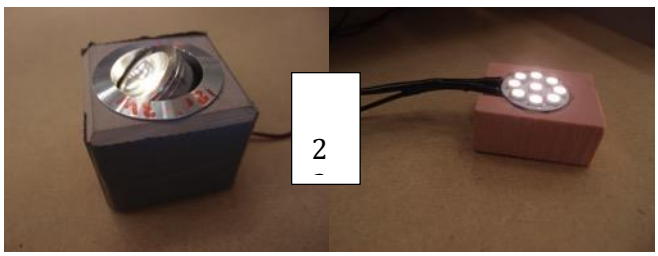

16 Appendix 6 - Flexible modelling

Table 16-1, answers from participants of Flexible modelling. Each participant were asked to design their own lighting environment. The table contains grey filled boxes which indicates a certain light source has been used.

Activity	Used light source				Comments
	Main lights	Spotlights	Monochromatic	"OLED"	
Participant 1					
Waking up				■	Would prefer the LED strip behind the instrument panel angled towards the front window.
Preparing food	■				Prefer warm and indirect low colour temperature light.
Short break					Rather take a walk outside than to be in the truck cab
Driving					None
Working with tablet				■	Prefer the LED strip being behind the driver seat angled towards the ceiling.
Reading book					Want to define the space with lights.
Reading book in bed		■			Want the warm light from spotlights.
Cleaning	■	■		■	All lights available.
Participant 2					
Waking up	■				Prefer a gradually increasing light that is as dim as possible initially.
Preparing food	■			■	Needs a lot of light when preparing, mixed the whiter light from "OLED" with the warmer from main lights. Function before aesthetics.
Short break	■				Wants a candle-like light. Uses the main lights at low intensity.
Driving					None
Working with tablet	■				Don't see any problems with reflections from the main lights. Would like to be able to technically evaluate and balance the lighting in the truck cab.

Reading book					Wants a higher intensity from "OLED" but still prefer it compared to spotlights.
Reading book in bed					Wants a light at low intensity since the purpose is not really to read but to soon go to bed. Don’t want any or very few shadows.
Cleaning					Wants light from several sources, preferably diffuse light. High intensity from "OLED" to get rid of shadows.
Driving at night					None
Participant 3					
Wake up					Soft starts the mornings and uses the snooze function on the alarm. Wants to wake up to a fresh and whiter light at low intensity. If the light is to warm he connects it with night and sleep.
Prepare breakfast					Still wants colder light but with more intensity. Wants the light evenly distributed and a little more light right in the working area. Curious about the mix of cold and warm light from spotlights and "OLED".
Reading book					A mix of main lights and "OLED"
Short break					Wants to be able to use directional and bright light to be able to screen off one half of the truck cab so that the driving and work place is not visible.
Reading in bed					Want to screen off the passenger side of the truck cab to define a lit area.
Going to bed					Wants to define a certain space in the truck cab, e.g. to make the steering wheel not or less visible.
Participant 4					
Wake up					Wants warm light in the morning to not cause stress. Complements the warmest "OLED" with yellow monochromatic light.
Prepare for breakfast					Don't want light cast from above the head, rather use spotlights just above the instrument panel slightly above the eye sight.
Short break					Rather take a walk than to stay inside the truck cab. Otherwise uses warm light from spotlights.
Reading a book by steering wheel					A spotlight at the book, preferably behind and above the left shoulder.
Using tablet by steering wheel					Wants indirect light created from spotlights to create just sufficient light.
Reading in bed					Spotlights for reading and warm indirect light at the wall directed downwards.

Participant 5					
Waking up					Wants to wake up to a medium colour temperature at low intensity.
Prepare for breakfast					Complements the "OLED" with a softer light from a LED strip directed from the back wall to the instrument panel. "OLED" is used at high intensity and with a whiter light.
Short break					Wants directional light in the middle. "OLED" gives to much diffuse light.
Night driving					Prefer a red monochromatic light but do not like the effect like a Christmas tree.
Reading by steering wheel					Complements the "OLED" with the main lights. Wants to create an environment that is a little warmer and where the environment is pleasant and well lit up.
Participant 6					
Waking up					Wants a discrete, warm and diffuse light at low intensity.
Preparing breakfast					Increases the intensity slightly and changes to a whiter light.
Night driving					Finds it important to have sufficient light to be able to find objects e.g. on the floor or nearby.
Reading by steering wheel					Only needs light at the book or the object you are reading from. Believes the light from the main light is sufficient.
Going to bed					Do not care about placement of light source as long as it is diffuse and indirect. The light should "just be there". Complements the warm lights from "OLED" with some indirect light from a LED strip.
Cleaning					Uses all light possible. Important to have light in tight spaces.
Participant 7					
Waking up					Wants indirect and diffuse light directed towards the walls and the ceiling. Want the environment the feel pleasant.
Prepare for breakfast					Wants to use the main light but screened off. Needs soft and even distribution of light.
Night driving					Wants a tiny light source in the roof, like the one she has in her car. The light should just be sufficient to highlight necessary objects in the truck cab. Do not accept any reflections on the instrument panel.

Short break					Want to have the darkest environment possible with indirect light. However it cannot impose sleepiness. She discusses automatic controlling of the light which gradually increases the intensity as it gets closer to driving time. To be able to use the light to create a spacious environment is important.
Reading by steering wheel					Don't prefer spotlights since there is a risk for blinding lights. Wants a little warmer light from the main light and a complement from "OLED" with low intensity.
Working with tablet					Wants indirect lights from spotlights directed to the walls, do not accept any reflections in the screen.
Prepare for sleep.					Important that the light source is not visible in the ceiling.
Participant 8					
Waking up					Uses "OLED" with warm lights and lowest intensity. Complements with indirect light from spotlights directed to the walls. Spotlights can also be replaced by a LED strip that creates the same effect.
Prepare for breakfast					Uses the same light as then waking up, only with a slight greater intensity.
Night driving					Sometimes prefer a monochromatic background light. Discusses the possibilities to use automatic controlling of the lights in the future. When the truck drives itself, e.g. in slow traffic the light could be used at more intense levels.
Short break					Wants an even distribution of warm lights from "OLED" and also some indirect lights from either spot lights or a LED strip directed to the walls and ceiling.
Reading by steering wheel					Stresses that she do not want any directional lights. Uses a mix of the main light and "OLED" to create a natural warm feeling. The intensity should be sufficient to be able to read.
Working with tablet					Needs a high intensity but never directional light. Still prefers warm lighting.
Cleaning					As much light as possible. Complements with a little blue monochromatic light to try to enhance the vision of objects. Also complements with the LED strip directed to the walls.

Prepare for sleep					Wants light to create a certain cosy environment. Wants to control the lighting according to "modes" and would not like to control the specific colour temperature. Prefer the use of directional lighting close to the walls to create a cosy environment.
Participant 9					
Waking up					Wants to place two spot lights in both back corners of the truck cab that creates sufficient lighting. Stresses that he does not need a dimmer.
Prepare for breakfast					Believes that the main light is a good complement to "OLED" since it casts light towards the walls.
Night driving					Light from "OLED" is disturbing in the field of view and cannot be used. He has a bad experience with monochromatic light positioned above the head as it is reflected either in the instrument panel or the window.
Short break					Takes is breaks in the passenger seat and would like a spot light positioned slightly above and in front of the head directed downwards. Thinks "OLED" with warm light is a good complement at low intensity.
Reading by steering wheel					Full intensity from main light is good enough.
Working with tablet					"OLED" gives a good distribution and works with a complement from spot lights and LED strip. Wants to place the spotlights in the top back corners as directional lighting. LED strips should not be directed downwards since it is regarded as unpleasant.
Cleaning					All lights possible
Preparing for sleep					Needs light in both ends of the bed and does not need any special controlling of the lighting such as an mobile application connected to the lighting system.
Participant 10					
Waking up					Want a fresh light where the light source is not visible. Discusses the possibility to cast light from the top of the curtains directed downwards. Wants the light to simulate the sun rise.
Prepare for breakfast					It is important to get a good distribution but also to have directional lighting to create an interesting and spacious environment.

Night driving					Thinks monochromatic lights are a reasonable solution. However the light source cannot be visible.
Short break					Wants to put on a general lighting to fast get an estimation of the environment and belongings.
Reading in bed					Wants indirect lighting and directional lighting combined. Discusses the possibilities of having a detachable reading light to place at preferred location.
Preparing for sleep					Wants to have a spacious environment created by indirect lights. Also, the main light can be used at low intensity. Prefers light directed upwards and discusses the possibility to use an installation of a light source integrated in the sun roof.

17 Appendix 7 - Questionnaire

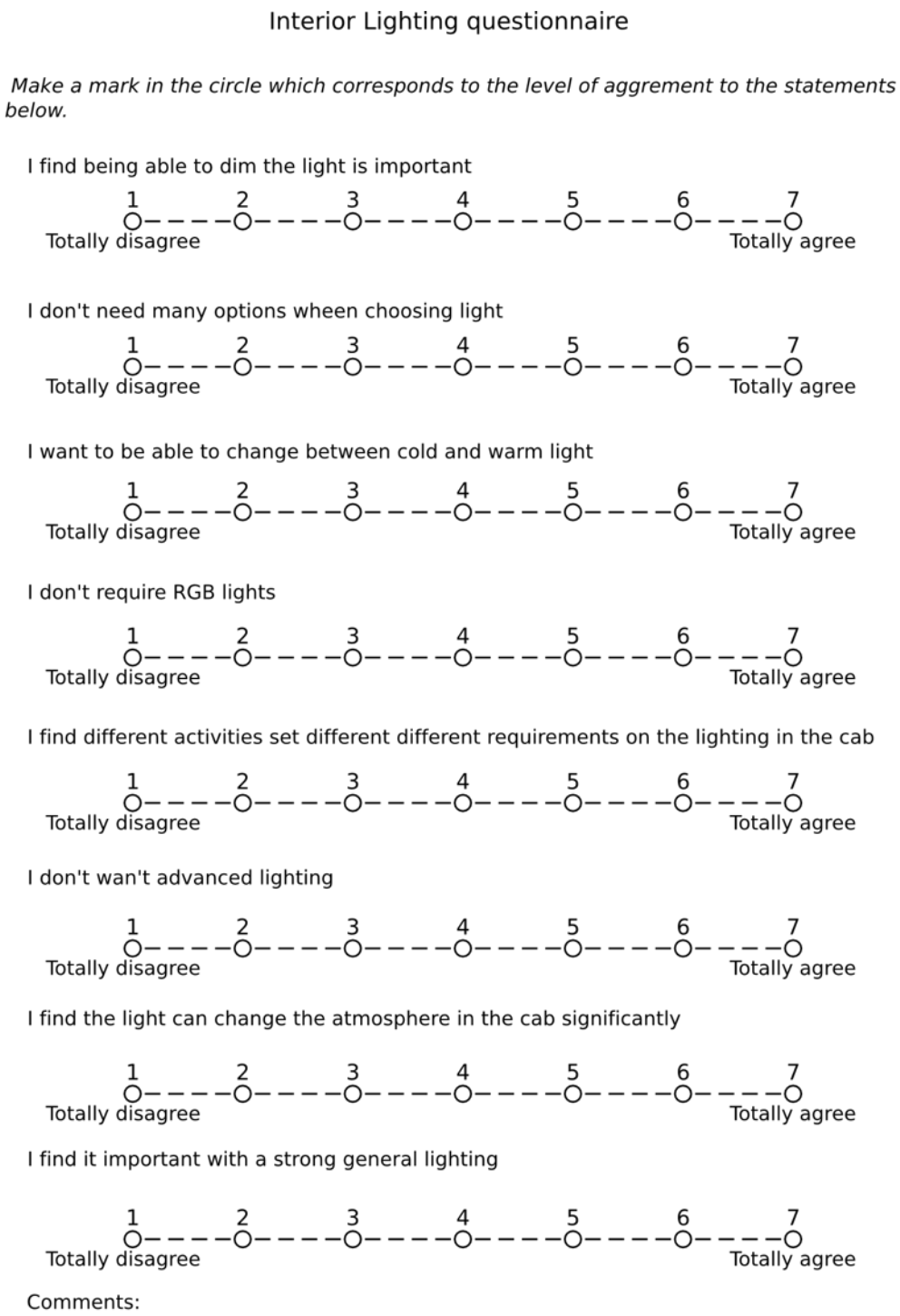

Figure 17-1, questionnaire from the flexible modelling workshop.

18 Appendix 8 – Visual/Physical – Conditions

Visual Condition	Physical Condition
Brightness	
● How bright or dark is it in the cab?	● Surfaces reflectance ● Luminous intensity ● Luminous distribution ● Light source colour temperature
Light distribution	
● Where is dark respectively bright spots?	● Position of light sources and configuration ● Surfaces reflectance
Shadows	
● Where are they shadows and how is their characteristics?	● The size of the light emitting area and distance to the object causing shadow ● Luminous level in the room ● Light sources spectral distribution
Reflection	
● Where are they reflections and how is their characteristics?	● Light emitting surfaces in light source ● The distance and direction relative to reflecting surfaces ● The position of the eye
Glare	
● Where is it and how noticable is it?	● The size of the blinding surface ● Its location in the viewing field ● The background luminance ● Adaption luminance
Illumination colours	
● How is the light perceived? Cold/Warm	● The lights colour temperature ● Luminous level ● Luminous distribution ● Glare ● Colour of surfaces in the room
Colours	
● Do the look real or warped?	● The colours spectral properties ● The lights Colour Rendering Index (CRI) ● The cooperation between surfaces with different colour.

Figure 18-1, Visual/Physical conditions inspired by (Ljuskultur, 2013)