CHALMERS

REFLECTIONS FROM GLOSSY SURFACES IN CAR INTERIOR

An Estimation Method for Glare Disturbance

Thesis work in Master Programme Industrial Design Engineering

AKIN BACIOGLU & BASTIAN SANDOVAL

Department of Product and Production Development
Division of Design and Human Factors
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Preface

This project has been carried out at the Ergononics department at Volvo Car Corporation Torslanda as a thesis work for the Master of Science in Industrial Design Engineering at Chalmers University of Technology.

We would like to express our gratitude to all Volvo employees who have helped us in our project and especially to our co-workers at the Ergonomics Department which has supported us in our progress and made us feel welcome. A special thanks to Magnus Jerksjö who has been our supervisor at Volvo Car Corporation and Ralf Rosenberg and Jessica Dagman who has guided us in the academic jungle.

Akin Bacioglu

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Abstract

This project aimed at finding requirements or a method which could be used to evaluate materials and concepts against reflections in a car interior.

Since all car manufacturers have almost reached to the same level in exterior design of the car, interior design features became even more important than ever to stand out among the competitors. In order to attract customers, design teams have been trying to differentiate the materials used in the interior and the placement of the units. Glossy surfaces help designers reflect their design language better inside the car. On the other hand, glossy surfaces reflect lights and objects with a higher percentage which may distract drivers while driving. Knowing that, Volvo Cars Corporation (VCC) wanted to learn more about gloss phenomenon and how to use glossy materials effectively for interior design within high safety standards.

The project consisted in gathering customer complaints and collect data from questionnaires to clearly define the problems existing today with glossy materials in car interiors. With the results from the data collection three laboratory studies were conducted to analyse the gloss and reflection phenomena further. ***A study on luminance dependency*** revealing how different interior parameters affect the luminance of the driving environment. ***A study on perceived reflection*** helped to find out if the perception of the annoyance from reflective surfaces differs from person to person and what type of reflections are more annoying then others. Finally, ***a study of gloss, lightness and radius*** gave an understanding on the behaviour of reflections related to the combination of these three parameters.

All the studies were analysed using statistical methods. The result made it possible to find effect coefficients on the parameters acting in an interior and create a data model which predicts the luminance and size of a reflection. The prediction is based on the properties gloss, radius and lightness of a surface and can be complemented with the position of the reflection and the surrounding background luminance.

Keywords: *Car Interior Design, Driver, Glossiness, Reflection, Glare, Light, Annoyance, Eye Ergonomics.*

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1. Introduction

Volvo Car Corporation is a successful car manufacturer and an internationally established company. It was founded by Assar Gabrielsson and Gustav Larson in 1926, and the 14th of April 1927, the first Volvo car rolled out from the factory on Hisingen. Since 2010, Volvo Car Corporation is owned by the Chinese company, Geely . Hereinafter, Volvo Car Corporation will be mentioned as VCC.

1.1 Car interiors

As an established car manufacturer it is important for VCC to continuously improve and develop. Today in the car industry, many car manufacturers offer cutting-edge exteriors with equivalent quality. Nowadays, interiors offer a larger opportunity to differentiate from your competitors. “If you don’t have a first-rate interior, the consumer is so mobile and has so many choices, you’re going to lose them, and I think everybody understands that” (Jackson, 2007)

As interiors are more in focus, they are developing a lot with new designs and innovations within communication systems. This forces car manufacturers to focus on the interior design more than ever. Concept designs from different brands show that car interiors are aiming at removing small details and use more digital solutions and continuos surfaces instead. However with more digital solutions and new use of glossy materials there is a need to investigate whether direct reflections can become a problem for the driver.

When driving a vehicle there is always the possibility of annoying reflections coming from exterior or interior surfaces. In order to try and minimise these types of customer complaints, VCC has some requirements in the area of reflections. The issue is that the existing requirements needs to be extended and become more specific.

When developing a vehicle one comes to a point where all requirements need to be balanced against each other. The reflection requirements that VCC has today treats each parameter that adds to the reflection separately which in some cases may not correlate with a correct description of reality. Instead, the requirement needs to be shown from a holistic perspective since each glossy surface and each parameter adds annoyance themselves and in comparison with others.

1.2 Purpose
The purpose of this project is to increase the knowledge about reflections in car interiors. Scientifically on how material properties and differences in the car interior, affect the reflections, but also how car drivers subjectively perceive reflections in different car environments.

1.3 Research questions
The research questions of the thesis are formulated as follows;

- In what way does the base colour of the car interior affect the luminance of the driving environment?

- What parameters affects the drivers the most regarding disturbing reflections?

- How do the reflections behave according to the glossiness, lightness, radius of the surface?

- Is it possible to predict the reflection caused by a surface with certain parameters to be able to compare concepts and material choices?

1.4 Delimitations
Only the lightness of the materials were studied. How colours affect the reflection was not considered within this project.

Anthropometric differences, such as body length, were not considered since reflections and glare still occur, only from other angles.

1.5 Limitations
The project was limited to only analyse surfaces inside the cars. Direct reflections which could occur from the exterior were not considered.

1.6 Sustainable thinking
Volvo's approach on sustainability is based on a holistic perspective. VCC aims to create cars that do not produce harmful emissions. With this in mind, as the thesis project is mostly about setting requirements about the reflections from high gloss surfaces, the authors will not suggest new manufacturing methods or materials which are harmful to the environment.

Nevertheless, the method being developed during the thesis project will help VCC foresee possible consequences of the design decisions without producing expensive prototypes for each alternative.

2. Theory

In this project, there are three main areas interacting with each other; the light, human and the human-car interaction. This is why the theory chosen are directed at these three areas. In this chapter the theory around these areas will be explained.

2.1 Light

Visible light is physically defined as electromagnetic radiation in the wavelength interval where the human eye can recognise and process the information given from the surroundings. This wavelength interval in air is between 400-780 nm and depending on wavelength the human eye will perceive the light in different colours, Boghard, et al (2008). Light is emitted when an excited atom gets rid of its excessive energy, Starby (2003).

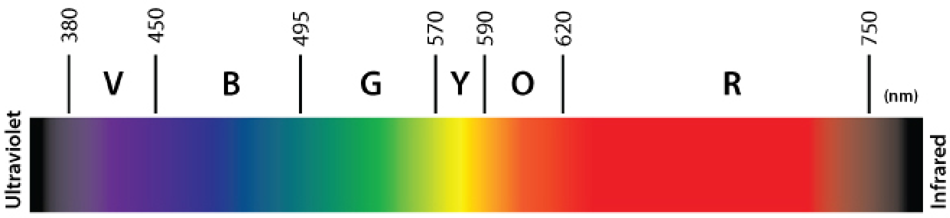

Figure 1: Linear visible spectrum (Adapted from Starby, 2003)

2.1.1 Units

There are two different sets of units used when measuring light; radiometry and photometry. Radiometry measures electromagnetic radiation which includes visible light while photometry measures light in term of how the human eyes perceive the brightness. In photometry the measured power is weighted on all wavelength against a factor based on sensitivity of the human eyes at each wavelength (Starby, 2003). For the type of calculations and tests conducted in this project the photometric units were used, see table 1.

Table 1: Summary of photometric light units and conceptions

Luminous flux	Φ	Lumen	$\Phi = I*\omega$
Luminous intensity	I	Candela	$I = \Phi/\omega$
Luminance	L	Candela/ Square meter	$L=I/A*\cos \varepsilon$
Illuminance	E	Lumen / Square meter	$E= \Phi/A$

2.1.2 Luminous flux
The luminous flux is the measure for perceived power of light. It is weighted against the eye's sensitivity to different wavelengths of light from light sources or surfaces. The unit for luminous flux is lumen and is mathematically defined as the Luminous intensity times the solid angle: $\Phi = I*\omega$. The luminous flux is used to specify how much light is emitted from a light source (Starby, 2003).

2.1.3 Luminous intensity
Luminous intensity is a measure of the intensity a light from a light source is in a specific direction. As the other units in photometry, it is weighted against the sensitivity on different wavelengths of the eye, based on the luminosity function. The SI-unit of luminous intensity is candela, which is defined as $I = \Phi/\omega$, and where 1 candela = 1/683 W/sr at the frequency 540*10^12, that corresponds to the wavelength 555 nm in air which is where the light adapted eye has the highest sensitivity (Starby, 2003).

2.1.4 Solid angle
A regular plane angled can be defined as the angle between a circles radius and the length of the arc it cuts out. In these cases the unit is radian. A solid angle is the three dimensional analogy to a regular angle. Instead of the relation between the arc and the radius of a circle, the solid angle is the relationship of a surface and the radius squared of a sphere resulting in forms such as a cone or pyramid, Figure 2. The SI-unit for this type of angle is called steradian and is defined as $\omega=A/r^2$ (Starby, 2003).

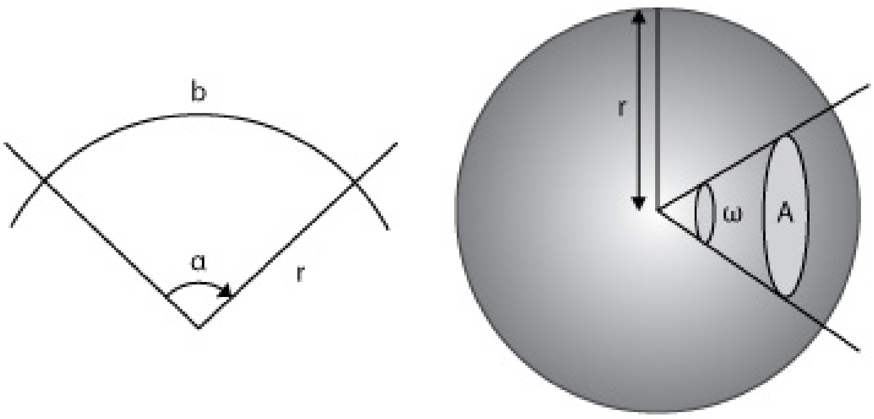

Figure 2: Plain and solid angle (Adapted from Starby, 2003)

2.1.5 Illuminance

In photometry the illuminance is the total luminous flux hitting a surface (Starby, 2003), defined in lux as lumen/m^2. In Latin lux means light which is radiated from a light source. It measures the intensity of incident light weighted against the luminosity function, correlating to human's brightness perception. The human eye can adapt to two-million fold differences in illuminance.

2.1.6 Luminance

Luminance is a measure of how light a surface or light source is and is defined as the luminous intensity per area unit. Often the light radiation from a surface of a specific size, gives different luminance depending on the angle a user looks at the surface. This means that when measuring luminance the angle of interest is the angle to where the user's eyes will be placed. Luminance is defined as $L=I_\varepsilon/A*\cos\varepsilon$ where I_ε is the luminous intensity coming from an angle ε, and A is the area of the light source perpendicular to the user's eye (Starby, 2003).

The earth receives a very large luminous flux from the sun. On a bright sunny day the illumination can be more than 100,000 lux. The luminance of a cloudy sky can be nearly 35,000 cd/m^2 or much lower if the clouds are dense and dark.

2.1.7 Summary of the light units

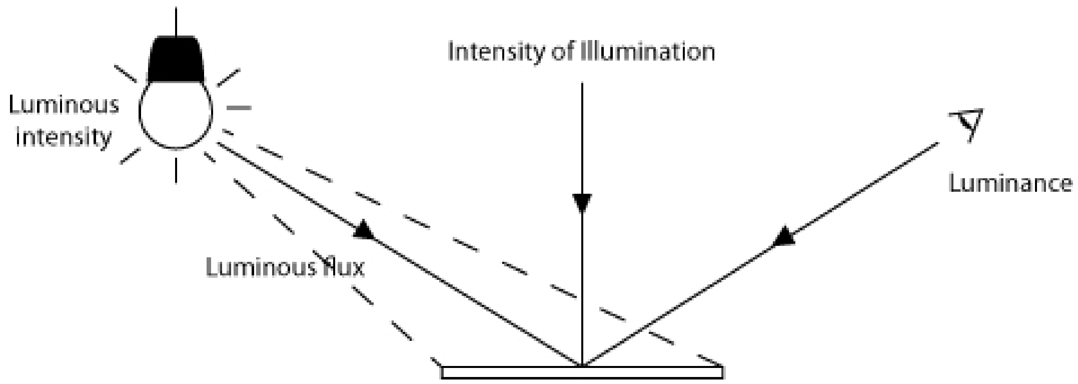

Figure 3: Summary of light units and conceptions (Adapted from Starby, 2003)

The luminous flux is basically the flux that is emitted by a light source per second. The Luminous intensity is the definition of the light intensity in different directions. The illuminance is the measurement of the light that hits on a surface. Finally, the luminance is the expression of the amount of the light on the illuminated surface that is reflected into one's eyes.

2.1.8 Brightness

Even though luminance is a measure of how bright a light source is, it is not the same as the perception of brightness for an observer. The term brightness is used for the subjective attribute of the luminance of an observed object, Gilchrist (2007). Even if two surfaces have the same luminance they can be perceived as they have different brightness depending on the context of the surfaces. In figure 4 there is a optical illusion which explains this phenomenon, where surface A and B are perceived as different regarding luminance but which actually have the same luminance. Actually, the brightness perception depends on three different effects; light adaption, spatial filtering and 3d interpretation.

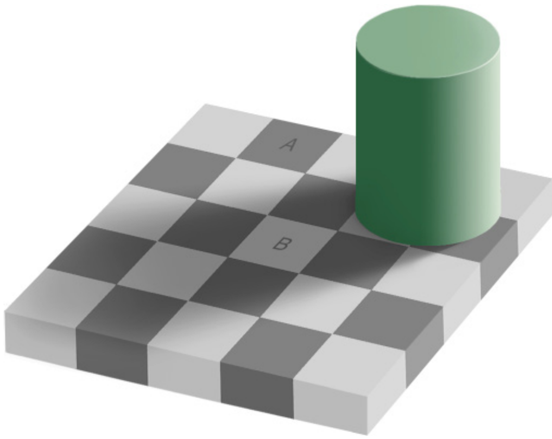

Figure 4: Optical illusion on different brightness perception according to context (E.H. Adelson, 1995)

Some researchers have tried to find a relation between the actual luminance and the perceived brightness and found that the brightness – luminance relation could be approximated with a logarithmic function.

2.1.9 Contrast

An object can only be seen if there is a contrast with its background. The contrast between an object of luminance and the background luminance against which it is seen can be represented with different equations. Contrast can be calculated in terms of differences in luminance values, B_1 and B_0, thus;

$$C = B_1 - B_0$$

Since visual sensations tend to correspond to ratios of stimuli, contrast is usual expressed as a ratio of the luminance difference to one or other of the luminances; thus

$$C = (B_1 - B_0)/B_1 \quad \text{or} \quad C = (B_1 - B_0)/B_0$$

For example, if an object has a luminance of 100 units on a background of 10 units, will have a contrast of (100-10)/100, that is 0,9. (Hopkinson, 1970)

The visual field can be divided into three zones; the task area, the close surroundings and the wider surroundings. There should be a brightness ratio 3:1 between the task area and the close surroundings. Similarly, the brightness ratio between the task area and the wider surroundings should not exceed 10:1, figure 5.

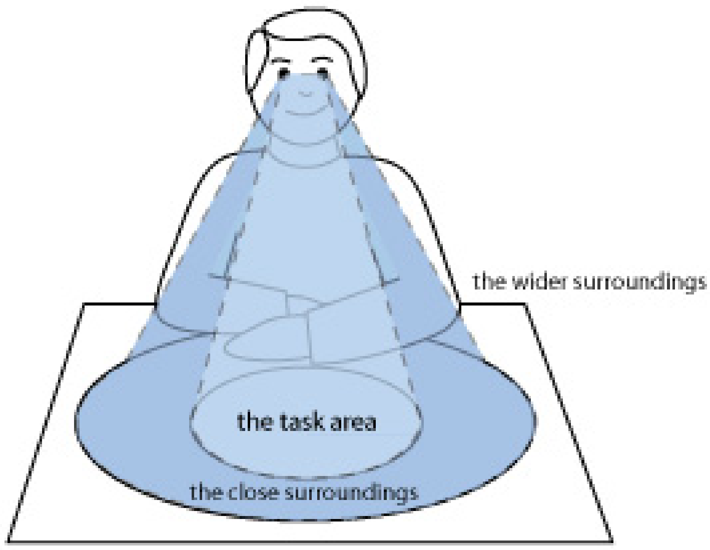

Figure 5: Three zones of the visual field with ratio 1:3:10 (Adapted from Boghard, et al 2008)

Luminance ratios greater than 10 are considered excessive. Excessive differences in brightness within the visual field must be avoided. An approximation of how humans perceive different ratios are presented in table 2.

Table 2: Perception by humans of different luminance ratios (Adapted from Dul)

Luminance ratio	Perception
1	None
3	Moderate
10	High
30	Too high
100	Far too high
300	Extremely unpleasant

2.1.10 Lightness

Gilchrist (2007) defines lightness as the perceptual dimension that runs from black to white, passing through shades of gray. In other words, lightness is the permanent property of a surface which determines what percentage of light the surface reflects. Surfaces that look white reflect 90% of the light hit them. On the other hand, black surfaces only reflect around 3%. In brief, one could define lightness as the perceived reflectance.

2.1.11 Reflection

A reflection is an abrupt change in direction for a wave front on a surface between two media sending the wave into the same medium it originated from. There are three types of light reflection; specular reflection, diffuse reflections and haze reflection (Starby, 2003), figure 6. Specular reflection is the phenomena existing in mirrors where a light ray with a singular incoming direction is reflected in a singular outgoing direction. Diffuse reflections, also called lambertian, spread the light evenly in all directions while haze reflections are a mix of specular and diffuse. To be able to have a good specular reflection the surface irregularities should be significantly smaller than the wavelength of the light. This wave phenomenon is described in the law of reflection where the angle of the incoming light ray and the outgoing light ray are the same according to the surface normal $\theta i = \theta r$.

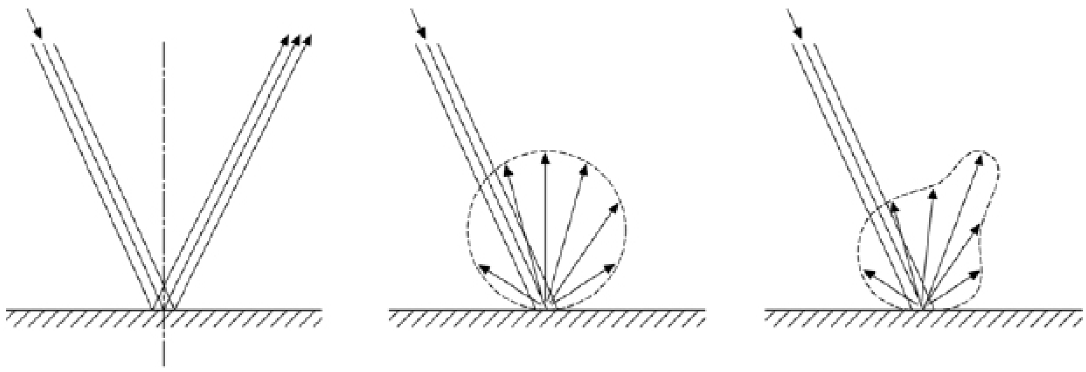

Figure 6: Types of reflections; specular, diffuse and haze, adapted from Starby (2003)

This law is obeyed for all materials and objects on a microscopic level. The differences between specular and diffuse reflection in this case is that if the surface irregularities are too large compared to the wavelength of the light, the reflection will be diffuse.

2.2 Eye ergonomics

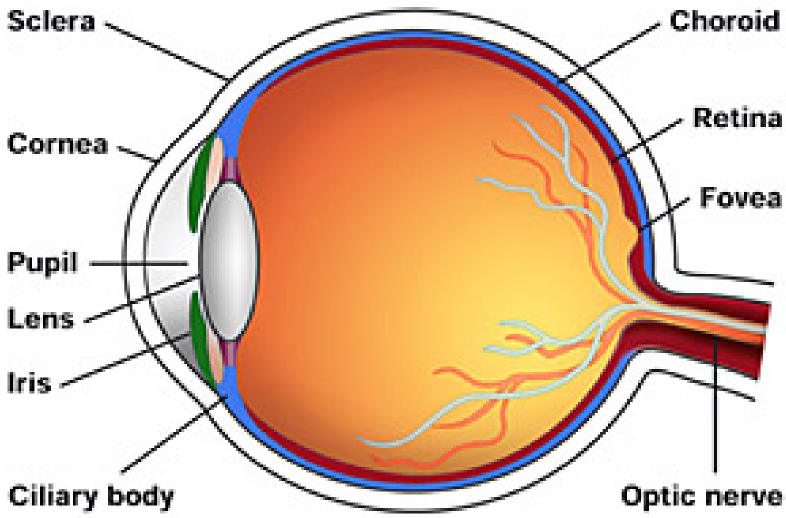

Figure 7: Anatomy of the eye (Healthy Eyes)

The eye is one of the most complex structures of the human body. It is unique among our other senses with the ability of perceive things, such as distant galaxies.

The shape of the eye is similar to a sphere with the bulge at the front. A white layer, called the sclera, covers the outer surface completely. At the front of the eye, it forms the cornea, which is clear. The conjunctiva is a protective thin layer which is fairly loosely connected to the eye socket, except at the point where the sclera and the cornea meet. The conjunctiva only covers the sclera, but not the cornea, figure 7.

The eye needs light in order to perform. Light, generally comes from objects, enters the front of the eye through the cornea. While cornea does most of the focusing, the lens which is just behind of the cornea fine-tunes the focusing and enable the eye to adjust its focus. Then, an image is formed at the back of the eye, on the retina. (Healthy Eyes, n.d.)

The visual sense has actually varying sensitivity depending on the light's wavelength within visible light. The spectral sensitivity curve (figure 8) shows the differences in sensitivity, and one can see that the visual sense is most sensitive around the wavelength of 555 nm which corresponds to a yellow-green colour.

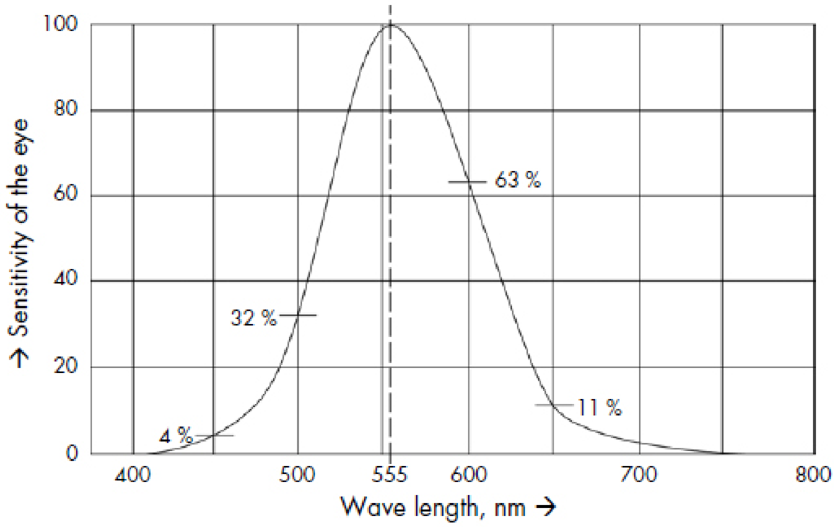

Figure 8: Spectral sensitivity curve (Adapted from Starby, 2003)

The transformation of light into understandable signals is done in the retina. Via the optic nerve the signals are sent to the brain's vision centre where the signals are translated into a picture. The retina contains two different light-sensitive cells which are focused on light and colour perception; rods and cones. The rods are cells which can be stimulated at very low luminous intensity which makes them essential for night vision; on the other hand they cannot register colours. The cells that can transform light into colours are the cones. They can be divided into three types which are sensitive to different wavelengths giving different colours; blue, green and red. These cells need higher luminous intensity to be able to give signals with high information level, and that is why these cells are primarily used for day light seeing (Starby, 2003).

The adaption process from light to dark vision is not an instantaneous change. It is a complex process which can take between ten and thirty minutes before the eyes are completely adapted to the dark and are able to obtain the maximum visual information from the low lighting levels (Boghard. et al 2008). How the adaption mechanisms are related to time can be seen in the adaption curve , figure 9. The first part of the curve shows the adaption of the cone system which takes around five minutes. The point of discontinuity in the curve is where the rods take over the adaption until the eyes are fully adapted.

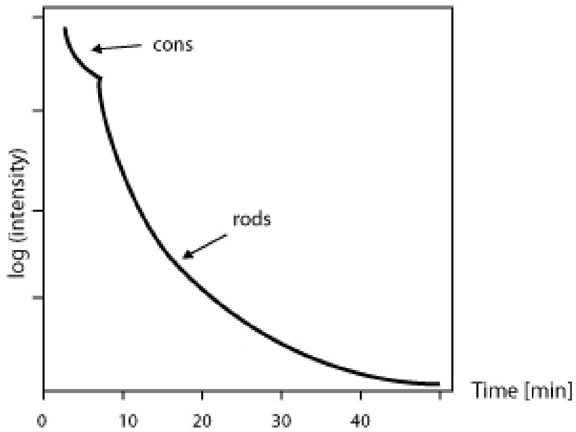

Figure 9: Light sensitivity as a function of the time for adaption to darkness (Boghard. et al 2008)

The regular sensitivity curve, is based on circumstances similar to day light meaning that it cannot be applied for night vision. For night vision there is another sensitivity curve where the maximal sensitivity is situated at 507 nm, making us more sensitive to the colour blue, figure 10 left. The same curves shown in real values are presented in figure 10 right, showing that the visual sense is much more sensitive in night vision than in day (Starby, 2003).

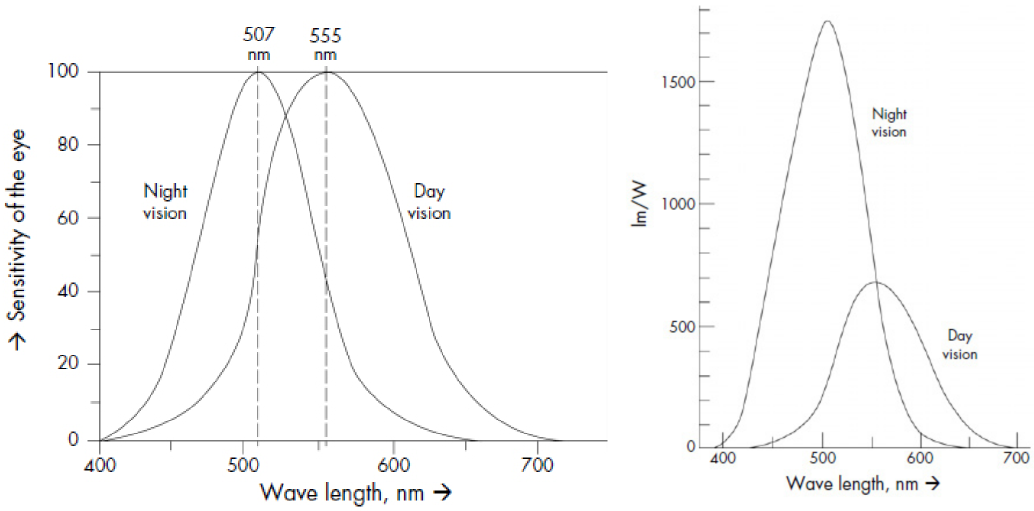

Figure 10: Left: Spectral sensitivity curves for day and night vision, Right: Actual sensitivity for day and night vision (Starby, 2003)

Day vision, where the cone mechanism is used, is called 'photopic vision', while night vision using the rods, is called "scotopic vision" There are situations where both the rods and cones are operating, a state called "mesopic vision" or twilight vision.

The eye has a complex structure consisting of a lens which focuses the light on the retina. More thoroughly, the light is being refracted in the cornea and the transparent tissue before reaching the lens. The lens itself can change the amount of refraction by changing the curvature radius, focusing the light as necessary. This phenomenon is called "accommodation".

The iris is the aperture of the eye and has the function to decide the light level in the eye. By widening or narrowing the opening in the iris, called pupil, the eye can adapt to different luminances (Boghard, et al, 2008). Other light adaption mechanisms existing in the eye are neuronal inhibition,meaning that signals with strong intensities are reduced before reaching the brain. Pigment bleaching is a mechanism where the concentration of rods and cones varies according to light intensity. These three adaptation mechanisms gives the eye a light sensitivity span of 10 000 000 times. In normal conditions the eyes adjust themselves to the average lighting condition in the surroundings. In bright sunlight for example, the eye can perceive a luminance span of 1:100, and in a dull day 1:1000. Depending on the eyes adaptation to the surrounding condition, people will perceive the same physical luminance differently. A low luminance, such as a shadow in day light, might be enough to look bright when looking with dark adapted eyes.

2.2.1 Visual performance

The determination of the visual performance of an individual is operated together by the eye as the organ of sight and the brain as the organ of interpretation. An individual may have a very high visual acuity but if his interpretative equipment is poor, his visual performance may be low. Similarly, even though an individual has relatively weak sight, his intelligence and experience of such an order might enable him to register a high degree of visual performance.

In order to measure visual performance, a detailed analysis both of the processes of sight and of geometric and photometric characteristic of the visual field is needed. Since we know more of the characteristics of the eye as an optical instrument than of the characteristics of the brain as an interpretative mechanism, much of the analyses determining the visual performance are concerned with the optics of the situation rather than with its interpretation (Hopkinson, 1970)

2.2.2 Fixation

High brightness, contrast or colour or any combination of the three can distract the eye from its acts of voluntary fixation. Especially, high brightness is the greatest source of distraction among them. The reason for that is the effect known as "phototropism", the reflex of turning towards the light. For instance, a car approaching with bright headlights on a dark night can be a phototropic distraction since the attention will be held easily by a bright area than by a dark area. (Hopkinson, 1970)

2.2.3 Glare

Glare is a problem caused by light hitting the eye in such way that it impairs vision or irritates the vision. Generally one can divide glare into discomfort glare and disability glare. These terms can be defined as:

Discomfort glare: *the cumbersomely distracting effect of peripheral light sources in the field of view.*

Disability glare: *the masking effect caused by light scattered in the ocular media which produces a veiling luminance over the field of view. (Vos, 2003)*

The distraction from discomfort glare could come from reflections due to glossy surfaces, both as indirect reflection and direct glare from specular reflections. This type of reflected glare causes distraction if it creates bright areas in the field near the field of view and especially if the glare source is on another plane as the task. This is because the glare source as seen by two-eyes is doubled when an observer performs the task, but is fused into a single source when looking slightly away and letting the eyes relax. This will become a continual process of convergence and relaxation which can become distressing (Hopkins, 1970). Experiencing discomfort glare often results in an intuition to look away from the glare source while disability glare will leave the vision completely impaired, a state called "being dazzled".

Other causes for glare are e.g.
- If the luminous intensity which hits the eye is so high that the eye do not have time to adapt enough.
- If light hits the eye so that the adaption changes from the optimal level making it harder to see an object's details and nuances.
- Light entering through the periphery of the vision field and spreads to a large part of the retina, disturbing the vision.
- Large luminous intensity differences in the vision field will do that the average adaption is not optimal for different parts of the vision field, usually called contrast glare.

There are some methods used to be able to calculate the glare. They are the result of various investigations showing that the magnitude of the glare sensations is related to the luminance of the source, the source size from the observer's position and the fact that the perceived discomfort is reduced in an environment with higher luminance level. Also the sensation of glare is reduced if the glare source is farther away from the line of sight. There are many different glare measures, but the authors chose to use the Unified Glare Rating (UGR) recommended by the international committee of illumination called CIE.

$$UGR = 8\log_{10}\frac{0.25}{L_b}\sum_{i=1}^{n}\frac{L_S^2\omega_S}{P^2}$$

$$R = \sqrt{H^2 + Y^2}$$
$$R < 0.6 \longrightarrow P = 1 + 0.8R/D$$
$$R \geq 0.6 \longrightarrow P = 1 + 1.2R/D$$

Where:
Lb = General background luminance
Ls = Luminance of each light source in the visual field
W = The solid angle to the source
P = The position index of the source. As the sources exist below the line of sight, specialised formulas are going to be used to calculate the position index.

D= Distance from eye to the plane of the source
H= The horizontal distance between the source and view direction
Y= The vertical distance between the source and view direction

The strength of UGR equation is that it considers the possibility of more than one glare source. To be able to evaluate whether the glare is good or not there exists a scale for the UGR values, table 3.

Table 3: Glare evaluation according to UGR values

UGR	
<13	Imperceptible
13-22	Perceptible
22-28	Disturbing
>28	Intolerable

2.2.4 Glare in visual field

According to Kim & Kim (2010), there are differences in how we perceive light sources in the different part of the visual field. They performed a test looking for the borderline between comfort and discomfort by glare on different angles in the vision field. Their results showed that there is no big difference between the level of discomfort comparing the left and right eye, but that the lower visual field is more sensitive to glare than the upper field. The higher luminance the light source has, the further away the light source can be and still cause discomfort. In figure 11 the result from their research is shown.

Each line (I-IV) represents a luminance value of the light source (3 000-30 000 lumina), showing that the discomfort limit is further away in the lower visual field.

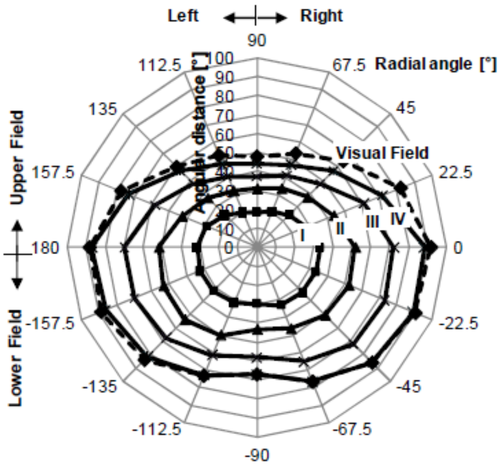

Figure 11: Sensitivity to glare sources across the visual field (Kim, 2010)

2.2.5 Aging consequences

Changes in vision are inevitable when aging. The aging changes in the eye affect almost all of the eye's mechanisms which have a significant effect on the vision. By an age of 40-50 the lens starts to stiffen leading to difficulties when focusing on objects near the eye (Boghard, 2008). The lens keeps stiffening after this age making a correction necessary, such as glasses.

Also there are certain changes in the eye which cause more light to be scattered in the optic media. Consequently, elderly people are more affected by stray or glaring light in their field of view (Hopkinson, 1970).

Another consequence while aging is the clouding of the eye's transparent tissue which makes the light spread more over the retina worsening the image. This condition is called Cataract and is a common condition for elderly; with 50 % suffering from early stages of cataract at the age of 75, and a 25 % suffering from more advanced cataract, Babizhayev (2003).

The clouding in the eye also increases the sensitivity against glare as light coming through the periphery will refract in other ways compared to a clearer eye, making one more susceptible to glare, Starby (2003).

2.3 Visual perception of materials

Materials have different visual properties depending on surface treatment and material structure causing them to be perceived differently when looking at them.

2.3.1 Gloss & matte

Gloss is the optical attribute which relates to a material's ability to reflect light in the specular direction. Refraction index, angle of incident light and roughness of the surface are the three parameters which will affect the gloss.

In order to achieve a high gloss surface, the surface roughness has to be low. This can often be seen in high polished smooth surfaces which are perceived as very shiny and reflective. In more detail, a smooth surface will have a more consistent normal than a rough surface, creating a specular reflection. A material which reflects the light in all directions is called "matte".

Different material structures will also affect the glossiness and specular reflection from its surface. Metals are able to reflect light from all angles, while some plastics and coatings have specular reflection only when illuminated from a great angle. This is because these materials can absorb the light or diffusely scatter the light on other angles.

2.3.2 Specular highlight

The specular highlight is the bright spot one can see on glossy surfaces when illuminated. This bright spot is created through perfect reflection, thereof the use of the word specular. As explained earlier, this happens when the surface normal is directed between the light source and the viewer causing a mirror like image of the light source. This phenomenon makes it possible to view the specular highlights as light sources by their own, (Doerschner, K et. al, 2010).

The intensity of the highlight depends on the microfacets in the material. As materials are not completely smooth they consist of many small facets, each with the possibility to have specular reflection. The direction of the microfacets' normal has a normal distribution over the approximated larger surface. How much the facets deviate from the normal distribution is caused by the roughness of the surface.

This means that on a point of a surface where the normal lies between the light source and the viewer, many of the microfacets normals will be directed in the same direction , causing the bright specular reflection. On points that are further away from the centre of the highlights, there will be much less microfacets directed at an angle between the light source and the viewer causing a decrease in intensity of the highlight.

Specular highlights often reflect the colour of the light source and not the colour of the reflecting surface. The reason for this is that materials usually have a thin clear layer above the coloured material causing it to not reflect the colour of the material.

2.3.3 Perception of gloss

There is research being conducted on whether there are attributes which could change our perception of gloss. Doerschner K et. al (2010), performed a test where it was investigated how spatial pattern, background, and dynamic range affected perceived gloss in brightly lit real scenes. What they found was that there was a connection between these parameters and the perceived glossiness. A glossy object placed in front of a white background was perceived less glossy than if put in front of a black background. The reason for this could be that the dynamic range in the scene is compressed causing the gloss and glare be perceived as less (Doerschner K et. al, 2010).

2.4 Human-car interaction

A driver, while performing different tasks inside the car, interacts with different elements. Driving environment should be well-designed in terms of aesthetics and ergonomics so that the driver is not annoyed by the different units of the interior design.

2.4.1 Partition of the car interior

Car interiors are made of hundreds of little instruments and the placement of them vary between different brands and models. However, for this study, it was necessary to specify the surfaces which the reflections come to the driver's eyes. Figure 12 presents a partition of different units in the front half of a car to bring ease while discussing human-car interaction. According to this partition, there are nine main units inside a regular car interior which are; steering wheel, dashboard, gear shifter, tunnel console, glove box and door panels, centre stack, headliner and seats.

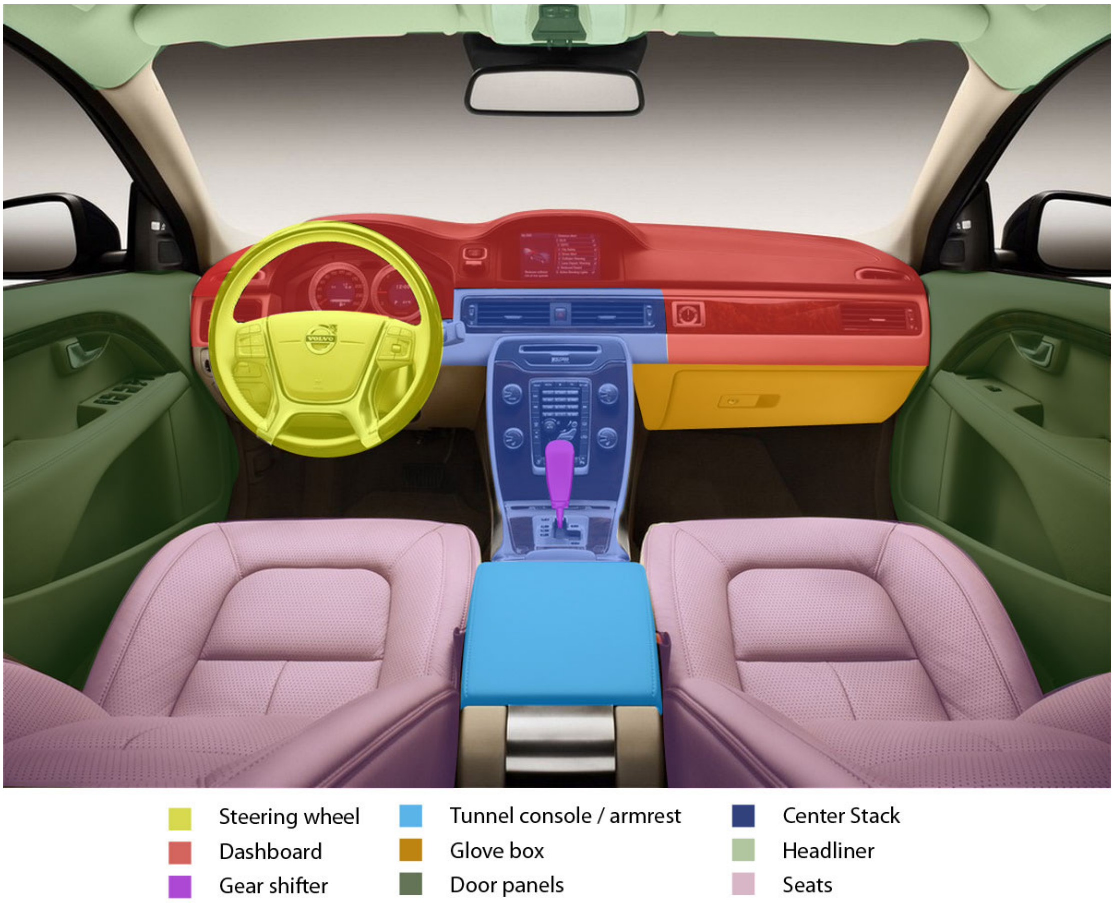

Figure 12: Partition of car interior

2.4.2 Car interior design

Car interior design refers to the appearance and the placement of the functional units inside a vehicle. Since drivers spend much more time inside the car, interior design is equally important as exterior design and it should meet customer needs in terms of form and function. For instance, while a buyer looking for economy-class cars would expect to see primitive and practical interior design, whereas buyers of expensive luxury cars expect innovative, well-crafted design all over the interior.

Material selection is an important step towards good design. Car manufacturers these days try to choose materials that reduce weight, save cost and make cars friendly to the environment not only for exterior but also interior surfaces. Petrochemical engineering helps to create new materials for the interiors of modern cars. These materials have strong resistance against the nature as they are water resistant, preventing the growth of mildew and mold. To name a few; polyvinyl chlorides, polypropylene ultra-fine fibers and other synthetic materials build up the car's interior from the dashboard cover to the floor mats. Natural fibers such as hemp are used for lining and cushioning the headliner.

Another important aspect of the car interior design is the safety. There are different requirements related with the interior materials such as occupant safety, acoustic requirements, weight, ELV (End of Life Vehicles) legislation, esthetics, telematics integration, sensory and smell. Other than universal requirements, brands set their own requirement to offer their customers a better driving experience.

2.4.3 Visual field while driving

When we stare at an object, we use our foveal vision which provides a maximum resolution thanks to high density of cone photoreceptors. As it can be seen in figure 13, foveal vision constitutes only 2 degrees of the whole visual field and because of rendering everything we want to see within this limited area, we are not aware of how low our peripheral vision is (Solso, 1996).

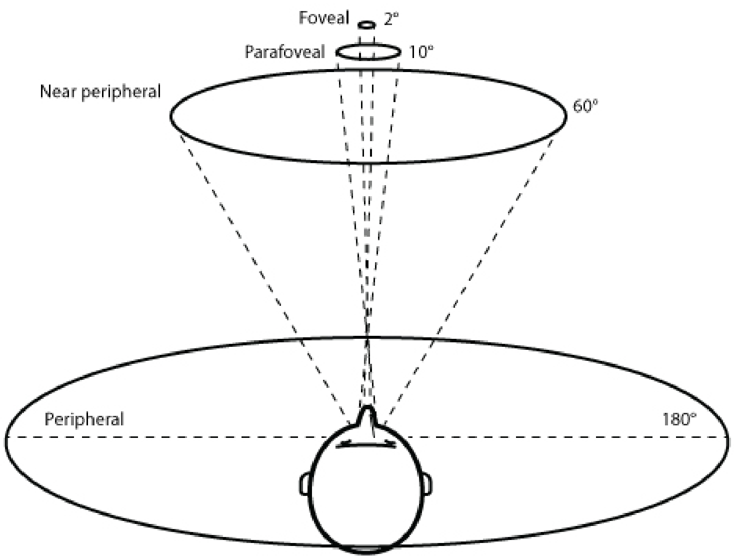

Figure 13: Visual Acuity in Foveal and Peripheral Vision adapted from (Solso, 1996)

The study by Nakayasu et. al, (2004) revealed that eye movements of the driver depended on the stimuli in the peripheral vision. They also found that the visual attention while performing a driving task might split up in case of having many objects to be processed. Another important finding was the relationship between the driving environment and the size of the useful field of view. According to the results, useful field of view was wider for the urban road course than the highway course.

Similarly, Kolanko(2010) stated that the field of vision is reduced by concentration and speed. A driver's field of vision may be as high as 190 degrees inside a nonmoving car. On the other hand, at the speed of 60 miles per hour, this angle will be narrowed to 40 degrees.

Kolanko(2010), in another article, mentioned the difference between how new and experienced drivers use their visual field while driving. New drivers tend to look just in front of the car and staring at the target object, while experienced drivers look at a reference point to use the visual field effectively.

3. Method

When conducting a project it is important to structure each step and method used. All steps should, in some way, contribute to the result and support the process to achieve the goals. In this chapter, each of these steps and methods of the project are presented.

3.1 Planning

An essential part of a project is planning. It is important to know from the start which areas should be covered and in what order the project should be performed. Also one needs to know how much time to spend on each area. Here the planning methods used are explained.

3.1.1 Work breakdown structure

Maylor (2010) defines work breakdown structure as the way of breaking down large activities into comprehensible or manageable units. He further exemplifies three types of work breakdown structures which are; activity breakdown, functional breakdown and physical grouping. Activity breakdown is dividing the major groups of activities into smaller parts while in a functional breakdown, the project is shared by functional areas such as IT, finance and operations. Finally, a physical grouping is the activity of splitting up the project according to its physical parts. For example, if installing a new computer system is a project, hardware and software could be the division of the physical parts. For this thesis project, the authors used activity breakdown structure to unveil the details of the project to be dealt with, see Appendix 1.

3.1.2 GANTT – schedule

A GANTT - schedule is a method of spreading out the necessary activities needed to finalise a project over the time period of the project. This way one can estimate how time consuming each activity is, and schedule them in the best possible way.

Maylor (2010) states two activities to consider while moving from WBS to the Gantt Charts which are; forward schedule and backward schedule. Forward schedule uses the start date of the project as reference and determine the end date later. On the other hand, backward schedule focuses on the end date of the project and other activities are planned backward.

Since it was hard to plan the whole project from the start, a forward schedule was created to manage time. A gate approach was also implemented to move forward between different phases. First gate inside the process was after performing a detailed research on the car interior, gloss and drivers. After collecting enough data on the subject, the second phase was started to perform laboratory studies and to understand how reflection changes according to different materials and shapes and how different users respond to different car interior settings. Finally, after the studies there was a discussion on how the results would be summarised and used regarding allowance of the reflection from high gloss surfaces in vehicle interior. For the complete GANTT schedule, see Appendix 1.

3.2 Quality management framework

Quality is a term which has numerous definitions, some examples are:

"The degree to which a set of inherent characteristics fulfils the requirements, i.e. needs or expectations that are stated, generally implied or obligatory" (ISO 9000:2005)

"Quality should be aimed at the needs of the customer, present and future" (Deming)

"The quality of a product is its ability to satisfy, and preferably exceed, the needs and expectations of the customer" (Bergman & Klevsjö 2010)

Quality management is a concept where values, methodologies and tools are combined in order to achieve higher customer satisfaction with fewer resources. This means that quality management is not only focused on the product itself but also the means of producing the product. When talking about quality management, one often talk about the cornerstones which are:

- Focus on Customer
- Base decision on facts
- Improve continuously
- Focus on processes
- Let everybody be committed
- Committed leadership

There are many different names and types of quality management systems but these cornerstones reoccur in most of the systems. The reason for using a quality management framework is to have a structure in the project, and to run through all the necessary parts to get a good result.

3.2.1 Six sigma methodology

As VCC works with Six sigma, it was used as a framework for the project. Six sigma is a quality management concept which was firstly introduced by Motorola as the name for their improvement programs. Its main focus is to reduce and minimise the variation existing in their different processes.

Variations in processes are often connected with costs and dissatisfied customers and that is why a reduction of variation could result in great improvements. The name Six sigma comes from the notation of standard deviation in statistics. Also it symbolises a goal where unsatisfactory characteristics of a process or product should exist as rarely as possible, less than 3.4 defects per million (Bergman & Klevsjö, 2010). At VCC, the Six sigma methodology was implemented in year 2000, and as it is being used in the whole company the authors decided to use the same methodology for this project.

3.2.2 DMAIC

The implementation of Six sigma in the project was through the DMAIC work process used in Six sigma. The DMAIC is a cyclic process used as a framework for improvement (Bergman & Klevsjö, 2010). As other cyclic improvement processes, the aim of DMAIC is to run through all phases thoroughly in order to cover all parts of the project and not forget anything. The abbreviation stands for a sequence of operations used for improvement as follows;

Define: Create a problem definition, and define the project and the process. Also make a clear definition on what should be measured or be improved.

Measure: Collect existing data to have a starting point and view of the current situation. This is important later to be able to compare improvements with how it was at the beginning.

Analyse: To find relations between the existing parameters and the output.

Improve: Use the results and data from the analysis to optimise the process.

Control: Verify the results; create requirements and standardise so that the results could be used in future projects.

The DMAIC process is connected to various tools and methodologies which can be used in the different phases of the process to achieve improvements. Methods such as design of experiments and KJ-analysis were used in this project. A process description of the project was created with the DMAIC as base, see Appendix 2.

3.3 Research methods

Research is made to collect information regarding the topic of the project. Different types of methods can be used to perform a research. Here all research methods which were used are presented.

3.3.1 Literature studies

Initially, a literature study is performed to take advantage of all research which already has been performed in the area. Books, articles, thesis works, are all good information sources to gather both objective and subjective data to gain fundamental knowledge necessary for the project. In this project, the literature studies were aimed at investigating the physics behind light and reflection, the ergonomic of the eye and how the visual sense works.

3.3.2 Questionnaire and forums

To be able to find customers opinions, experiences and expectations according to reflections, it was necessary to look for information in performed questionnaires and discussions on car brand forums.

Also, by creating an own questionnaire, one gets the advantage of gathering a large amount of specified data about the customers and their opinions related to the project in a short time. It is though, important to ask good formulated questions in order to get answers which can be useful in the end (Ejlertsson, 2005). Having a large base of customer opinions is a good base to decide which areas should be prioritised over others, and is why a questionnaire was created in this project.

3.3.3 Benchmarking

Bergman & Klefsjö (2010) define benchmarking as a method to find opportunities toward process improvement. The idea behind is comparing the process of the company with the same or similar process of another company or another unit at the same company and benefit from this work. They define four different types of benchmarking as can be seen in the figure 14.

Internal benchmarking	Comparing site to site, department to department, country to country within the organization
Competitior benchmarking	Comparing our own performance to that of our direct competitiors
Functional benchmarking	Comparing ourselves, not just against our competitors, but against the best organizations operating in similar fields or performing similar activities.
Generic benchmarking	Comparing ourselves against the best from all industry groups

Figure 14: Different types of benchmarking, defined by Bergman & Klefsjö (2010)

In this project, this method will be used to understand how different car brands and competitors, divide their car interior elements and make use of glossy materials, to compare it to the chosen Volvo model.

3.3.4 User analysis

In a user- focused development work, it is essential to know who your users and what their characteristics are. User analysis is a method used to answer these questions. By knowing the user, one can focus the development work on the aspects that really would do a difference for the users. For the development process, it is important that the user profile is as accurate as possible since it will have a large influence on the requirements settings done at the end of projects.

The analysis of the users was used in the project to analyse whether different personal characteristics, regarding vision had any influence on how users perceived the reflections. Anthropometric differences were not considered in the project since direct reflections occur independently of the length of the driver. The sun angle will be different for creating reflections will be different for different lengths, but reflections as such will still occur.

3.4 Experiment methodology

There are different ways of performing an experiment or study. Since many parameters would be analysed, it was important to find methods which systematically collect and treat data.

3.4.1 Design of experiment (DoE)

One important aspect when working with quality is to base decisions on facts, (Bergman & Klefsjö, 2010). As VCC has felt that the facts and requirements in this area needed to be expanded, it was necessary to collect some straight facts on how different parameters affect the reflections. One way to calculate each parameter's contribution and their combined contribution is to perform a design of experiments which is a methodology to identify which factors and parameters that affect the output, (Bergman & Klefsjö, 2010).

In the project, this methodology fits well as it is necessary to compare different parameters affecting the reflections and how these parameters are related to each other. It will be used to structure and analyse the experiments where parameters regarding the reflections will be studied.

The procedure when working with DoE is to vary the important parameters according to a matrix, (table 4), and measure the output, Goh (2011). The matrix is called a full factorial design matrix where you analyse three parameters, getting the effects of the parameters themselves and the combined effects. Each parameter is set with a low and high level, represented either with a (-) or (+). A full factorial matrix done with three parameters needs 8 runs. The amount of runs needed for a DoE is based on the relation between the number of levels (L) and parameters (P) as L^P , Goh (2011).

Table 4: Full factorial design matrix

Main effects and interactions								
Run No	A	B	C	AxB	AxC	BxC	AxBxC	y
1	-	-	-	+	+	+	-	67
2	+	-	-	-	-	+	+	79
3	-	+	-	-	+	-	+	59
4	+	+	-	+	-	-	-	90
5	-	-	+	+	-	-	+	61
6	+	-	+	-	+	-	-	75
7	-	+	+	-	-	+	-	52
8	+	+	+	+	+	+	+	87
Estimated effects	23	1.5	-5.0	10	1.5	0.0	0.5	

Accordin to Goh (2011), the effect of the main factors is calculated by averaging the effects of changing an effect from low to high as:

$$E_1 = \frac{1}{4}\left(-y_1 + y_2 - y_3 + y_4 - y_5 + y_6 - y_7 + y_8\right)$$

$$E_2 = \frac{1}{4}\left(-y_1 - y_2 + y_3 + y_4 - y_5 - y_6 + y_7 + y_8\right)$$

$$E_3 = \frac{1}{4}\left(-y_1 - y_2 - y_3 - y_4 + y_5 + y_6 + y_7 + y_8\right)$$

For interaction effects one calculates the effect on raising A on high B level – the effect of raising A on low B-level. To get the equation as for the main effects above, one uses the modifiers from the matrix for each interaction column with the output, getting equations for E4-E7.

$$E_4 = \frac{1}{4}\left(+y_1 - y_2 - y_3 + y_4 + y_5 - y_6 - y_7 + y_8\right)$$

$$E_5 = \frac{1}{4}\left(+y_1 - y_2 + y_3 - y_4 - y_5 + y_6 - y_7 + y_8\right)$$

$$E_6 = \frac{1}{4}\left(+y_1 + y_2 - y_3 - y_4 - y_5 - y_6 + y_7 + y_8\right)$$

$$E_7 = \frac{1}{4}\left(-y_1 + y_2 + y_3 - y_4 + y_5 - y_6 - y_7 + y_8\right)$$

If it is necessary to analyse more parameters, one could increase the amount of runs or do a fractional factorial design matrix which means that an extra parameter is exchange with one of the combined effects (Bergman & Klefsjö , 2010). This is often done in order to save time and costs as one will need less runs to analyse more parameters. Even though the interaction effects will be confounded in each other, it is an effective way of decreasing high amounts of parameters early in an experiment.

When the effects have been found, one has to decide whether an effect actually is an influencing factor or if it is variations in the runs. Each effect is estimated as the sum of a number of independent random variables which according to the central limit theorem means that the effects are roughly normally distributed (Bergman, Klevsjö 2010). If the effects are normally distributed, then one can use the standard deviation of the effects to know whether an effect is actively influencing the output or not.

3.4.2 Response surface design

The disadvantage of the DoE is that it only returns a first-degree polynomial approximation model, meaning that the effects are based on a linear relation which is not accurate for many cases. The response surface methodology is used for more complicated models, returning second and third-degree polynomials. By increasing the degree of the polynomial, the effect approximation of the results will be more accurate (NIST/SEMATECH, 2012). With more accurate effect coefficients, it is possible to construct a data model to calculate and predict an output using the analysed parameters, which is one of the set goals for this project.

There are different response surface designs that could be used depending on the situation. For experimentation with 2-4 factors, it is preferred to use a Central Composite Design (CCD), (NIST/SEMATECH, 2012). The CCD is a factorial design with a centrepoint and star points, with a distance α, to help decide the curvature of the polynomial expression.

The value of alpha depends on what type of CCD is performed. The three types are circumscribed (CCC), inscribed (CCI) and face centred (CCF). These CCD types also determine how many levels each parameters will need. Both the CCI and CCC and CCF require five levels, while the CCF only needs three, (NIST/SEMATECH, 2012). One can see that it is the CCC design which considers the largest amount of points within its area, and is why this design will be chosen for the analysis, figure 15.

By augmenting the DoE matrix already created, with extra star points, it is possible to calculate the coefficients needed for the response surface. Such a matrix for three parameters looks like table 5, with α defined as:

$$\alpha = (2^k)^{\frac{1}{4}}$$

.

Table 5: Response surface matrix

Run	A	B	C
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+
9	-α	0	0
10	α	0	0
11	0	-α	0
12	0	α	0
13	0	0	-α
14	0	0	α
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0

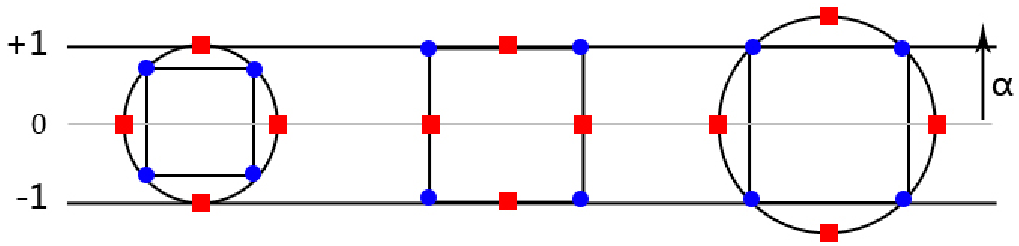

Figure 15: Different types of Central composite designs, CCI, CCF ,CCC

3.4.3 Conjoint analysis

One way of using the design of experiment more subjectively is to do a Conjoint analysis. The primary aim of the analysis is to understand which characteristics are important for the customers Bergman & Klefsjö (2010). Customers are asked to evaluate different products with characteristics that have been chosen according to an experimental design. By ranking or marking on a grade one can get “output” values that could be used to get the effect coefficients. In our case, it was used to identify the characteristics that customers associate with annoyance and reflections.

When gathering subjective values, the environment where the test is performed is important. The environment can be divided into two groups; a natural environment (informal) and a constructed test environment (formal). The constructed test environment is a laboratory where researches try to imitate the environment where the system often is used. A test in the natural environment is to do the test in the normal environment of the system. The natural test has the advantage of being more realistic and making the test participants more relaxed giving the test a higher validity. On the other hand, it lacks in control compared to a test performed in a constructed environment (Preece et al, 2003. In this project, the studies were performed in controlled environments as it is hard to create the wanted situations in the normal environment.

3.4.4 Volvo Scale

The Volvo scale was firstly introduced in 1997 as a rating system used to rate different characteristics of a car. The ratings spans on a scale from 1 to 10. In this project, the scale was used in different studies to get a rating on different situations. It was used as it is a scale which employees at VCC are familiar with and which they have used many times.

3.4.5 Study equipment

Dedolight 400D Sun lamp

A dedolight 400D is a lamp used for simulating daylight. It is a portable light with a maximum power of 400W and was able to come up to a value of 80000 lux, at a distance of 1 m with small solid angle. It is useful when it is needed to do studies which needs a lamp to simulate the sun.

Prometric PM-1000-0 Photospectrometer

The PM- 1000 is a photospectrometer camera and a measuring tool used for measuring optical properties such as luminance, radiance and illumination. In our studies, it was used as it can gather a lot of different measurements at the same time, increasing the speed of the study.

The camera is used by taking measurements in photos which are sent to a connected computer where the data can be analysed according to the output of interest. The advantage of using the camera is, as it takes measurements over a photo, that it is able to do measurement over an area. That makes it possible to measure luminance means, minimal and maximal peaks of many glare sources at a time.

Luminance meter Minolta CS-100A
The CS-100A is used for measurements of luminance and could also be used for finding standard colour value properties. The measurements of luminance and standard colour values can be measured with an acceptance angle of 1°. When using it, one look into the viewfinder and aim the small circle, relative to the 1° angle, against an illuminated area. The luminance meter will then calculate the luminance mean in that area. Its measurement range, from 0,1 cd/m2 to 299 000 cd/m2, makes the CS-100A applicable for many different situations. It contains a neutral density filter in order for it to be able to measure strong and bright light sources.

Illuminance meter Minolta T-10M
A Minolta T-10M was used to know how large the illumination from the sunlamp was at a given position. A constant lux value is important for the experiments to decrease the possible variations caused by the sun lamp. The T-10M has a measurable range from 0,01 to 299 900 lux. By placing the measuring head of the illuminance meter directed at the sunlamp at a reference point, it could be verified that the lux value was kept constant over the course of the experiment.

Figure 16: Equipment, from left, Illuminance meter, Luminance meter, Photospectrometer

3.5 Data analysis

All data collected from research and studies needs to be summarised and analysed. These are the methods used in this project for that.

3.5.1 KJ-Analysis

The KJ-Analysis, also called affinity diagram, originates from the Japanese anthropologist Jiro Kawakita. It is used in order to facilitate the organisation of large amount of verbal and qualitative data. This method is supposed to be performed in a group with people who are analysing a question or problem statement whereas the group write opinions and group them under larger headings (Bergman & Klevsjö, 2010). In this project, this method is not going to be used to create data through group discussion but is going to be used in order to analyse and group the gathered qualitative data from the perceived reflection studies into larger aspects, also to summarise the opinions and complaints of today's problems found by questionnaires. By summarising the qualitative data under larger headings, one can see the problem areas existing, and also see if some areas are more problematic than others.

3.5.2 Minitab

Minitab is statistical software often used within the Six Sigma improvement program. It has statistical tools, making it easy to perform and calculate everything needed for the design of experiments and the response surface methodology. All numerical data and measurements gathered in the project will be analysed with this software.

3.5.3 Requirements settings

When setting requirements, it is preferred that all requirements are measurable. Having measurable requirements is important as it makes it easier to evaluate them objectively. It makes it clear whether a concept passes the requirements or not and is not a matter of opinion which would be the case if one would have non-measurable requirements.

4. Project Realisation

In this chapter, the realisation of the project will be explained, with explanations on all contributing methods used. The methods are here presented in the order they were carried out in the project.

4.1 Customer Complaints

The customer complaints regarding reflections were gathered by compiling comments from surveys, annually performed by VCC and by searching opinions on internet forums specified on different car brands. The comments were counted to see how many were experiencing the same issues, and connected to the specific car model which were commented on. This gave the opportunity to search for the car models which had complaints and compare the different interior designs. Another important aspect with this part was that it gave a hint on where in the interior, drivers were experiencing disturbing reflections.

4.2 Questionnaire

The aim of the questionnaire was to get information whether drivers are actually getting annoyed with reflections from the interior. As the project were aimed at Volvo cars, it was decided to send the questionnaire to employees within VCC. This because it was known that the majority of Volvo employees are driving Volvo cars and in that way the majority of data will be regarding Volvo cars.

As for the customer complaints, it was necessary to further specify where drivers are perceiving disturbing reflections with the questionnaire. This data was gathered by having questions regarding where they feel reflections, and by asking the respondents to rate different surfaces.

The questionnaire was created with GoogleDocs and distributed to 489 employees, which of 264 responded. 100 female and 164 male responded to the survey with an average height of 177,9 cm. 135 of the respondents wore glasses. 230 of all respondents were driving Volvo cars, with the Volvo V70 as the most common one, with 74 people, see appendix 7.

4.3 Benchmark

The benchmark was conducted to compare how the interior design of Volvo is in comparison with the competitors. The main focus was to look at where different brands place reflective materials and whether one can say that they are better or worse from a reflection point of view.

4.4 Laboratory studies

To be able to draw conclusions regarding the interaction of different parameters, it was necessary to perform three studies to complement the knowledge existing in VCC, each focused on different aspects of the reflection in the interior.

The studies and their aims are:

- Study on luminance dependency:
  Aims to find a relation between different parameters regarding the interior of a car and luminance.

- Study of perceived reflections
  Aims to find how drivers perceive reflections in the car and what makes drivers get more or less disturbed by the reflections.

- Study of gloss, lightness and radius
  Aims at finding how the parameters gloss, lightness and radius affects the lumi nance and glare size.

The relation between the studies is that the study of luminance dependency analyses the overall interior parameters and the perceived reflection study finds how these parameters are perceived by drivers. Finally the study of gloss, lightness and radius will be used to create a data model to predict how good or bad a surface is regarding reflections.

In the next chapters, each study will be presented and explained more in detail.

4.4.1 Study on luminance dependency

The study was performed in order to measure the maximum luminance from the different glare sources across the interior. Measuring their luminance was needed to be able to draw conclusions regarding how the luminance is related to the interior of the car. A full factorial design of experiment with three parameters was used for this study. Look at Appendix 3 for further details.

The interior design of the S80/V70 was chosen for the analysis, as the surfaces of interest are easy to analyse in this interior. Figure 17 shows which areas of the interior were analysed, chosen from the results of the customer complaints and questionnaire.

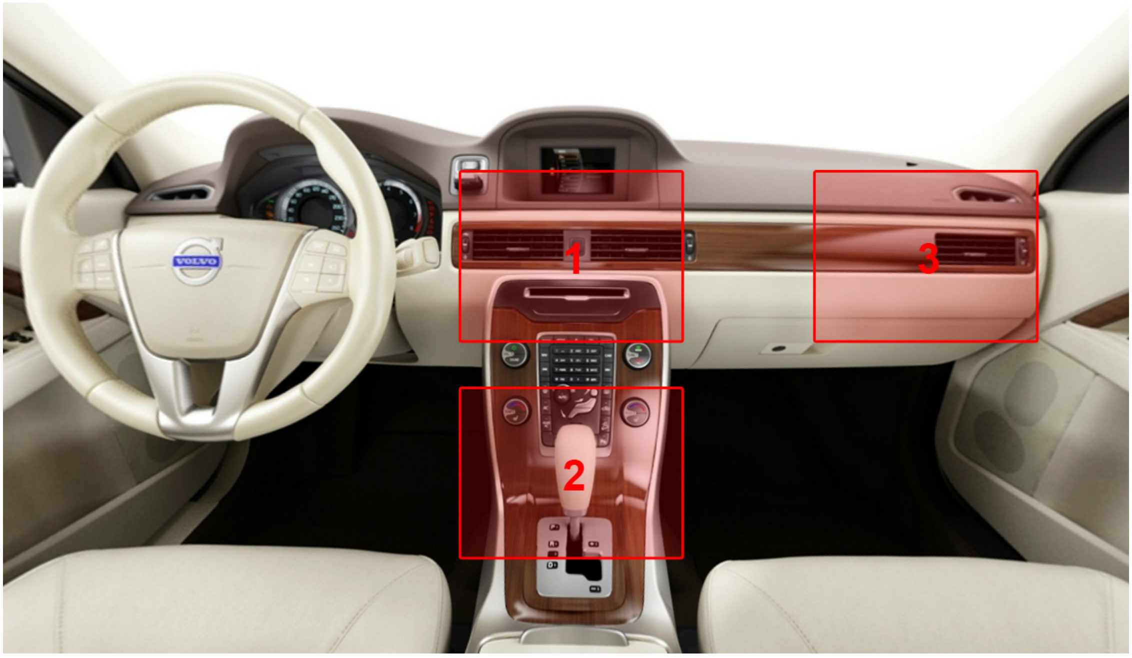

Figure 17: Analysed areas of the interior

Parameters:
The studied parameters in this study were the sun direction angle, interior lightness and panel type, see table 6. The goal for the study was to investigate whether there is a relation between the lightness of a car interior and which type of decorating panel used, for the amount of luminance being directed at the driver. The sun direction angle was used to investigate whether one strong glare source close to the driver would be worse than many smaller glare sources in a distance.

The panels used were of two different types and materials, glossy wood and aluminum. These panels were used as they act differently when reflecting light. The lightness of the interior material was a dark and light colour, see figure 18. The sun direction was focused on both the deco panel, horizontal surface, and the centre stack, instrument surface, see figure 18.

Table 6: Investigated parameters for material properties

	-	+
Sun direction	Centre Stack	Deco Panel
Interior lightness	Light	Dark
Panel type	Aluminum	Wood

Figure 18: Different parameter settings with panels and interior lightness.

For each parameter setting, the maximum luminance for each area and the background luminance was measured. The maximum luminance is a measurement of the intensity of the reflection. The background luminance is needed as it relates to the contrast between the surface and the surroundings; a high background luminance gives less contrast, and according to theory, results in less perceived annoyance.

Set up:

A flexible set-up was needed to be able to change parameters as quickly as possible according to the DoE used. Therefore, two cars with same interior design were chosen for the study, V70 and S80, 2012 model. The difference between the cars was their base colours which were, Off-black and Soft Beige. Exchangeable panels of glossy wood and aluminum, (see figure 18) were used to test the relations between different lightness and panel type.

To be able to change panels quickly, the cars were modified before the study by loosening the connections on the deco panel and the centre stack so they were easily removed and placed back.

A sunlamp was used to simulate the sun and was set, with help of an illuminance meter to a constant value of 80000 lux from the lamp, in order to get worst case scenario measurement. This resulted in a value of 700 lux at the surface of interest. The sunlamp was placed outside the front passenger seat (1000 mm behind the dashboard and 400 mm out from the B-pillar line) and directed at either the deco panel or the centre stack, depending on what is being measured, figure 19. The height of the sun lamp was set to create a direct reflection against the camera inside the car, and was kept at the same height for both sun directions.

A photospectric camera was rigged in the middle of the car where it could be rotated and measure different parts of the interior, figure 19. Maximum luminance was measured for each area. For validating the results of the camera, a manual luminance meter was used to verify the numbers received by the camera.

Figure 19: Photos of the study set up

Procedure

The full factorial design used in this study can be seen in table 7. In order to consider the possibility of "noise" in the measurements, the same experiment was conducted four times to be able to calculate the standard deviation and identify the noise.

For each experiment run, the cars were modified and set according to the parameters of the run. The camera was set in the correct position by an operator inside the car and the measurements were taken by a second operator situated outside of the car. After all needed measurements were taken, a new run was picked and the same procedure was done over again, see appendix 3 for a detailed experiment explanation.

Table 7: Experiment matrix

	Main Parameters			Parameter relation				Output Values					
	Sun Position	Lightness	Panel Type	IxT	IxS	TxS	IxTxS	Ls1	Ls2	Ls3	Lb1	Lb2	Lb3
1	Right	Light	Aluminum	+	+	+	-						
2	Left	Light	Aluminum	-	-	+	+						
3	Right	Dark	Aluminum	-	+	-	+						
4	Left	Dark	Aluminum	+	-	-	-						
5	Right	Light	Wood	+	-	-	+						
6	Left	Light	Wood	-	+	-	-						
7	Right	Dark	Wood	-	-	+	-						
8	Left	Dark	Wood	+	+	+	+						
E													

4.4.2 Subjective study of perceived reflections

According to brightness theory (chapter 2.1.8), visual stimulus is perceived very differently depending on the environmental context which means that the objective data might not cohere with the user's perception. For this reason, a subjective analysis with test users was performed to find the relation between the objective data and the user's perception. The aim for the subjective study was to receive qualitative and quantitative data on how reflections are perceived, and which factors are affecting the perception.

The study was performed with 30 Volvo employees. The participants were 13 men and 17 women, with an age span from 28-66 and a body length span 10 % - 90 % percentile for both men and women. The number of participants who used visual correction tools were 16, against 14 who did not use any.

Parameters

Since it should be possible to compare the results from this study with the luminance dependency study, the parameters were kept the same for this study. The only difference was that the sun power was added as an extra parameter, see table 8. The sun power was changed by adding or taking away a filter on the sunlamp.

Table 8: Investigated parameters for perceived reflections

	-	+
Sun direction	Centre Stack	Deco Panel
Interior lightness	Light	Dark
Panel type	Aluminum	Wood
Sun Power	High	Low

Set up

The set up is also similar to the luminance dependency study where a sunlamp was used to simulate the sun and two cars with different interior colours were used, see figure 20. The difference was that, instead of using a camera to measure the actual luminance strength, the participants told the test leaders their rating for perceived annoyance of the luminance with help of the Volvo scale.

Figure 20: Set up for subjective test

Taking all parameters into consideration, resulted in 16 ratings for each car, 32 in total. In order to have a substantial grounded data, the test was performed with 30 Volvo employees from different departments.

Procedure

Even though it gives best result to do each measurement run randomly, it would take too much time to do with so many participants. Instead, the procedure of the experiment was set to work best practically. By modifying the experiment according it was possible to have a better flow during the studies compared to if it was necessary to change cars for each run.

The test started by introducing the experiment to the participants, where the test leaders explained the purpose of the study and how the experiment would be performed. The test continued by having the participants seated in one of the car and letting them adjust the seating so that the eyes were situated to receive direct reflections from the target area. The eye reference was set so that direct reflections from the sunlamp would be created in the same way for all participants. When the eye level was set, the parameters were set according to the experiment plan.

The test leader asked for a rating for two points of interest; one looking through the front window, imitating a driving situation, and one looking at the centre stack, simulating a task of interaction with the center console. As there were two test leaders, one was responsible for the interaction with the participant while the other was responsible for the sun lamp and changing the panels. When all the necessary ratings were taken the subjective test was finalised with some complementary questions outside of the car.

4.4.3 Study of gloss, lightness and radius

The study was an experiment focused on finding relations between material properties, radius, the created glare size and luminance. This experiment only considered one surface compared to the other two studies which considered the whole interior. The study was made according to a response surface matrix (CCC), for three parameters and four replications. All runs were made randomly to have a better result without any noise, see Appendix 5 for further details.

The output was analysed with a regression model in order to find coefficients for the parameters which can be used to predict impact of the chosen parameters.

Parameters

15 different cylinders, with different radius, created through rapid prototyping was used for the study. They were painted with different lightness and colours to get all variations needed. To know how double curved surfaces reflects, one sphere was used also. The reason for choosing cylinders for the study was that it was necessary to try different radius on the surfaces, and cylinders were the forms which were easiest to control.

The lightness, glossiness and radius parameters were chosen to analyse the form and material properties, see table 9.

Table 9: Investigated parameters for luminance and glare size

	-α	-1	0	1	α
Lightness	0	25	50	75	100
Glossiness	10	25	50	75	90
Radius (mm)	10	50	90	130	170

The measurements taken for this study was the maximum luminance and the size of the glare for each setting.

Set up

One of the cylinders was placed in the middle, between the photospectric camera and sunlamp in order to create the half angle for creating the specular reflection, see figure 21. The sunlamp was set to the maximum level, for a worst case scenario. As this study was focused on single surfaces and not performed in a car environment, it was decided to perform the test in complete darkness. This way the materials only reacted to the sun lamp and not interact with a background luminance which does not cohere with the luminance inside of a car.

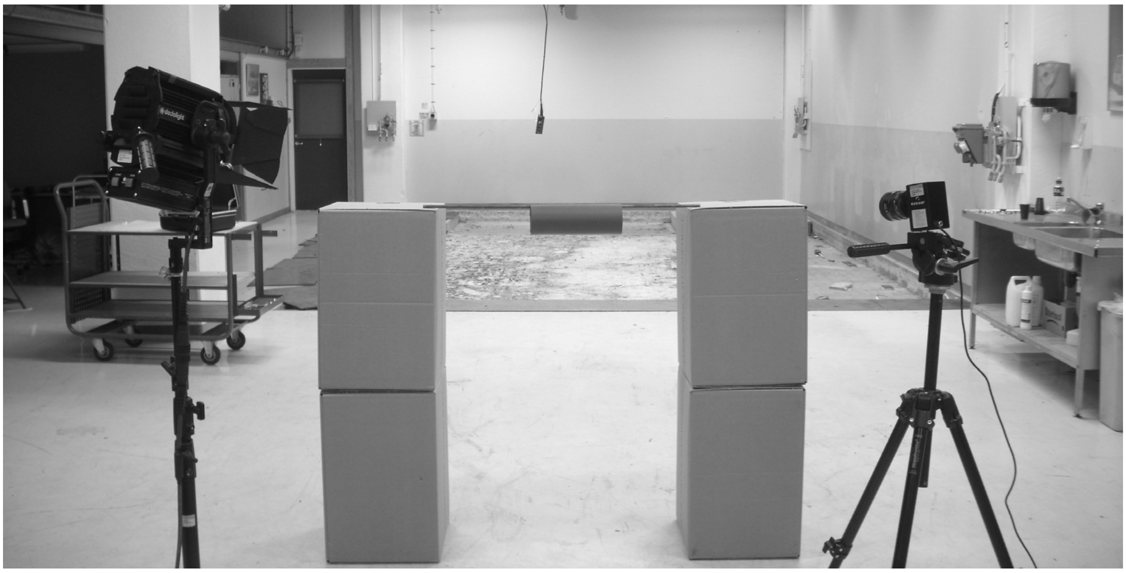

Figure 21: Set up of cylinder study

Procedure:
Each setting, according to the response surface matrix, was a cylinder, see figure 22. When a run was randomly picked, the cylinder for that run was placed for measurement. Markings had been made to be sure that the cylinders were all on the same place.

When a measurement had been taken, a new run was picked and measured. This was done until the whole matrix has been measured four times, for more valid results. Since the cylinders were of different sizes, there was a need to redirect the photospectric camera a little, to get the whole glare area within the picture.

Figure 22: Cylinders and sphere used for study

5. Results

In this chapter, all data and measurements collected from the different methods will be presented.

5.1 Research

The research resulted in an understanding on problems that can occur with direct reflections in car interiors. It also helped to decide what type of studies were necessary to perform in order to create a method to analyse reflection issues.

5.1.1 Customer complaints

“Brushed aluminium trim on dashboard and gear lever console catch the sun and reflect it into driver’s vision. Looks nice but poor design from a practical and safety standard.”

“We suffered frequent temporary blindness because of the very pretty but impossibly shiny chrome trim that’s all over the instrument and gear panels.”

These are two of the comments found which summarise the problems with reflections in the interior. It is clear that the reflections are causing problems for the driver as they are complaining on getting blinded by the reflections and also questioning the safety of using such glossy materials.

All complaints were summarised according to the complained area, as seen in figure 23. Each number stands for how many customers were complaining on that area of the interior. This result worked as a base to decide which areas of the interior would be important to analyse. For example, the gear shift area was not thought to be a problem from the beginning but resulted being the single part which was complained at the most, with 16 complaints. For all comments see Appendix 6.

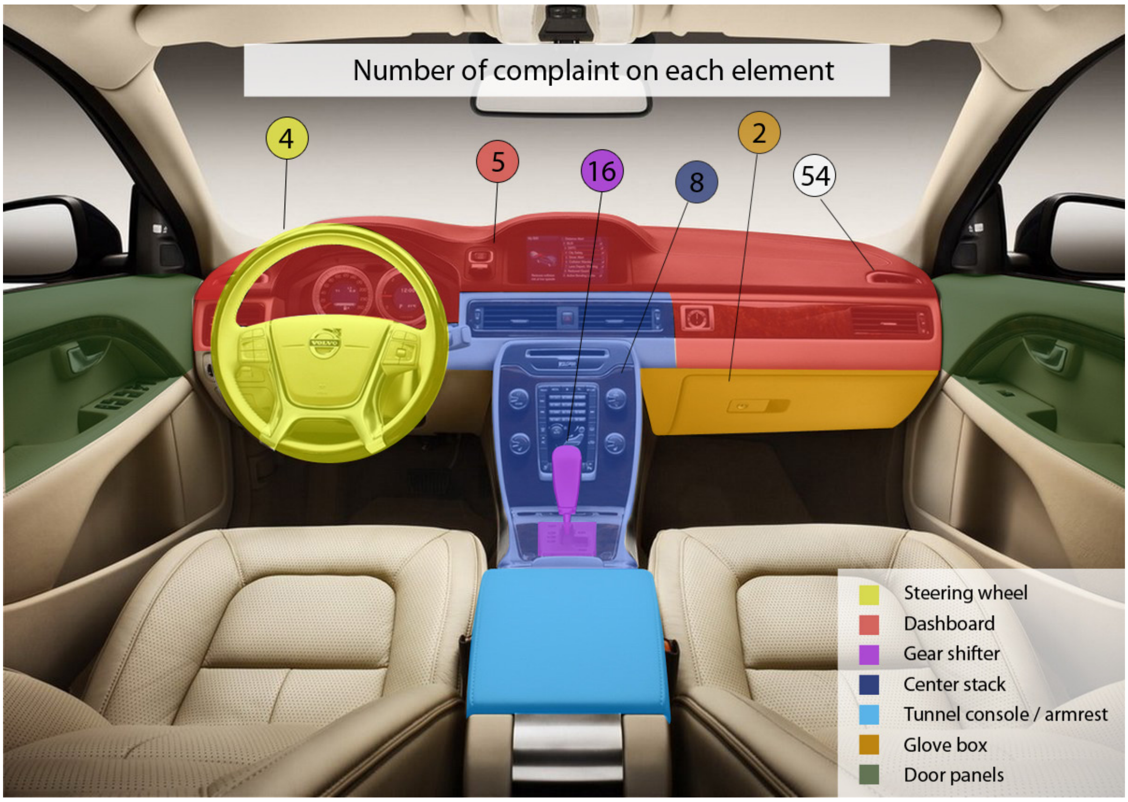

Figure 23: Number of complaints on interior elements

5.1.2 Questionnaire

What was found in the results from the questionnaire was that the respondents were rating the reflection as worst on the dashboard, centre stack and steering wheel. Figure 24 shows the percentage of respondents who rated on each cluster of the Volvo scale. It might not seem much looking at the figure, but having 7-8 % of the respondents saying that the reflections are four or worse at the dashboard is a problem considering the total customer number which are affected.

The comments of the respondents were summarised by a KJ-analyse. The three major groups of comments were; annoyance of reflections on windscreen (Veiling glare), direct reflections from details in the interior and also the opinion of dark interiors being better to decrease reflections than light interiors.

As both the customer complaints and the questionnaire were showing similar results, the surfaces to analyse in the studies were chosen. They were the lower and upper part of the centre stack, and the deco panel.

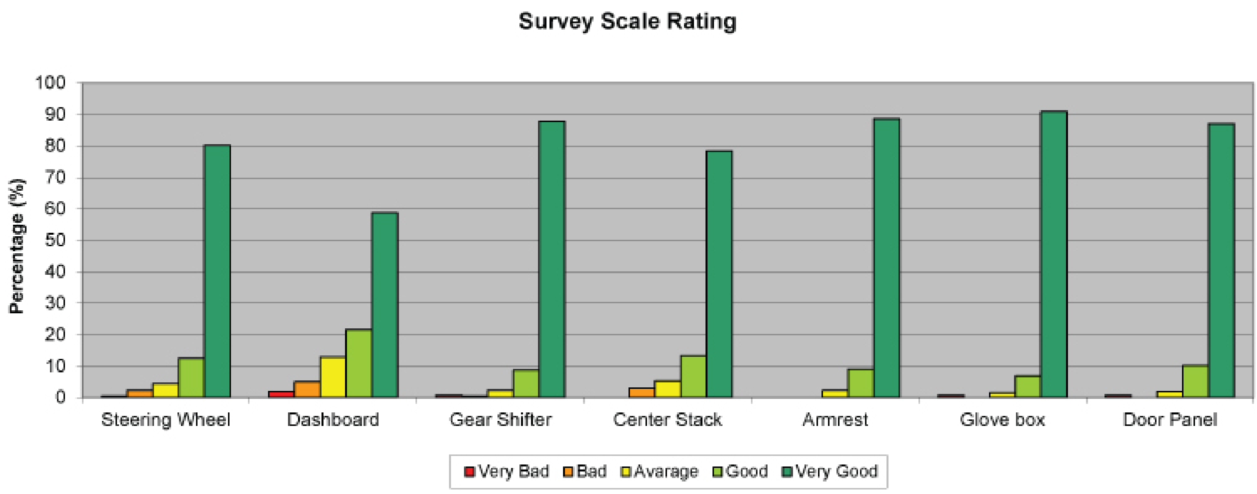

Figure 24: Percentage of each rating according to Volvo scale

5.2 Benchmarking

According to the benchmarking study which was done between model S80 and five other cars which are competitors to the S80; the placements of the reflective surfaces are very similar as can be seen in figure 25.

Even though they have different wooden patterns, and different base colours on the surface, all the competitor cars include a long and reflective deco panels. Moreover, to maintain the consistency along the interior, they add the same reflective materials to the other parts of the car such as centre stack or door panels. Another interesting finding is the small details on the steering wheel. All the brands preferred adding little metallic surfaces along it.

Figure 25: Benchmark of (1. Volkswagen Passat 2012, 2. Mercedes E, 3. Lexus GS, 4. Acura RL, 5. BMW 5 GT

5.3 Laboratory studies

What we found from our studies were the effect coefficients from the different parameters, on how they affect the luminance and glare size, reflected from surfaces. Here we present the main results found throughout the three studies performed.

5.3.1 Luminance dependency in car interior

The luminance dependency experiment was conducted according to the experiment plan, see appendix 3, where maximum luminance and background luminances on the different surfaces were measured. The data was analysed with the DoE, getting the effect of each parameter and the effect of all parameter relations, table 10.

Table 10: Effects in magnitude order for each analysed surface

Centre Stack [1]		Gear Shifter [2]		Deco Panel [3]	
Panels [C]	134,3	Lightness [B]	56,0625	Panels [C]	234,875
B x C	39,2	BxC	46,3125	SunPos. [A]	67
A x B	23,4	A x B	34,6875	Lightness [B]	58,875
A x C	22,6	SunPos. [A]	30,3125	B x C	54
A x B x C	13,6	A x B x C	12,8125	A x C	27,375
SunPos. [A]	13,7	A x C	12,9875	A x B x C	8,5
Lightness [B]	4,6	Panels [C]	7,1875	A x B	0,375

The effects showed that for the centre stack and deco panel area, it is the panel change which has the largest effect for the luminance reflected. For the gear shifter it is the lightness of the car, but this value is probably a false value. The reason for this false value is that two cars were used to be able to change interior lightness quickly, and the two cars had different gear shifters making that measurement skewed.

To be able to know whether the effects are of significance, it is necessary to analyse the effects against a normal distribution curve. Effects which are insignificant should follow a normal distributed curve while significant effects should deviate from such curve. Figure 26 shows the normal probability plot of the deco panel area. It is clear from the plot that there is only one effect deviating, which is the effect of panel type, meaning it is the only effect of significance.

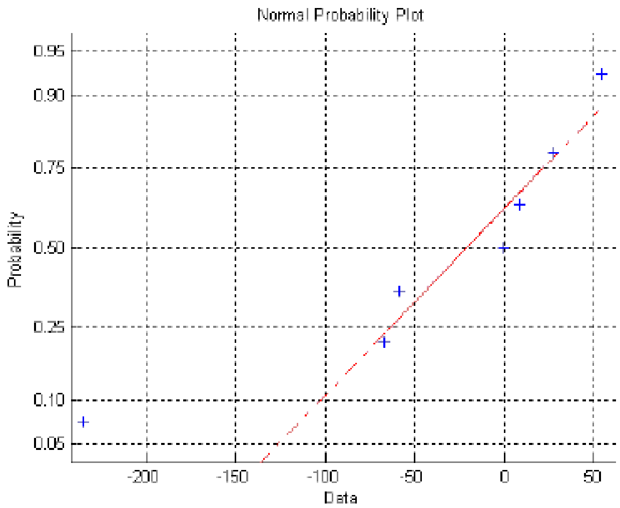

Figure 26: Normal probability plot for calculated effects in deco panel area

Finally, one can see in figure 27, how the parameters are affecting the luminance in both the deco panel (Right D) and top centre stack (Mid CS). What it shows is that the luminance is similarly dependent on the panel type used. The difference is that the area around the deco panel seems to have larger effect on the luminance with different sun position and interior colour. For all data and plots from this study, see Appendix 8.

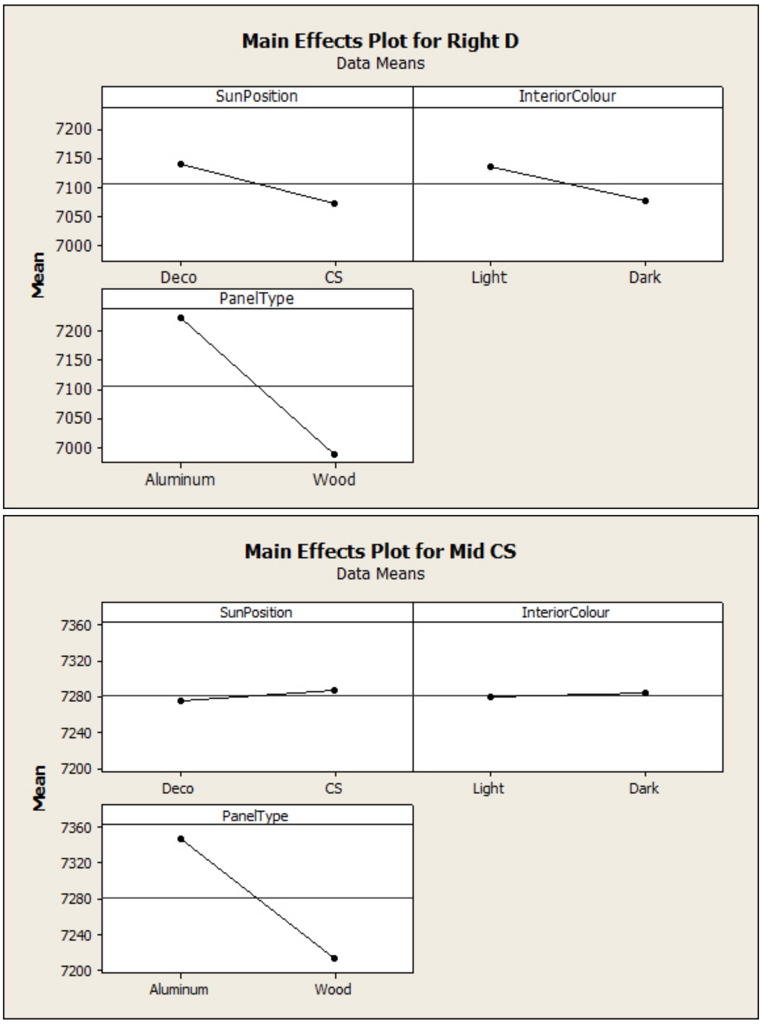

Figure 27: Main effect plot for the deco panel area (top) and Centre stack (bottom)

5.3.2 Background Luminance dependency

How the background luminance was dependent on the parameters was simultaneously found in the study of luminance dependency. The effects calculated are seen in table 11.

Table 11: Effects in magnitude order for each analysed surface

Centre Stack [1]		Gear Shifter [2]		Deco Panel [3]	
Lightness [B]	51,37	Lightness [B]	57,06	Panels [C]	225,3
B x C	27,12	SunPos. [A]	24,19	SunPos. [A]	132,7
A x B x C	9,87	BxC	21,94	Lightness [B]	38,5
A x C	8	Panels [C]	14,94	B x C	7,2
SunPos. [A]	7	A x B	8,44	A x C	5,5
Panels [C]	2,25	A x B x C	8,31	A x B	1,8
A x B	0,62	A x C	2,69	A x B x C	1,5

Here one can see that the lightness of the interior affected the background luminance much more than it affected the maximum luminance. So even though the lightness of the car might not affect the reflection itself, it changes the overall lighting environment inside of the car which is related to the contrast differences between reflecting and other surfaces, thus also altering the perception of the reflection. As before, the values from the gear shifter are not precise due to different gear shifters, but the background luminance is less sensitive to that as it is the average luminance of the whole analysed area. How the different parameters affect the background luminance for the different areas can be seen in appendix 8. Since the background luminance should be averaged over the whole visual field, we estimated the background luminance in the car interior by averaging all of our measurements on the different areas, resulting in the plots in figure 28, showing that the background luminance is decreasing with lightness, and when changing panels.

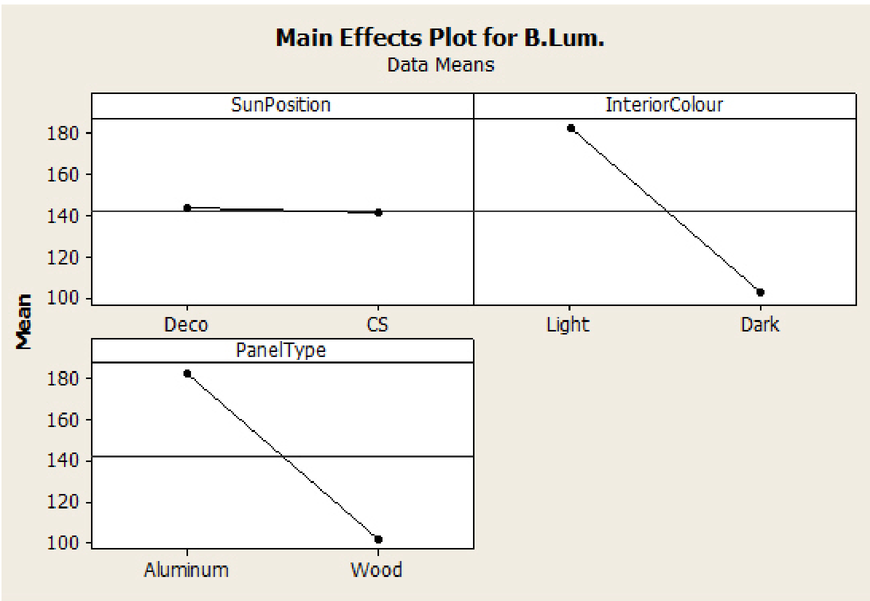

Figure 28: Main effect plot for average background luminance

5.3.3 Ratings on perceived reflections

32 ratings were taken from all participants on how the light and reflections were perceived, with help of the Volvo scale. Also, comments from the participants were documented and grouped according to a KJ-Analysis, see appendix 9.

As the study was set up as a DoE, it was possible to perform a conjoint analysis on the participants' rating, to see which parameter was affecting their rating the most. The effects of each parameter were calculated and plotted in the same manner as for the first study, from all participants' ratings, resulting in figure 29.

What can be seen here is how the sun power has quite large influence in the participants' ratings, but that parameter is nothing that could be improved from Volvo's perspective. The parameters which are connected to the interior such as interior lightness and panel type, have different characteristics. According to these results, the interior lightness affects the ratings very little compared to the panel type which has the largest rating different with better ratings for wood than for aluminum. The sun position parameter shows that the closer the glare source, the more annoying the participants are perceiving it.

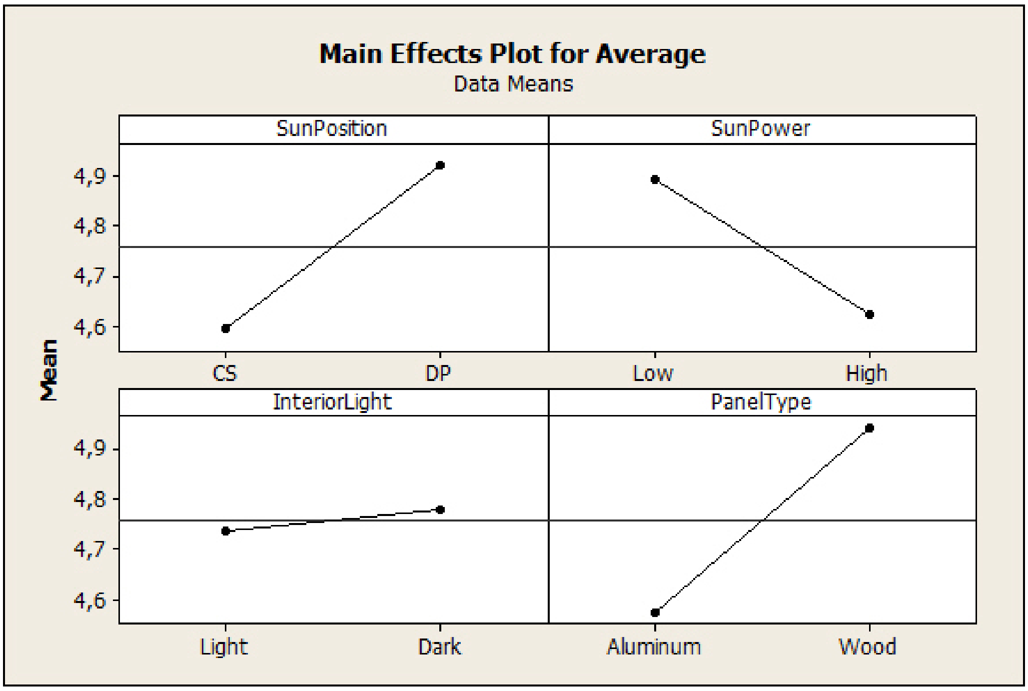

Figure 29: Main effect plot for average subjective rating

If one would compare all four different car settings, according to lightness and type of panel it shows that the wooden panels are receiving the better ratings, with light interior as the best and dark as second, while the aluminum panels seems to be a lot worse, see figure 30.

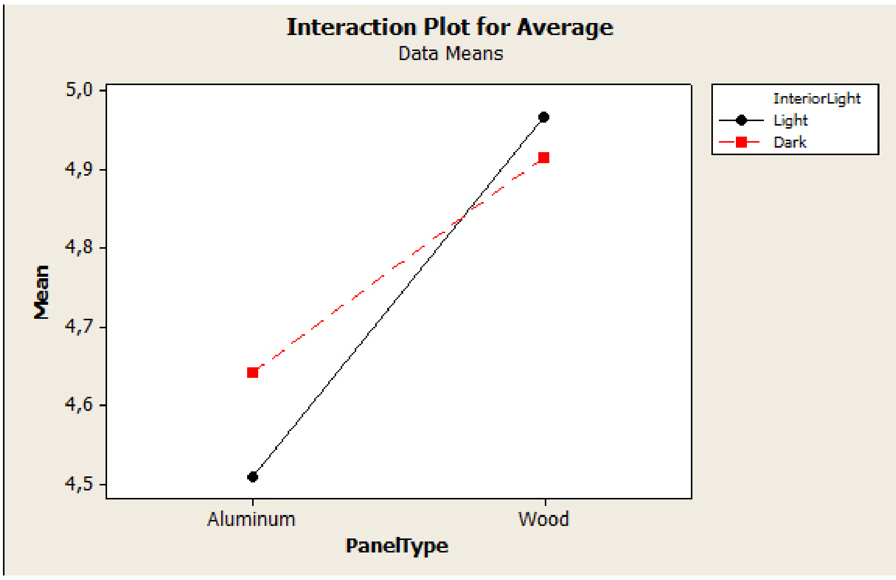

Figure 30: Interaction plot of panel type and interior lightness

Even though the DoE showed which parameters were affecting the ratings it was hard to draw any larger conclusions from that. It was necessary to do an analysis which shows the changes more concretely.

As the Volvo scale was used in this study, a rating under five was discomforting , while a rating from 7 upwards is an unproblematic environment. This is why the data was grouped together to three bins, 1-4 (bad), 5-6 (ok) and 7-10 (aim). These charts were then analysed by looking at how the ratings were shifting upwards or downwards when changing settings, an example can be seen in figure 31.

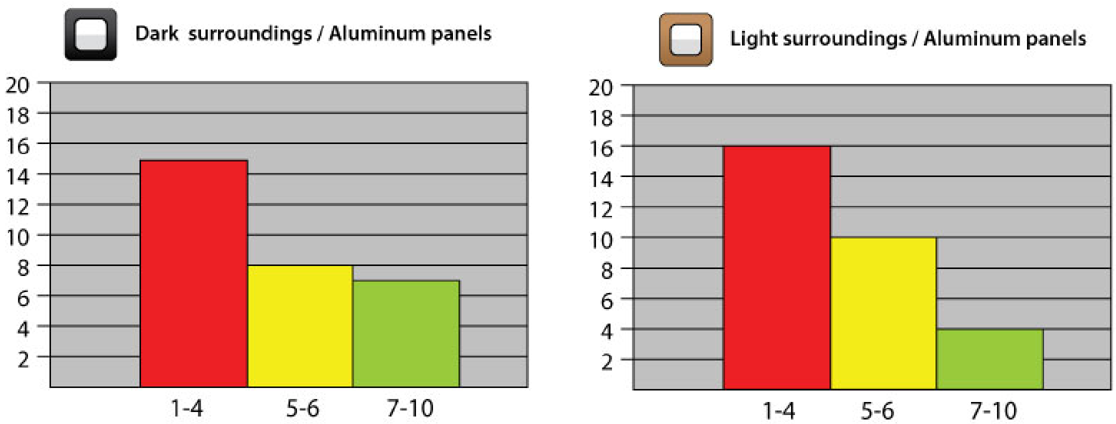

Figure 31: An example of rating shift changing interior colour. Here three participants changed their rating to a lower value (-3).

Table 12 shows how many participants changed their ratings across the bins and in that way, see whether the ratings are becoming significantly better or worse. The table shows that when the light power increased, there were more participants giving worse ratings for wooden panels then for aluminum panels. Also we can see that the overall rating, changing wooden panels to aluminum, were decreasing a lot.

Table 12: Shift in ratings across the groups

	Dark Wood	Dark Alu	Light Wood	Light Alu
Low to high light power	-10	-8	-16	-7
Light direction far from driver to close	-6	-10	-16	-11
Driving compared to looking at CS	-3	-1	-7	3

	Dark Interior	Light Interior
From wooden panel to aluminum	-15	-20
	Wooden panel	Aluminum panel
From dark to light interior	-2	-4

Research on theory showed that the perception of light and reflection was very individual. This fact was empowered when analysing the comments received during the study. The number of participants giving positive or negative comments, against a certain setting, were almost equally divided, an example is shown in table 13. For the rest of the data and comments, see appendix 9.

Table 13: Negative, Neutral and positive comments on aluminum panels

Comments on Aluminum panel		
Negative	**Neutral**	**Positive**
Aluminum worse	Aluminum spreads light.	Aluminium in dark interior is good. Not as sharp reflection.
Aluminum gives sharper reflection.	Aluminum spreads the light more.	Aluminum spreads the light better, more comfortable.
Aluminium have sharper reflection.	Aluminum spreads the light.	Aluminum spreads more, "warmer" reflection.
Aluminum in dark is the worst.	Aluminum lights up.	Aluminum panels better, spreads the light.
Aluminum spreads light everywhere, a bit more annoying.	Aluminum reflects more.	Aluminum does not reflect as sharp as wood. More even light.
Aluminum glares more.	Aluminum more reflective	Aluminum reflects softer.
Aluminum gives very strong reflection, prefer wood.	Aluminum scatters the light.	Aluminum better in light interior.
Aluminum reflects in the eyes.		

5.3.4 Luminance and glare size dependency on surfaces

The data collected is here visualised in DoE plots, figure 32. It shows the main parameter effects and the interaction effects affecting the luminance of the surfaces. Looking at the main effects, it is clear that the only parameter which is actively affecting the luminance is the gloss. The graph shows that with higher gloss the luminance increases. It seems that neither of the interactions have any larger effect on the luminance reflected.

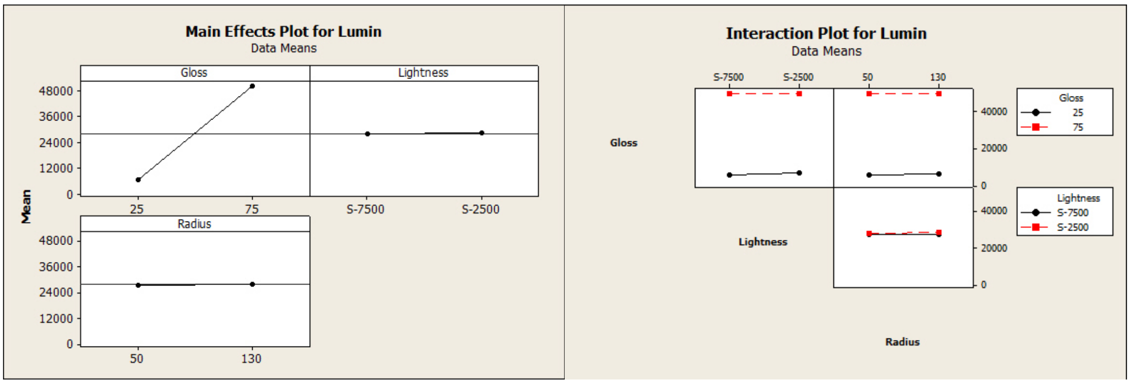

Figure 32: Main effect (left) and interaction (right) plot for the luminance

The same plots can be seen for the glare size in figure 33. The plots show that the three parameters are affecting the glare size in different ways. With increased lightness and radius the glare size becomes larger, while with higher gloss the glare size is decreased. According to the interaction graphs, the size of the glare is more sensitive for lightness and radius when the gloss is low compared to high. An example of the gloss-glare size dependency is visualised in figure 34.

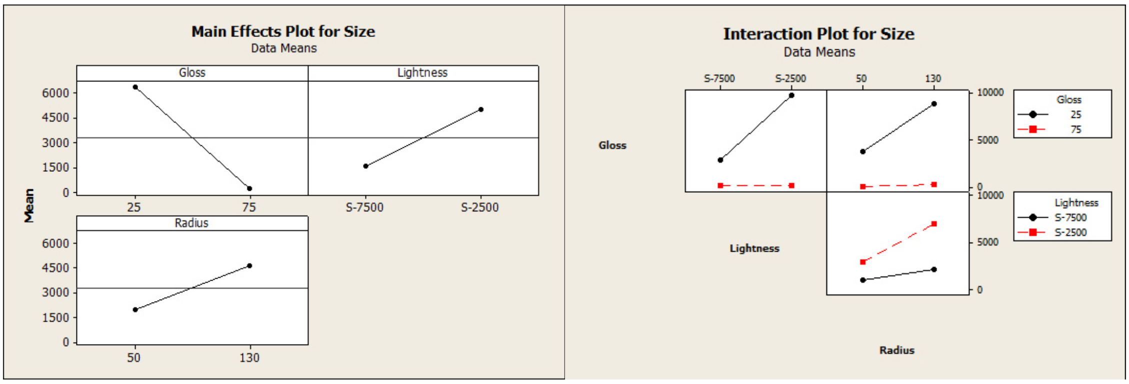

Figure 33: Main effect (left) and interaction (right) plot for the luminance

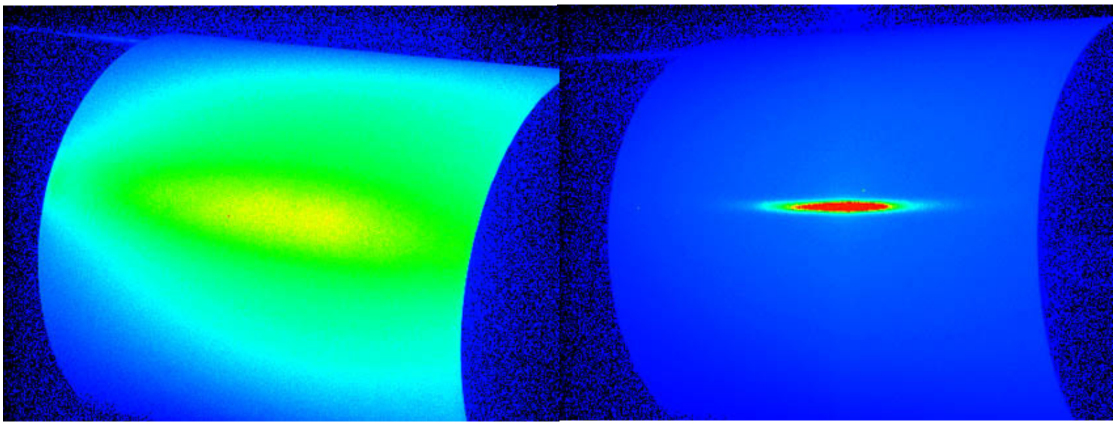

Figure 34: Glare size depending on gloss. Gloss 25 (left), Gloss 75 (right)

As there were no time to make a test of double curved surfaces we decided to try one sphere and see whether it was better or worse than a single curved surface. In figure 35 one can see a comparison between a single curved surface and a double curved surface, with 50 mm radius in both directions, showing that the glare size becomes significantly smaller when using double curved surfaces . For all data and measurements see appendix 10.

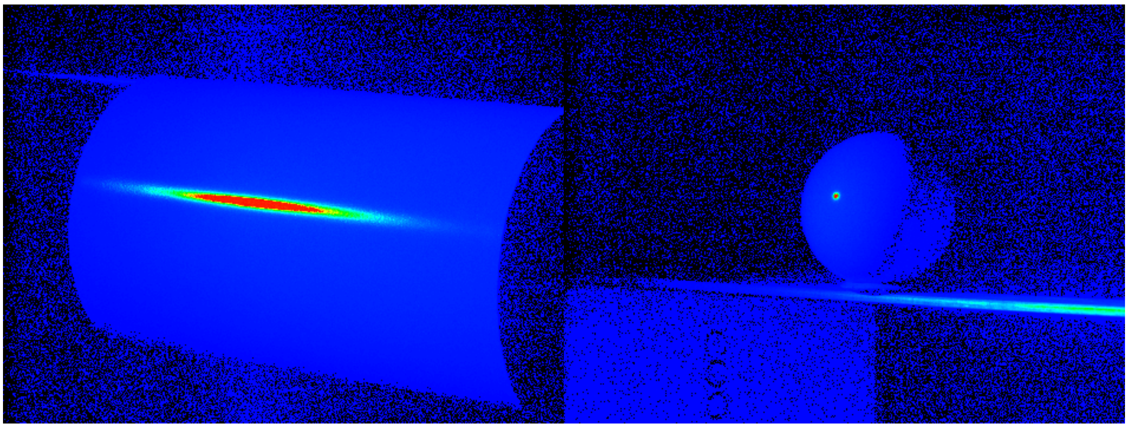

Figure 35: Comparison between single curved and double curved surface

The last step of the studies was to summarise all data into a data model where one could calculate and predict the luminance and glare size for a certain setting of gloss, lightness and form. For this reason, the data was analysed with a response surface. The response surface gave us coefficients for both luminance and glare size, which could be used to predict these outputs.

All measures from the study were transformed to logarithms before the response surface analysis, to get valid numbers. The equation for the luminance and the glare size was put together with the help of the coefficients from the analysis, given by Minitab, using uncoded units, see table 14, and presented with an excel sheet. In the Excel sheet it is possible to write the values for each parameter (gloss , lightness and radius) and get the predicted luminance and glare size. To understand the implication of the luminance and glare size, it was decided to also present the predicted perception of those values with the help of the UGR-equation. This way, one gets a direct indication whether the setting is okey or not.

Table 13: Response Surface coefficients for luminance left, size right

Constant	3,64796
Gloss	-0,0392413
Lightness	0,0141694
Radius	-0,00619495
Gloss*Gloss	0,000239347
Lightness*Lightness	2,02354E-005
Radius*Radius	4,85572E-005
Gloss*Lightness	-0,000219796
Gloss*Radius	2,12563E-005
Lightness*Radius	0,000019005

Constant	2,43328
Gloss	0,054544
Lightness	0,00585173
Radius	0,00716034
Gloss*Gloss	-0,000367647
Lightness*Lightness	-4,56696E-005
Radius*Radius	-3,46939E-005
Gloss*Lightness	-3,28686E-005
Gloss*Radius	-1,14814E-005
Lightness*Radius	8,32046E-006

5.4 Data model

With the coefficients found in the previous study, a data model was constructed to be able to evaluate reflections in a car interior. It was done by joining our coefficients for calculating luminance and glare size with the UGR-equation (see chapter 2.2.3). Two models were created, one basic for quick evaluations of materials and one advanced where it is possible to analyse a whole interior.

The basic model, see figure 36, can estimate the luminance reflected and the glare size of one material sample at a time. It also returns a UGR-value for a worst case scenario where the glare source is 1 m straight forward. By testing different material properties one can find which combinations are the best regarding luminance, size, and annoyance. The dissadvantage is that you can only test one material at a time.

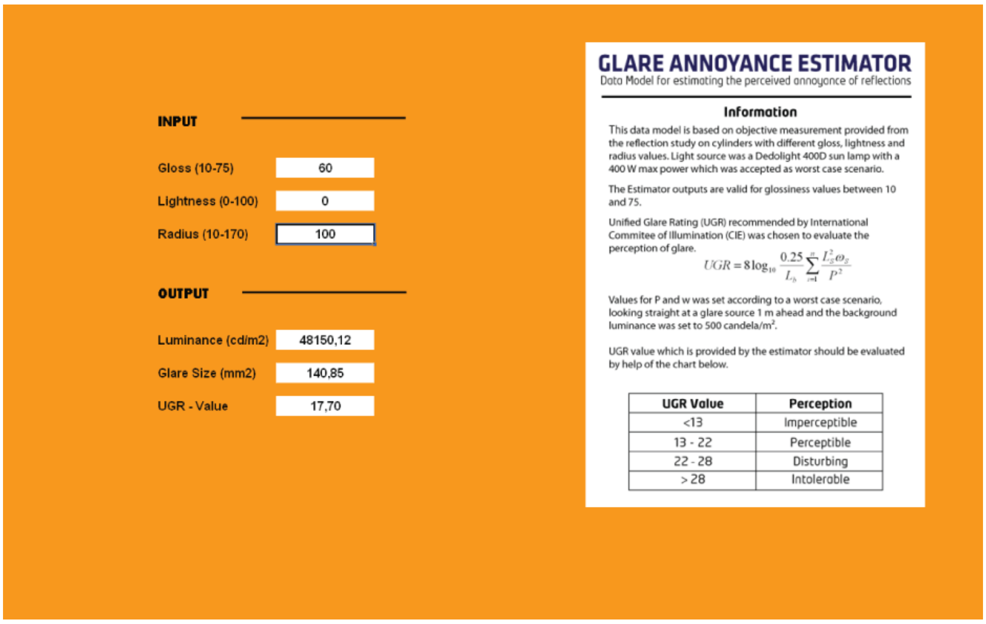

Figure 36: Basic model for glare estimation

The advanced model, see figure 37, is created to have the possibility of evaluating a whole interior with many glare sources. The difference with the first data model is that it needs more data compared to the basic model. The background luminance needs to be approximated, and the distances to each surface has to be known. If this data is available then it is possible to enter all inputs to the model and it will return luminances and glare sizes for each glare source, and also an approximation for the UGR-value regarding the whole interior.

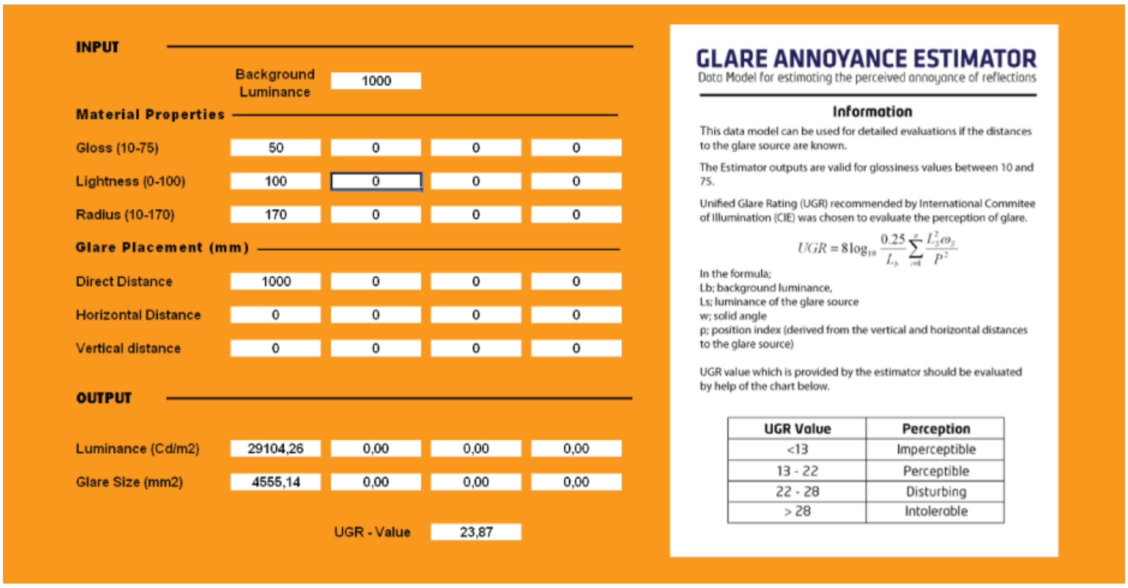

Figure 37: Advanced model for glare estimation

6. Analysis

In previous chapter, all data collected throughout the project was presented. This chapter aims at analysing and discussing the data collected against our own experience and knowledge.

6.1 Research conclusions

At the start of the project, it was necessary to know how large the issue of reflection was and in that case, where the problematic areas were. What we found was that the direct reflections were an occurring problem and that people were complaining on different areas of the interior. Apart from the expected problematic areas, such as shiny details and centre stack, we found that a lot of drivers were complaining on the area around the gear shifter. The area around the gear shifter is often decorated with shiny surfaces and panels, causing light to be reflected upwards against the eyes. Also, a surface in that position might be able to catch the light from more angles than surfaces placed at the dashboard.

6.2 Experiment conclusions

Our aim from the start was to investigate the issue of reflections from different perspectives, with both objective measurements and subjective data. We decided to create two of the studies, one measuring luminance and one taking subjective ratings, in the same way, to be able to see whether the measurements and the subjective ratings were similar.

Glare size relation to annoyance

We could see that the results from the two first studies were pointing in the same direction. According to the first study, the largest amount of luminance was registered for the aluminum panels. We could also see that the size of the glare source was considerably larger for the aluminum panels compared to the wooden panels, see figure 38. In the perceived reflection study, the participants were complaining on the same issue, stating that the aluminum panels felt more annoying due to the larger glare source. Of course this can be explained by different finishes on the aluminum and wooden panel, but as we would see further on in the project, there is a dependency on gloss and glare size also.

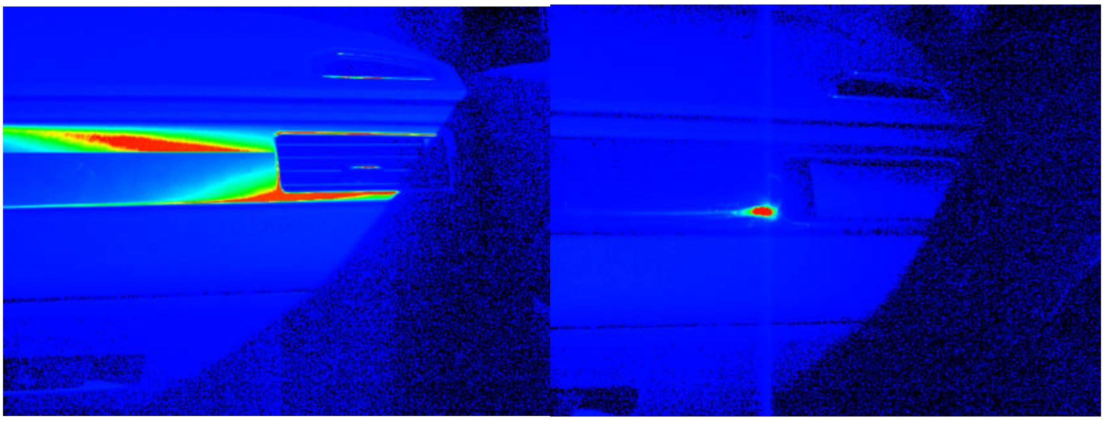

Figure 38: Differences in glare size, aluminum (left), glossy wood (right)

Interior lightness related to annoyance

The lightness of the interior did not show any larger differences regarding the measured luminance or the ratings given from the participants. Even though the ratings were similar for both light and dark interior, the participants were commenting on that the reflection actually felt different in the cars, but were not able to explain why. We believe that this sensation of difference was because of the contrast ratio, between the glare source and surrounding surfaces, beeing larger in the dark interior then the light interiors, a fact that we could see when looking at the background luminance dependency with the interior lightness.

Glare source placement

Another comment that was brought up by participants during the subjective study was that, the participants felt that the glare source was more annoying when they had it in their peripherical visual field compared to when they had in the centre, (looking outwards compared to looking at the centre stack in our study). We know from theory that peripherical glare occurs, but this awoke the question whether it is better to have glare sources in the visual field where the eye can adapt to the luminance then glare sources which are on the outskirts of the visual field?

The glare annoyance estimator

From the results of the luminance dependency and perceived reflection studies, we found that high gloss might not be the only thing affecting the perceived reflection. The size of the glare a surface reflects might have the same or more effect on how drivers perceive the reflection, meaning that a lower luminance with large glare size might annoy as much as a high luminance with small glare size.

At the gloss, lightness and radius study we found that it would be hard to set any specific threshold values for the different parameters analysed. We found that the luminance was only depending on the gloss of the surface, while the size of the glare depended on all three parameters. We believe that by putting threshold requirements for the parameters one might many possibilities regarding the use of glossy materials in the interior. We say this based on the knowledge that by choosing a proper radius or lightness of the material, one can keep the reflections within tolerable limits.

The calculator for the luminance and glare size needs to be used with caution. Even though it predicts the values for luminance and glare size, it is not an exact formula. It works well for most values for the parameters, but it might get inaccurate against the extreme points for each parameter. The strength of the calculator is that it gives the opportunity to quickly access different materials in a reflection perspective.

The UGR equation, also used in the calculator, usually have more parameters needed than just the glare size and the luminance. Usually the background luminance and the position of the glare source is needed. In the case of the calculator we decided to put the background luminance and position of the glare source with fixed values. An average from the background luminances derived from our studies, and a position in the centre of the visual field, a meter in front of the observer. This will give an approximation of a worst case scenario for the equation also.

Since it was a simplified model, we decided to create an extra calculator where one could put in all needed parameters. By doing this it is possible to analyse a whole interior with many glare sources, but it needs more information and measurements from car interiors, see figure 39, or appendix 11 for larger image. This might become useful further down a development project to analyse the position of reflecting materials.

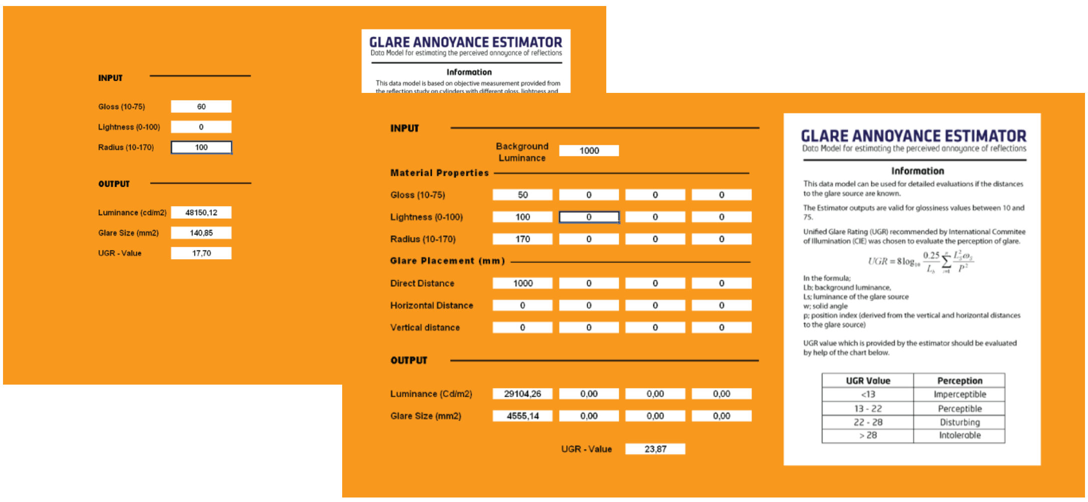

Figure 39: Simplified model (left) and Advanced model (Right)

7. Discussion

There have been many parts of the project where decisions have been made which drove the project to one or another direction. We will discuss here, the reasons for some of our decisions and for parts of the project which could have been performed differently.

7.1 Theory

When performing literature studies and research about gloss and visual perception we noticed that much of the research conducted in this area was performed with computer-based models, and not with experiments performed in real situations or with actual persons. We felt that in our case it was a necessity to do our studies with real participants and using real cars since the perception of the reflection is so individual.

Research performed on glare has also a clear focus, which is glare sources above the line of sight. The reason for this is due to that this type of research often is performed for architecture and light design. Since situations where the glare source is under the line of sight, are not that common, it was hard to find relevant research on this area.

Articles on the visual field while driving were focused on what a driver sees outside the car according the changing speed. There was not any information on how much a driver sees inside the car while driving and if the annoyance of reflections changes. It would be good to create a study were one investigates whether the percpetion of reflections changes according to speed or concentration.

7.2 Methods

The methods used in this project had its advantages and disadvantages. Here we discuss the consequences and results of each method

7.2.1 Customer Complaint

The gathering of customer complaints was done in the start of the project to try and get a picture of the situation and to find out what areas were creating disturbing situations. We made this search for complaints very wide and along different brands which ment that we had many different models which had very different interiors. But since the aim was to find which area in the cars were causing disturbing annoyance, we felt that it was still valid to look on different car models and brands.

7.2.2 Questionnaire

While collecting the data from the questionnaire, the respondents were asked to rate annoyance of the reflections inside the car by pointing out the surface of the reflection source. Since this study was held at the end of February, some participants had difficulties in remembering the surface where they get annoying reflections. This might also affect the ratings since there was no powerful sunlight in those days. Maybe it would have been better to do such questionnaire in a season when the respondents are exposed to the sun more and associate to sun reflections.

What we also noticed was that, it would be difficult to create questions relating the perceived reflection with the Volvo scale. We did though use it in the questionnaire to let the respondents rate their perceived reflections. But when it came to the subjective study we decided to modify the scale in order for it to fit better with the issue of reflection. The problem it had with rating reflections is that the words used for the scale are not compatible with explaining a sensation of reflection. A bad reflection is understandable, but how and what is a very good reflection? A scale going from "Not annoying" to "Very annoying" was instead used to make the scale more understandable regarding the perceived reflections.

7.2.3 Benchmarking

The reason for performing the benchmarking was to see whether different competitor cars were better or worse regarding reflections. The results might not have had a larger impact on the conclusions of the project but showed that a by working with reducing the reflection disturbance, it could be an area to differentiate and improve the Volvo cars against competitors.

7.3 Laboratory studies

We decided in the project that we would perform all studies on real objects and with user participation in the tests. The other way of doing it would have been to perform the measuring in computer based models which might have been a quicker method. The reason for us not doing this was because we thought that we might miss something by testing on a computer model.

With the decision of doing the studies on real cars, the order of the studies were clear. We wanted two studies analysing the whole interior environment (Study on luminance dependency and perceived reflections) both by measuring luminance and having drivers rate their perception, and also one study analysing single surfaces (Study on gloss, lightness and radius). This study order, made us decide for a sun direction which would be used for the studies from the start. Since the direction was an approximation to create direct reflections there might have been other angles causing more troubles. One can discuss whether it would have been better to find the most disturbing angle first, with a user study, and do the measurements afterwards. According to us, such order would have been very complicated to perform practically, and would only give the result on which angle was the most disturbing. More detailed discussions on different aspects of the studies are presented in the next part.

7.3.1 Set ups

For the studies, there was a need to have two cars which had the same interior design and elements but different base colours for the interior. However, because of the tight schedule and the limited options of the rental cars department at VCC, it was not possible to select exactly the same two cars. Instead, one Volvo S80 Sedan and one Volvo V70 Station were used to perform the study. There were two main differences between the two cars. As it can be seen in figure 40, two cars were identical for the front half in terms of design and the dimensions inside and outside. On the other hand, second half of the cars were totally different.

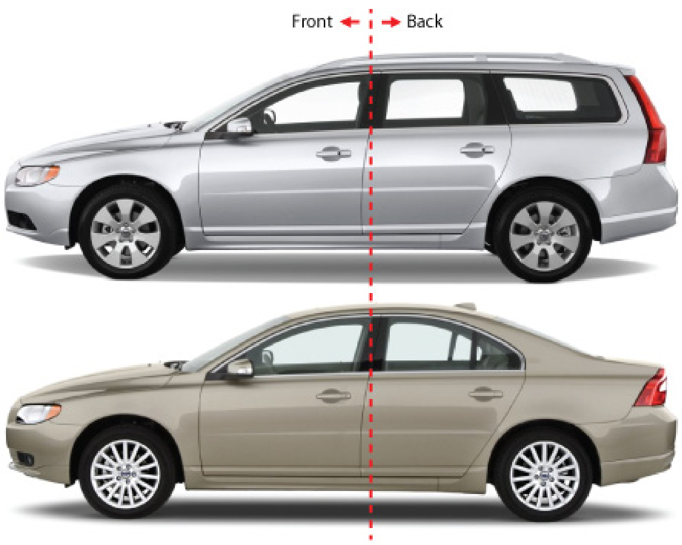

Figure 40: Differences between used cars

Because of the difference at the back half of the cars, the placement of the measurement camera through the back windows differed slightly concerning the distance to the selected target areas on the interior parts.

Another difference was the gear shifters. While one of them had a dark leather gear shifter, the other one had a transparent plastic gear shifter. This difference resulted in an unexpected luminance value on the gear shifter images which were taken by the photospectric camera. This is why we had some unexpected results on the luminance dependency study when we analysed the effect coefficients for the gear shifter area. It showed that, the lightness of the car had the biggest effect on the luminance, however looking at the pictures we noticed that it was the difference in gear shifter that was causing the strange effect coefficient.

Other than the cars, the camera itself had a very limited view field because of the type of lens used. That is why, it was a necessity to take separate pictures for all the three target areas for each run. The optimal would have been to be able to photograph and measure the whole interior at once, that would have given very accurate results and also been easier to analyse in a holistic manner.

7.3.2 Study validity

All studies were performed in a controlled environment, which could create different values compared to a study performed under real life conditions. On the other hand, providing the same environment for the experiment would not be possible because of changing weather and lighting condition outside.

During the subjective study we noticed that it was hard for the participants to rate the reflections. We believe that it might have to do with adaptation to the light, making it harder for them to perceive the differences created by the parameter changes. They also gave comments such as “This felt much worse”, but when they had to rate, it did not change dramatically. Maybe the Volvo scale is not adapted for these types of reflection studies.

The study of gloss, lightness and radius gave us the relation between these parameters, luminance and glare size. The study was very dependent on the surface treatment of the cylinders. There is always an uncertainty when different samples have to be painted with different gloss and lightness. The desired values for these parameters might not be met precisely, which might have an influence on the results. Still, the results showed quite clear and consistent trends.

One issue when analysing the data was how to measure the size of the glare. The software used did not have any tools for this so it had to be done manually, fitting ellipses to the glare. This was made many times to get a mean value which were stable. This uncertainty might have done so the response surface did not fit as good as wanted.

7.4 Result contribution

We feel that our study conclusion differs from what we have found in literature research. When reading about the reflections one can find subjects regarding different aspects of reflections but no research which includes all important parameters. We think that our contribution to already existing theory is that it is possible to unify material properties, such as gloss, lightness and radius, with luminance and glare size, and in the next step also with glare disturbance.

The data model created has a narrow span since it is only useful for the values analysed in the study. We believe that if it would be possible to increase the span of the parameters the model could be useful in other areas than car interiors.

7.5 Future work

What we feel is missing in our study is the effect of surface finish to reflections. A study which analyses the effect of surface finishes regarding luminance and glare size is something that might make the model even more useful.

As the model looks today, the estimation for annoyance is borrowed from the International Committee of Illumination (CIE). For VCC it would be a good idea to create a study to develop an own list for estimating the annoyance in a car environment, which for example could be connected to the Volvo scale. There might be a need to have stricter values for glare disturbance in a car since it influences the safety aspect.

8. Conclusions

After performing all the studies and analysing the results, we are able to answer our research questions that we aimed at the beginning which are;

In what way does the base colour of the car interior affect the luminance in the driving environment?

Our results from the studies showed that the luminance is not affected by the base colour of the interior. What is affected is the background luminance , which was very dependant on which base colour is used in the interior. The background luminance is not a problem by itself, but it can decrease or increase the contrast against surfaces with higher luminance, which can change the perception and increase the annoyance of the luminance.

What parameters affects the drivers the most regarding disturbing reflections?

According to the results from the perceived reflection study the parameters which affected the most were the type of panel used in the interior and the distance from the glare source to the driver. Why the type of panel had such large affect is hard to know but regarding the comments from the participants one possibility is the larger glare size created by the aluminum panel. As the participants where rating the car interior worse when the glare source was closer, one can conclude that it might not be optimal to put glossy surfaces close to the driver.

How do the reflections behave according to the glossiness, lightness, radius of the surface?

How the reflections behave can be divided in two parts, the luminance and the glare size. Our results showed that the luminance reflected from a surface is only dependent on the glossiness of the surface. The size on the other hand, is dependent on all three parameters. With increased gloss the size is reduced, with lighter colour and/or with larger radius the size increases. We also found that double curved surfaces creates even smaller glare sizes than a single curved surface with same radius.

Is it possible to predict the reflection caused by a surface with certain parameters to be able to compare concepts and material choices?

From the studies, we have plots showing how the luminance and size is depending on the analysed parameters. These plots can be used to analyse concepts and get a first notion of how good or bad a concept is, regarding luminance and glare size. The estimator that we developed can also work as an assessment tool to evaluate concept against reflections and glare. The next step to create requirements for reflections at VCC would have been to perform a study to find the ratio between glare size and luminance where drivers start to perceive annoyance and to create an own scale for annoyance estimation.

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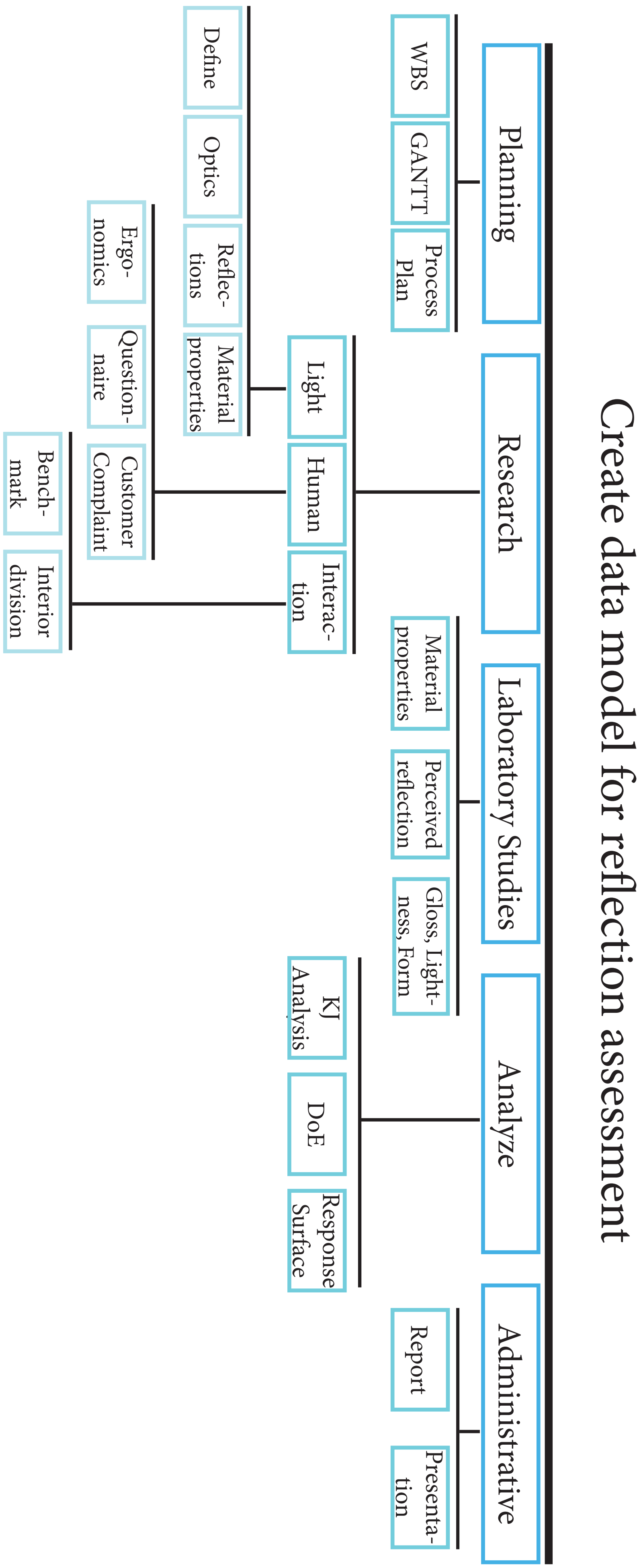
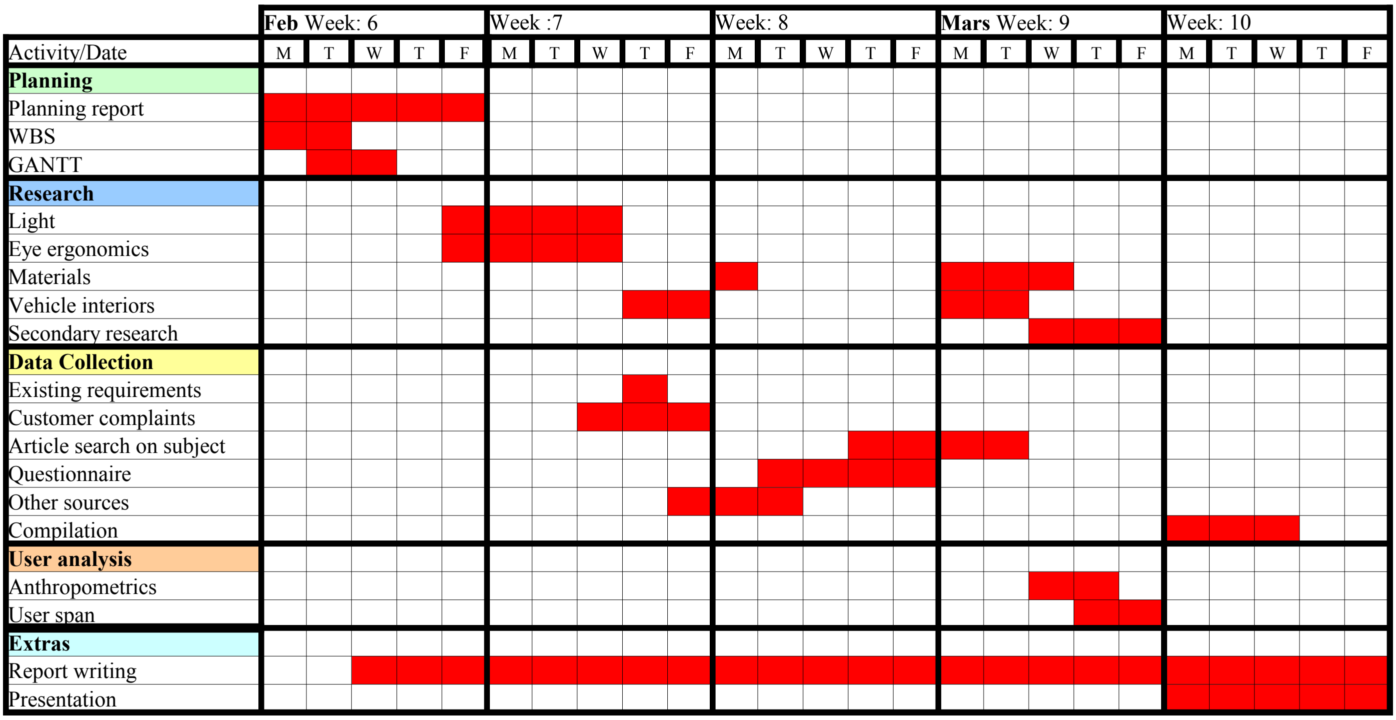
Appendix

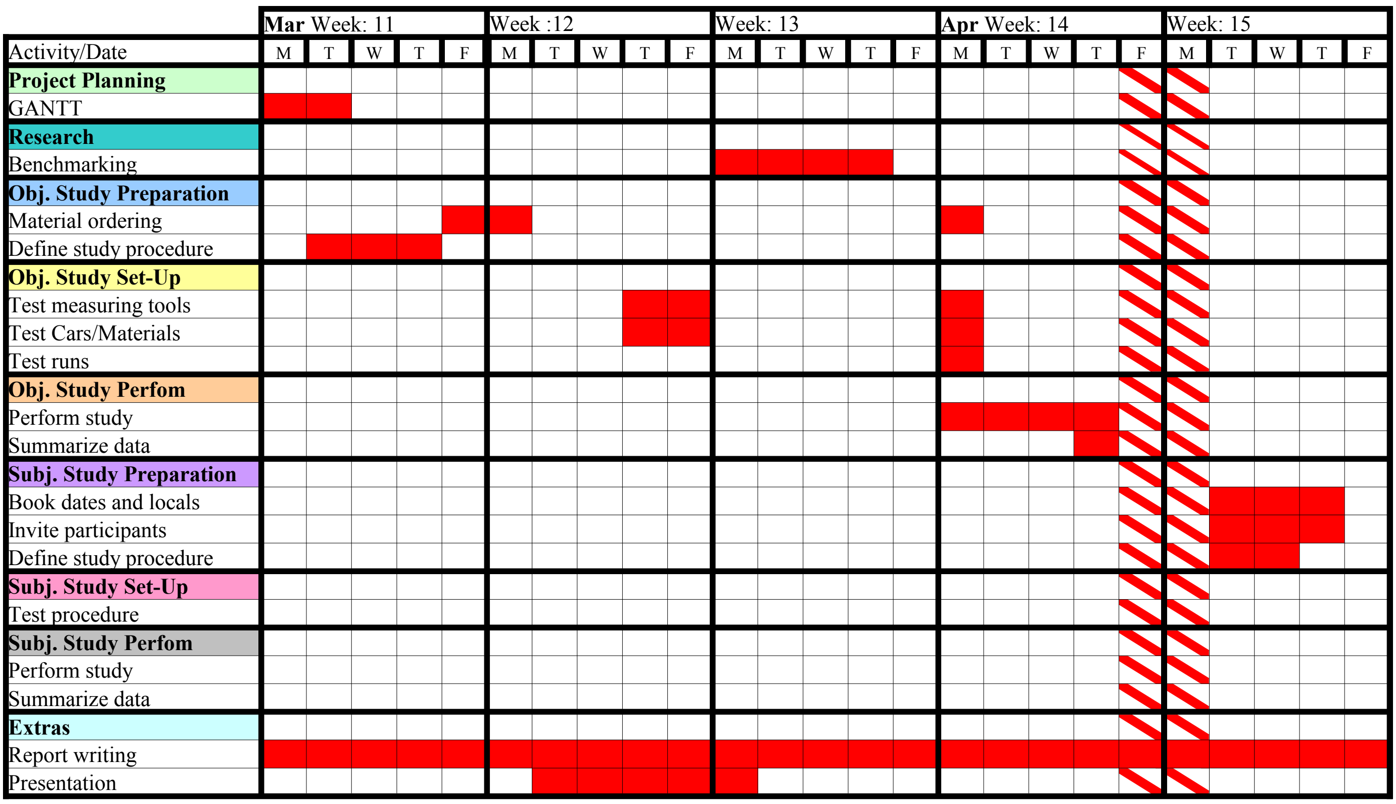
Appendix 1: Planning schedules
Appendix 2: DMAIC process description
Appendix 3: Study on luminance dependency
Appendix 4: Study of perceived reflections
Appendix 5: Study of gloss, lightness and radius
Appendix 6: Customer Complaints
Appendix 7: Questionnaire
Appendix 8: Study of material properties - Results
Appendix 9: Subjective study of perceived reflections - Results
Appendix 10: Study of gloss, lightness and radius - Results
Appendix 11: Glare estimator

Appendix 1: Project planning -WBS

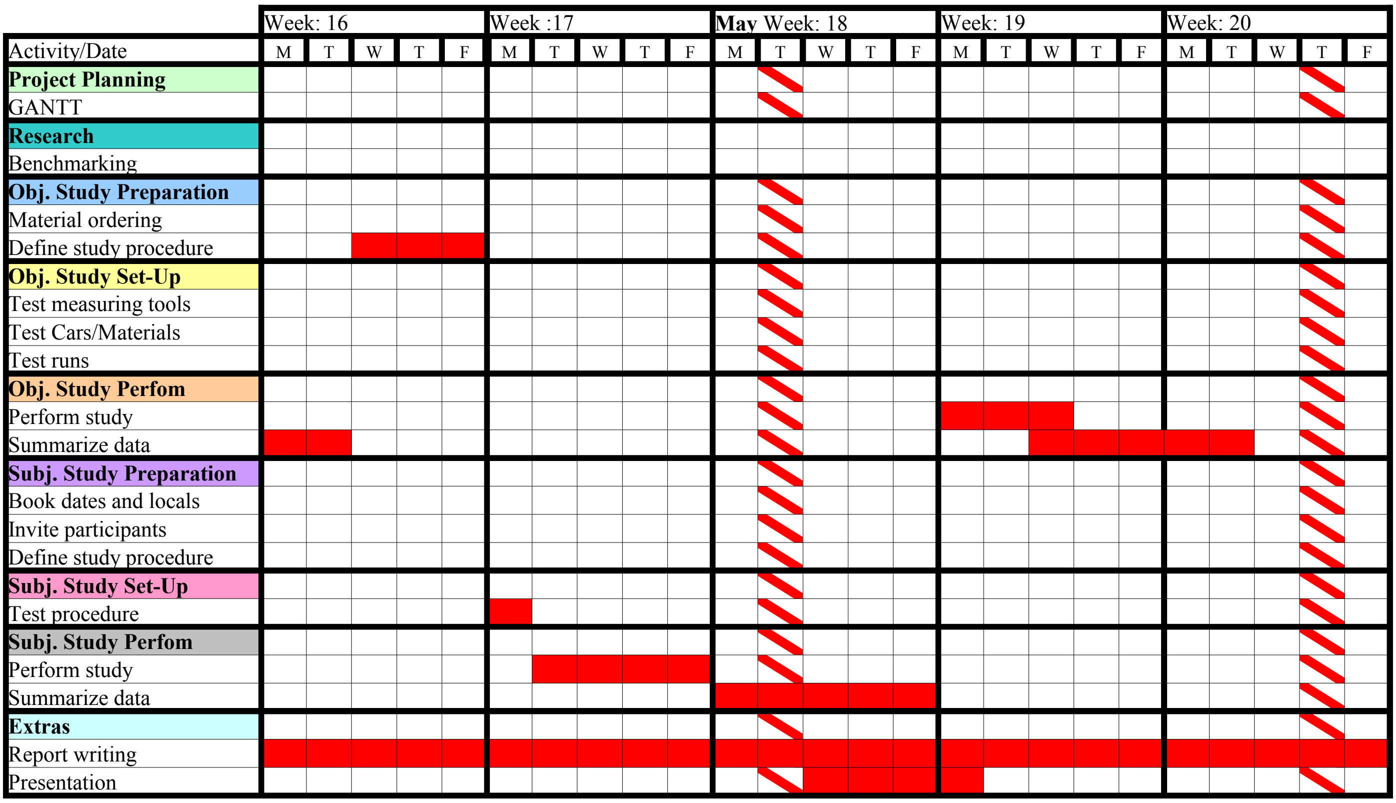


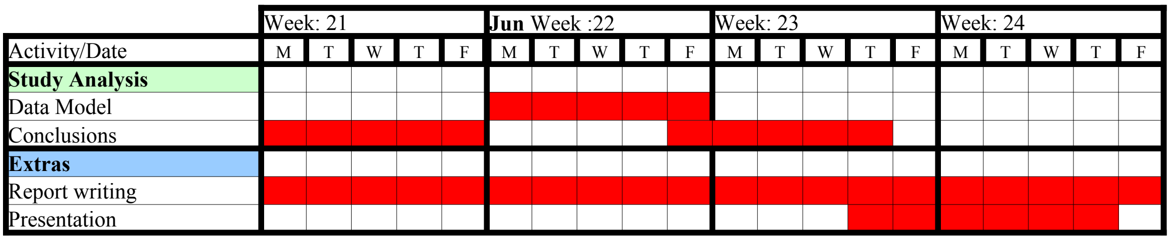
Appendix 1: Project planning -GANTT



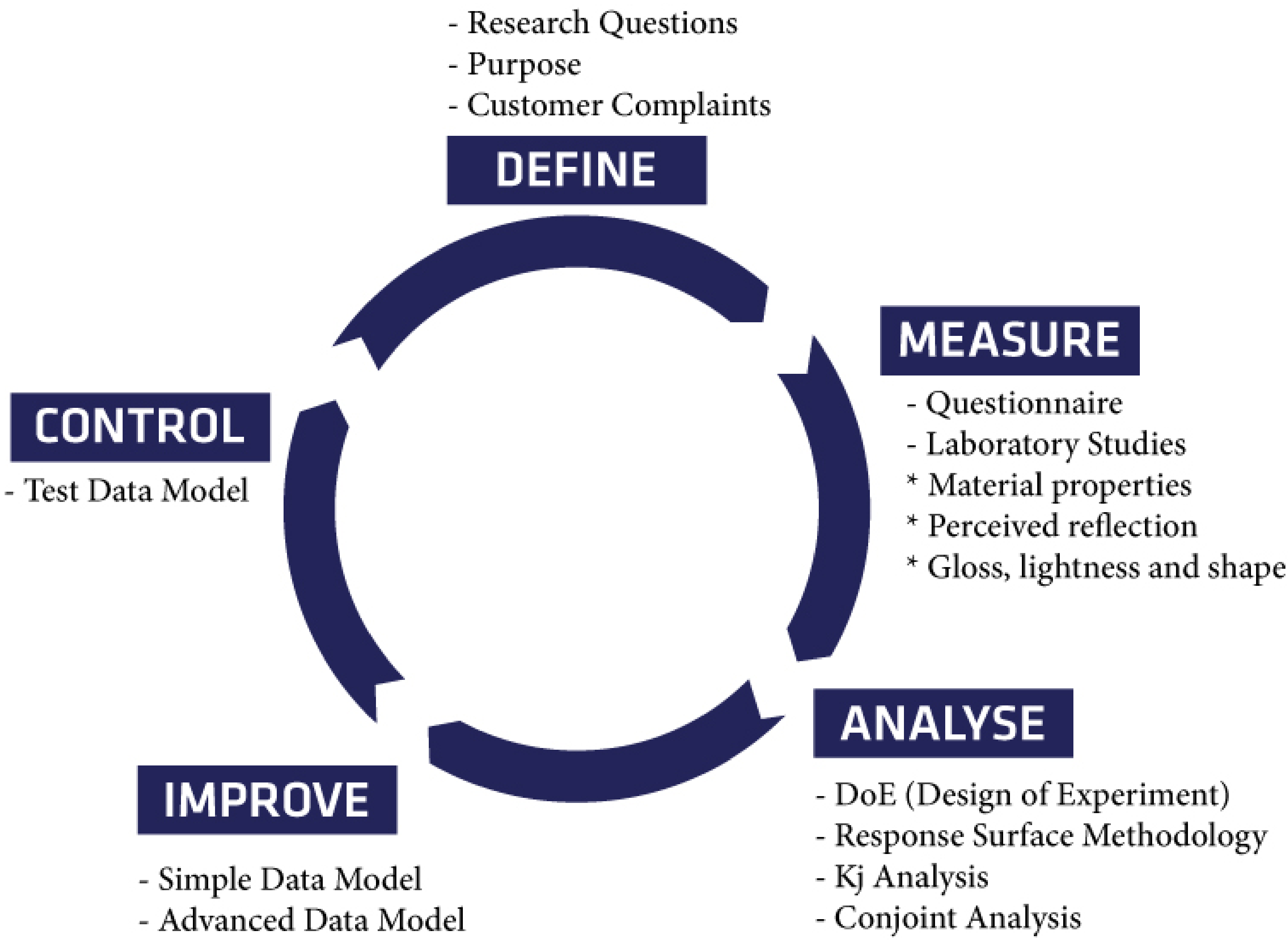


Appendix 1: Project planning -GANTT





Appendix 2: DMAIC process description



Appendix 3: Study on luminance dependency

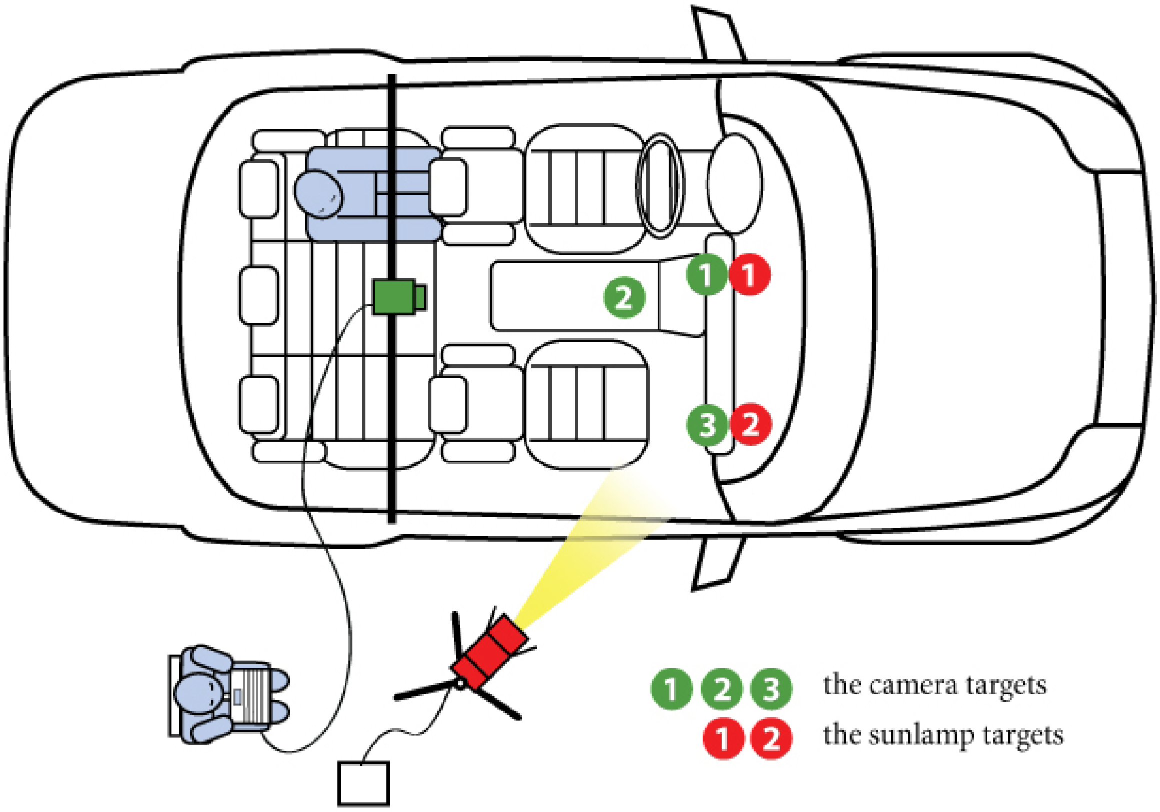
Procedure:

Before the laboratory studies, the centre stack and the decopanels of the selected cars were loosened in order to switch them easily during the studies. The important thing while loosening the centre stack is that only the screws around the frame should be loosened not the other details. Pictures below shows the steps to pull out the centre stack.

The decopanels should be loosened and the elements behind it should be removed, to be able to change it quickly. Otherwize one has to use a tool to bend loos the deco panel from the sides. During the study, the deco-panels were pulled out / in easily by holding them around the air vent windows, as seen below.

The surfaces on the camera targets should be cleaned to prevent receiving irrelevant results from the camera.

Appendix 3: Study on luminance dependency



An overall illustration of the study can be seen above.

Study Steps
(TL1 stands for Test Leader 1 and TL2 stands for Test Leader 2)

TL2 places the sunlamp outside the front passenger window
TL2 marks the points on the decopanel and the centre stack to target the sunlamp.
TL1 sits on the back seat to adjust the camera for each run.
TL1 places the camera between the back windows.
TL2 connects the camera to the computer.
TL2 starts the program in the computer to take photos.
TL2 operates the computer to record the images.
TL2 records the image data.

The settings are set according to the table below. All settings should be measured four times to minimise the variance of the measurements.

	Main Parameters			Parameter relation				Output Values		
	Lightness	Panel Type	Sun position	IxT	IxS	TxS	IxTxS	Ls1	Ls2	Ls3
1	Light	Alu	Deco	+	+	+	-			
2	Dark	Alu	Deco	-	-	+	+			
3	Light	Wood	Deco	-	+	-	+			
4	Dark	Wood	Deco	+	-	-	-			
5	Light	Alu	CS	+	-	-	+			
6	Dark	Alu	CS	-	+	-	-			
7	Light	Wood	CS	-	-	+	-			
8	Dark	Wood	CS	+	+	+	+			
E										

Appendix 4: Study of perceived reflections

Before starting, test leaders should be sure that the cars were prepared for the study as explained in appendix 3.

Study Steps

TL 1 places the cars in the lab with the necessary distances.
TL 1 places the sun lamp in the same distance to the both cars.
TL 2 introduces the study to the participant.
TL 2 lets the participant sit on the driver's seat.
Test leaders perform each run according to the order in table x.x
TL 2 asks the participants to rate the annoyance for each run.
TL 1 aims the sun lamp on the target areas for each run.
TL 1 cleans the decopanels and the centre stacks after switching them.

All the runs necessary are seen in the table below and the ratings should be taken for both a driving situation and looking at the centre stack.

	Lightness	Panel Type	Sun Power	Sun Position	Rating Driving	Rating CS
1	Light	Aluminum	Low	CS		
2	Light	Aluminum	Low	Deco		
3	Light	Aluminum	High	CS		
4	Light	Aluminum	High	Deco		
5	Dark	Aluminum	Low	CS		
6	Dark	Aluminum	Low	Deco		
7	Dark	Aluminum	High	CS		
8	Dark	Aluminum	High	Deco		
9	Light	Wood	Low	CS		
10	Light	Wood	Low	Deco		
11	Light	Wood	High	CS		
12	Light	Wood	High	Deco		
13	Dark	Wood	Low	CS		
14	Dark	Wood	Low	Deco		
15	Dark	Wood	High	CS		
16	Dark	Wood	High	Deco		
E						

How the cars and the sun lamp were placed in the lab.

Appendix 4: Study of perceived reflections

The four interior setting for the study can be seen in the picture.

How the sun lamp was aimed on the target areas inside the car.

Appendix 5: Study of gloss, lightness and radius

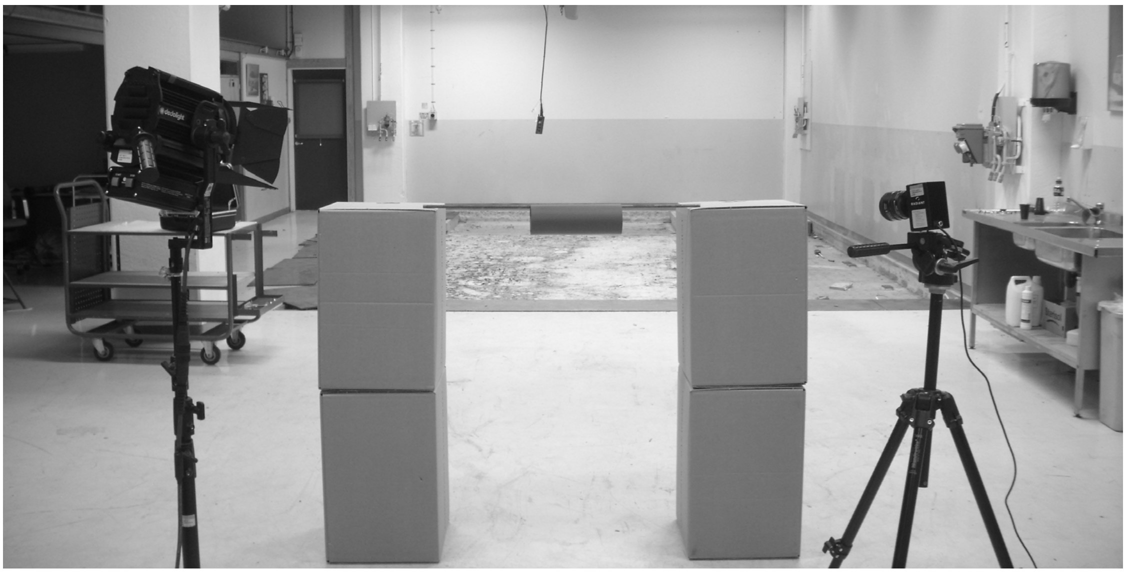
For the study, 15 cylinders and 1 sphere are examined, see pictures below. They have the specifications according to the response surface table as seen in the table below.

Run	Gloss	Lightness	Radius	Luminance	Glare Size
1	25	25	50		
2	75	25	50		
3	25	75	50		
4	75	75	50		
5	25	25	135		
6	75	25	135		
7	25	75	135		
8	75	75	135		
9	10	50	90		
10	90	50	90		
11	50	0	90		
12	50	100	90		
13	50	50	10		
14	50	50	170		
15	50	50	90		
16	50	50	90		
17	50	50	90		
18	50	50	90		
19	50	50	90		
20	50	50	90		

The lab setting for the study can be seen in the picture below. The camera and the sun lamp should be placed in the same distance from the object to have consistency in glare position and the size.

Objective Study 2 Steps

TL 1 opens the sun lamp
TL 1 closes the environment lights
TL 2 places the cylinders according the a run chosen randomly
TL 2 aims the camera at the middle of the cylinders
for each run.
TL 1 takes and saves the photos of each run.



Set up of the study

Appendix 6: Customer Complaints

Steering Wheel

Opinion	Car	Complaints
Glare, glare everywhere! Exterior chrome trim on driver side window… Metallic/silver trim around the audio unit. And last but not least, the Mz logo on the steering wheel...	Mazda Atenza	2
I do however, from time to time, get a glare off the Chrome Steering-wheel badge, and the chrome trim around the tacho's etc.	Superb Estate 170CR Elegance DSG	2

Dashboard

Opinion	Car	Complaints
Wood grained dashboard too shiny resulting in bright reflection in drivers eyes.	Acura MDX	1
Light reflection on dash of night is distinctive.	Volvo S60	1
Reflected light from dash - very dangerous.	Volvo C30	1
The wood dash veneer is prone to cracking and to deterioration of the "varnish" and the reflections off the glossy surface drove me crazy when driving at night.	Saab Aero	1
Poor design of dashboard as the silver strip on the passenger's side, blinds both the driver and the passenger when the sun is on it at the wrong angle.	Volvo XC70	1

Dashboard Trim

Opinion	Car	Complaints
Bright trim rings on defroster vents on each side of dash	Volvo XC70	1
Reflection of sun off dashboard trim	Volvo V70	1
Brushed aluminium trim on dashboard and gear lever console catch the sun and reflect it into driver's vision. Looks nice but poor design from a practical and safety standard.	Volvo V70	1
Have experienced several instances of the sun reflecting off fascia inserts and dazzling driver!	Volvo V70	1
Bad reflections (from sun) off of shiny metal trim.	Volvo XC70	1

Appendix 6: Customer Complaints

Brushed aluminum trim catches the sun impairing driver's vision.	Volvo V70	1
Dash board air vents reflect on the glass or wind shield - which is blinding to the driver or front seat rider.	Kia Rio	1
Interior metal alum. Trim highly reflective of sunlight, very bothersome.	Volvo XC70	1
Revise the dash trim...that sunlight reflection into the driver's eyes is annoying	Buick Regal CXL Turbo	1
I was wondering why the view in the wing mirrors wasn't too clear and then I realised that I was getting a massive reflection from the (silvered) dashboard trim	Superb Estate 170CR Elegance DSG	5
Test drove a platinum on this slightly overcast day and was overcome by the bright, distracting reflections from the cabin trim	Hyundai Genesis	1
The car is good except for the brushed aluminum trim. When the sun is at a certain angle the reflection shines in my eyes - Very annoying. ...	BMW 1er coupe	6
chrome dash trim reflects too much sunlight.	Dodge Journey SUV	1
when the sun is about directly overhead, the chrome trim shines into my eyes!	Hyundai Sonata	3
Is anyone else being blinded by the shiny reflective trim around the instrument panel, door handle, gear shift know, gear shift trim, etc	Ford Explorer Ranger	5
is anyone else experiencing the extremely annoying sun glare off the chrome trim around the center air vents?	Ford Mustang GT	2
The little plastic chrome Trim ring around the power button on the dashboard.........On sunny days.......the glare and reflection from this thing is KILLING ME!.......	Toyota Prius Gen II	3
we suffered frequent temporary blindness because of the very pretty but impossibly shiny chrome trim that's all over the instrument and gear panels.	Buick Enclave CX	7
Just drove off with a gorgeous new 335i coupe today, and was noticing how much glare came off the dark wood trim from the passenger side.	BMW 335i	2
i have aluminum trim and i hate it. dings easily and glares with the sun.	BMW 335i	3
I don't like the wood cuz it's high-gloss and glares in the sun.	BMW 335i	2

Appendix 6: Customer Complaints

The first is one we whine about ofter and one which is truly unmerited -- chrome gauge bezels. As you can see, they create distracting glare.	Kia Optima	3
Interior trim reflects glare.	Acura MDX	1
It reflects into my eyes/ comfort level	Lexus GS	1

Gear Shifter

Opinion	Car	Complaints
Chrome trim on transmission shifter creates glare in sunny situations.	Volvo XC70	1
The silver reflective material used around gear shift is blinding in sunlight.	Volvo V70	1
I have the OEM brushed AL in mine but the biggest pain is the glare from the shifter	VW Passat 2.0T Sport	4
the only bright work is the chrome around the shift gate. Sure enough, the sun was reflecting off it into my eyes while stuck in traffic yesterday.	Cadillac SRX	1
My '07 Max SE has a chrome trim plate around the shifter. When the sun hits it right the glare blinds me....	Nissan Maxima SE/Altima SE	3
I get a constant sun glare from the shifter surround	VW Passat	4
And now and then, it shines directly onto the nearly flat brushed aluminum panel that covers the automatic gearshift selector on my 2011 Outback. It's quite annoying	Subaru Outback	2

Centre Stack

Opinion	Car	Complaints
Silver around radio causes major sun glare	Dodge Charger	1
My only complaint is the sun bouncing off all the aluminum (or what ever it is) on the dash and console. It gets in my eyes and reflects off the glass.	VW Passat	3
Nav screen – difficult to see when sunlight shines on it. Actually reflects in drivers eyes.	Acura TL	1
Depending on the outside light sometimes the panel is difficult to read; there is a glare that effects the panel.	Volvo S40	1
Glare surrounding center dashboard display makes it impossible to see at times.	Lexus RX 300	1

Appendix 6: Customer Complaints

The highly polished woodgrain surface on the centre console, occasionally reflects sunlight etc. which is annoying.	Volvo XC70	1

Glove Box

Opinion	Car	Complaints
The brushed silver piece above the glove box gives me a bad reflection when the sun hits it the right way, which is almost every sunny day.	Cadillac ESV 08	2

Appendix 7: Questionnaire

Direct reflections in vehicle interior

This survey aims to collect data from car drivers about the annoyance of direct reflections (direkta reflektioner-solkatt) in vehicle interior. Please answer all the questions to help us develop better vehicle interiors for future.
* Required

1.Your gender? *

- Male
- Female

2.How tall are you (cm)? *

3.Do you have any problem with your eyes? *

- Blurry vision (short / long vision problem)
- Color blind
- Cataract (katarakt / grå starr)
- No problem
- Other:

4.Do you have a car? *

- Yes
- No

5.Which car have you driven recently ? If you drive more than one car, please choose one of them for the questionnaire *

Brand / Model / Year

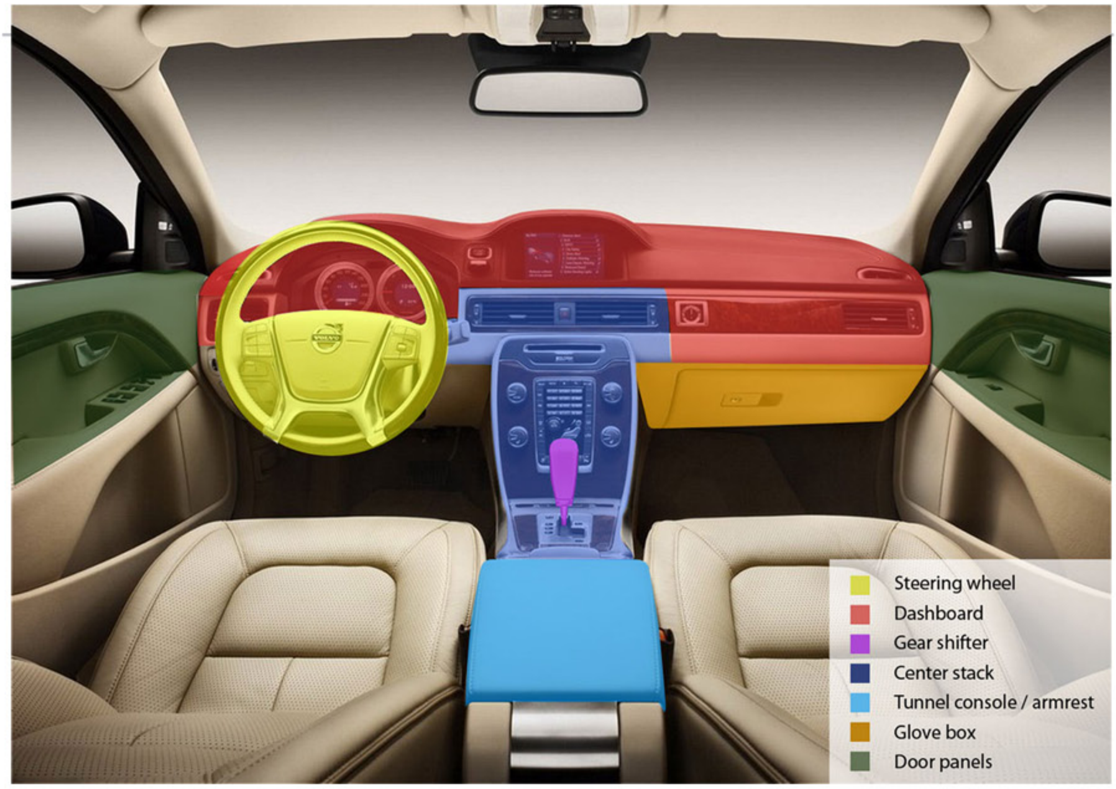
6.For how many years have you had a driver's license? *

- 1-2 years
- 2-5 years
- 5-10 years
- 10+ years

7.Do you wear glasses while driving? *

- Yes
- No
- I wear sunglasses while driving

Appendix 7: Questionnaire



8.Do you receive direct reflections to your eyes from the interior surfaces of your car? If yes, specify the region according to the picture above. *

Please describe the chosen problems further in the space below.

- ☐ Steering wheel
- ☐ Dashboard
- ☐ Gear shifter
- ☐ Center stack
- ☐ Tunnel console / arm rest
- ☐ Glove Box
- ☐ Door panel
- ☐ No problems with reflections
- ☐ Other: ________

9.Grade the experience of reflection on the steering wheel *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

Grade the experience of reflection on the dashboard *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

Appendix 7: Questionnaire

Grade the experience of reflection on the gear shifter *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

Grade the experience of reflection on the center stack *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

Grade the experience of reflection on the tunnel console / armrest *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

Grade the experience of reflection on the glove box *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

Grade the experience of reflection on the door panels *

	1	2	3	4	5	6	7	8	9	10	
Couldn't be worse	○	○	○	○	○	○	○	○	○	○	Not annoying at all

10.Do you use a product to reduce the reflection inside the vehicle? *

- ☐ Anti-reflection spray
- ☐ Anti-reflection filter
- ☐ Another surface on dashboard
- ☐ I don't use anything
- ☐ Other: ______

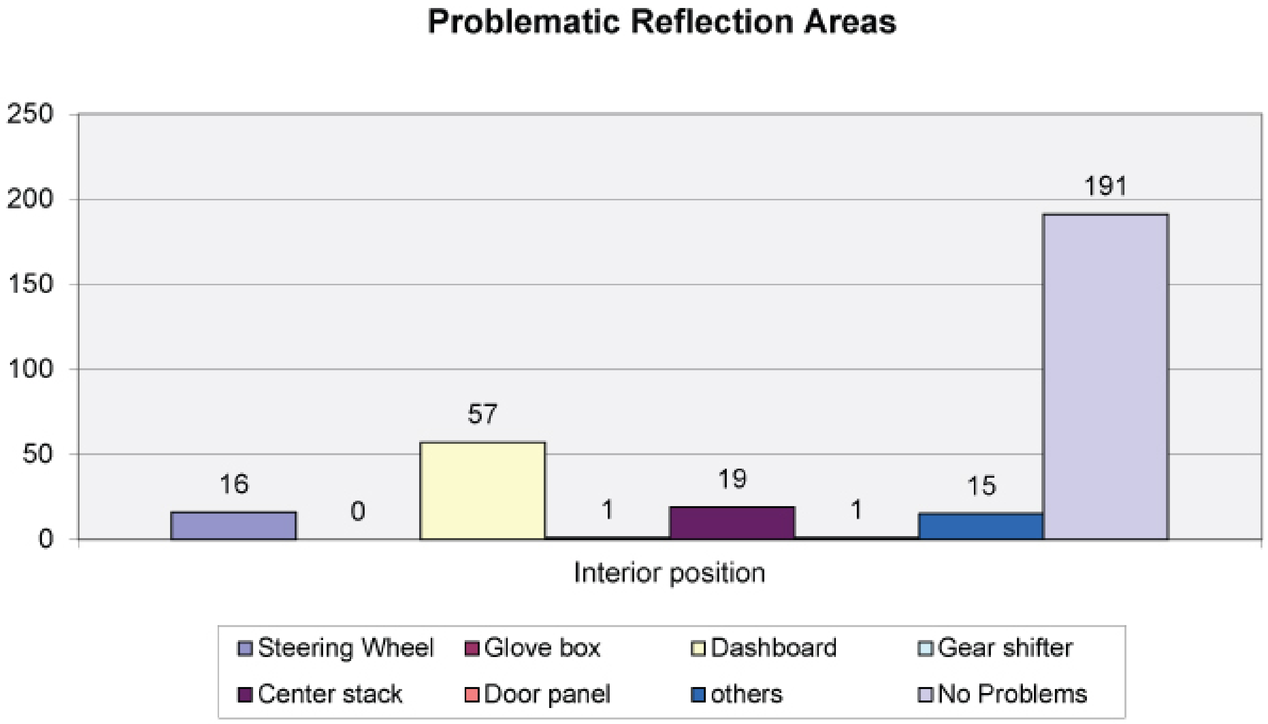
11.Do you have a comment to add related with the reflection inside the car ?

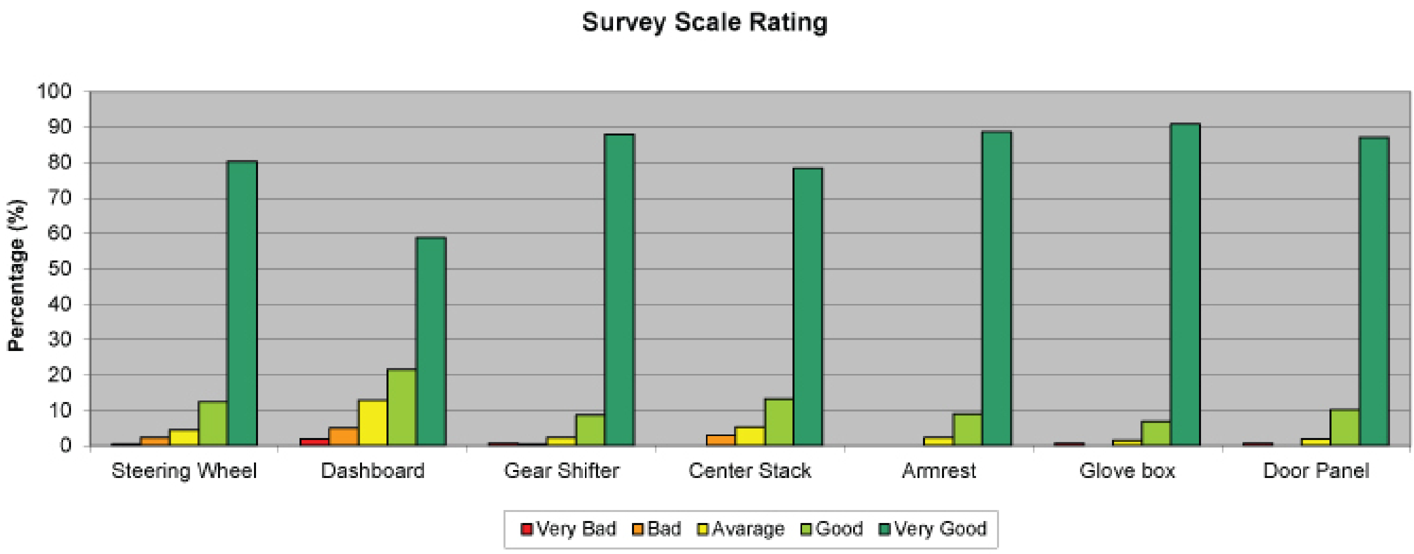
Direct or indirect reflections

[ ]

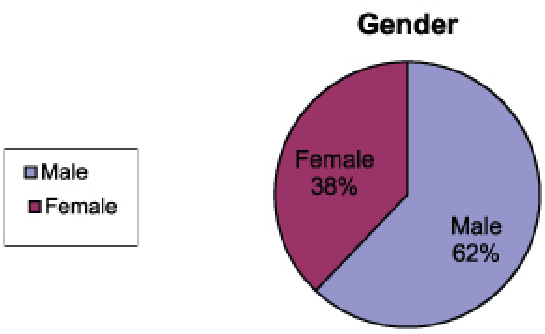
Submit

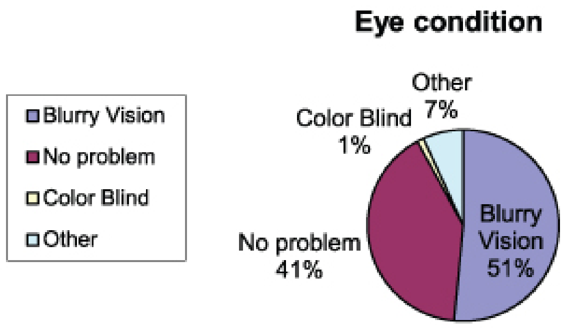
Appendix 7: Questionnaire - Result

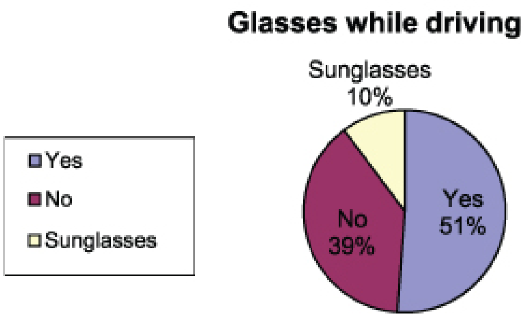


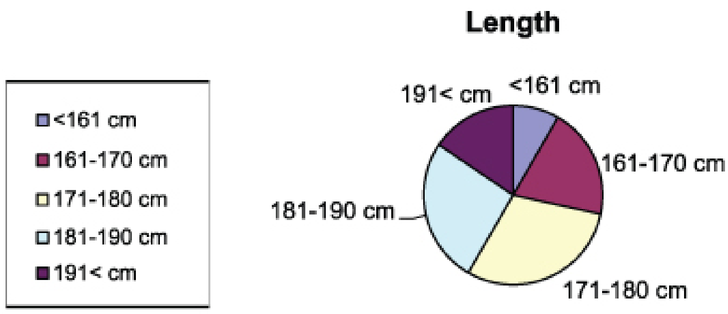


Appendix 7: Questionnaire - Result









Appendix 7: Questionnaire - Result

Reflection in windows

- Dashboard reflections in windscreen is by far the most annoying reflections for the driver
- Reflections on front screen from the front air vents.
- The raster on the dashboard top, mirrors sometime in the windscreen
- During driving in dark I see reflections from the DIM in the upper part of windscreen
- I have more problems with the sun reflecting in the windscreen/side window or by passing cars front lights.
- Worst reflections issues are with blasted windscreen
- From the "combi instrument" I get reflection onto the windscreen
- I can see the instruments in the windscreen. Does not bother me, but it doesn't give a "thought through" appearance.
- Direct reflections is normally not a problem for me, however reflections of the dashboard in the window is very critical.
- instruments in the dashboard (speedometer and tachometer) is reflected in the upper portion of the windshield
- It would be great if the wind screen didn´t reflect the instrument panel at all
- Sometimes the reflection of the dashboard in the windscreen can be annoying, especially when entering a parking garage.
- Reflections from instruments and dashboard in the front and side windows is a huge problem.
- Reflections from the lightswitch, to the left of the steering wheel, is visible i the driver side window. I think thi is quite an noying since the reflections lands where you look in the sidemirrors.
- I have the dark interior. I found that light instrument panel sometimes could make visible in the windshield.
- I do get irritated from reflections of the top of the dashboard in the windscreen.
- I have indirect reflections from combi and centre screen in the windscreen when driving at night. Not good
- The reflection from the dashboard ends up in the front window when it is sunny. I have a beige interior.
- The worst problem with reflections is the dashboard reflecting in the windshield.
- Premium sound logo on the centre speaker is creating a disturbing reflection in the windscreen
- The dashboard reflects too much on windscreen.
- The V70 I have been using have brown dashboard, specification at inserts ==> brushed aluminum. The only thing concern ing me is that the dashboard sometimes reflects to the inside of the front window. No issues at all from all the aluminum inserts
- I have had a lot more problem with my former cars as Volvo S60 (old) and V50, where mirroring dashboard in windshield during bright sunny days was really annoying.
- It is fine and I choose dark panel to avoid reflections in windscreen
no problems at all
- Light interior reflects in the windscreen and makes it difficult to see in bright weather. Dark colours is OK
- I chose dark interior to avoid problem with reflections.

Appendix 7: Questionnaire - Result

- It’s more disturbing that you see a reflection in the side door glass from the lamps to all buttons in the dashboard.

- Reflections in the wind screen from dashboard annoying.

- See above. The projection of the DIM (combined instrument frame around the speedometer and tachometer) are clearly visible in the upper part of the windscreen when driving in the dark.

- The only problem I have is that it’s very difficult to clean the rear window inside. When the sun is shining there are a lot of reflections from this but I have no problem with the interior in my nice old car :)

- More concerned about the reflection in window like left air system vent.

Black is better

- Have a V50 Classic Momentum with black inside, much more comfortable for reflections than the previous I had with bright plastics and fake-walnut plastic panels.

- Reflections depend on the interior colour. A dark interior is no problem, such as mine. A lighter though can be a problem in bright light.

- Avoid light and beige colours in dashboard top. Offblack as I have in my car is to be preferred Otherwise I don´t have any reflections that disturb me, as I can remember right now...

- Fully black interior

- My car V50 has dark interior and very little brightwork that reflects. Other cars can have annoying reflexes.

- My dashboard is black, Dark wood trim

- I have black interior and therefore very little problems. Problems mainly emerge with light interiors.

- This study should be made in sunny countries where the problems are bigger like California and Saudi Arabia. This coun tries buys lighter interior on a larger scale also.

- Everything is dark in my car so I have no problems.

Reflections

Exterior

- Reflections from engine hood (out of your area...) might be annoying/disturbing while driving against a morning/evening sun

- The most reflection I get in my eyes is from the mirrors when somebody is driving behind with cenon lights when it’s dark,ex Audis lights are very sharp..

Interior

- The speaker grille on the dash is the most reflective, but no problem.

- On the speaker grille is a little emblem (PSS) that is very visible but the size is ok. ´Larger size had been a real problem.

- With the sun in a certain angle from rear it makes a “wash out” of the combined instrument or centre stack display. The displays become total white and unreadable.

- Chrome frame on centre stack could be some reflections

- I experience more reflections in my Volvo V50 DRIVe than in my Mercedes Benz A170 Avantgarde, it might depend on the different material in the dash but also on the slightly different driver’s position.

- Reflections get worse if something is put onto the dashboard, for instance a ticket

Appendix 7: Questionnaire - Result

- There may be some reflections from centre stack, under certain conditions (very sunny, coming from specific direction)
- Main problem is definitely the aluminum decor on the right hand side of the dashboard.
- The reflection on the steering wheel is only on worn surface.
- In newer Volvo cars, I often get reflections from the steering wheel centre " the Volvo logotype"
- I suppose it has happened that I got reflections from the silver coloured parts of the steering wheel for instance, but since I like those silver parts, and its very seldom it happens, I'm not at all annoyed by it. Nothing I think about or can recall now.

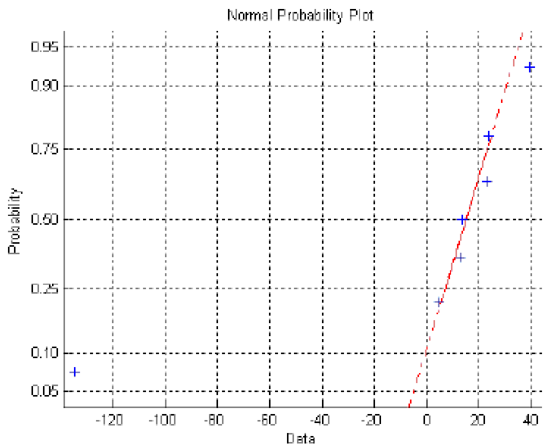
Instruments

- No reflections distract except from instruments. Real bad in night driving.
- It is only one thing really but it is SO annoying: In the dark, the area around 140 kph on the speedo is unreadable because there is a light reflection from the instrument lighting hiding this area on the dial. It is impossible to get around. Just a bad design of the instrument and its function
- The only place is sometimes the RTI that can be hard to see due to reflections. But this new (see above) is clearly better then my old car with pop up RTI.

Appendix 8: Study on luminance dependency Results

Data and effect values for luminance at Centre Stack

	Main Parameters			Parameter relation				Output Values				
	Sun Position	Light-ness	Panel Type	IxT	IxS	TxS	IxTxS	Lum1	Lum2	Lum3	Lum4	Mean
1	Right	Light	Aluminum	+	+	+	-	7349	7362	7382	7408	7375,25
2	Left	Light	Aluminum	-	-	+	+	7336	7270	7316	7500	7355,5
3	Right	Dark	Aluminum	-	+	-	+	7349	7322	7316	7336	7330,75
4	Left	Dark	Aluminum	+	-	-	-	7336	7349	7322	7316	7330,75
5	Right	Light	Wood	+	-	-	+	7257	7211	7158	7145	7192,75
6	Left	Light	Wood	-	+	-	-	7191	7158	7224	7191	7191
7	Right	Dark	Wood	-	-	+	-	7198	7224	7178	7198	7199,5
8	Left	Dark	Wood	+	+	+	+	7270	7198	7257	7362	7271,75
E	12,6875	4,5625	-134,3125	23,4375	22,5625	39,1875	13,5625					

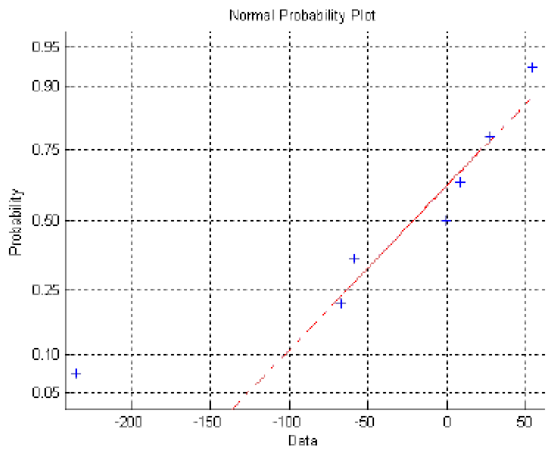


Normal probability plot of the effects (E) seen in the table above. The effect deviating from the probability curve is the effect of the change of panels.

Data and effect values for luminance at Deco Panel

	Main Parameters			Parameter relation				Output Values				
	Sun Position	Light-ness	Panel Type	IxT	IxS	TxS	IxTxS	Lum1	Lum2	Lum3	Lum4	Mean
1	Right	Light	Aluminum	+	+	+	-	7487	7257	7257	7290	7322,75
2	Left	Light	Aluminum	-	-	+	+	7244	7224	7165	7316	7237,25
3	Right	Dark	Aluminum	-	+	-	+	7210	7270	7197	7198	7218,75
4	Left	Dark	Aluminum	+	-	-	-	7112	7145	7073	7132	7115,5
5	Right	Light	Wood	+	-	-	+	7099	6987	7007	6967	7015
6	Left	Light	Wood	-	+	-	-	7007	6941	6967	6954	6967,25
7	Right	Dark	Wood	-	-	+	-	7040	6974	6974	7020	7002
8	Left	Dark	Wood	+	+	+	+	6941	6954	6967	7020	6970,5
E	-67	-58,875	-234,875	-0,375	27,375	54	8,5					

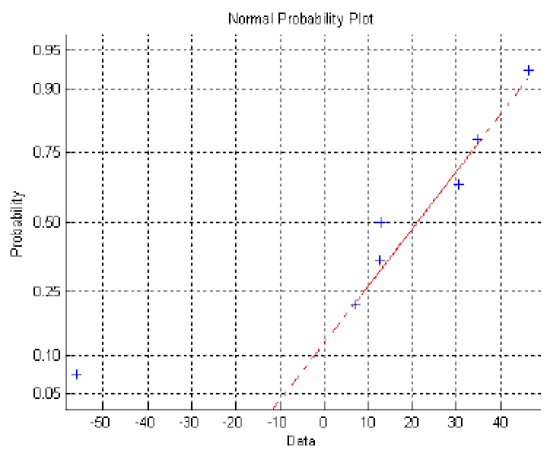
Appendix 8: Study on luminance dependency Results



Normal probability plot of the effects (E) seen in the table above. The effect deviating from the probability curve is the effect of the change of panels.

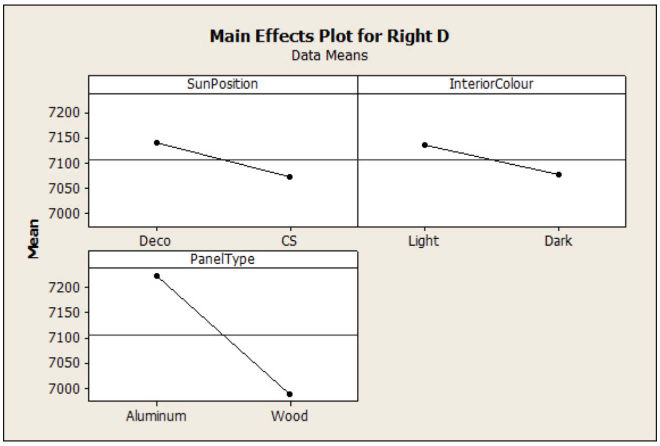
Data and effect values for luminance at Gear shifter

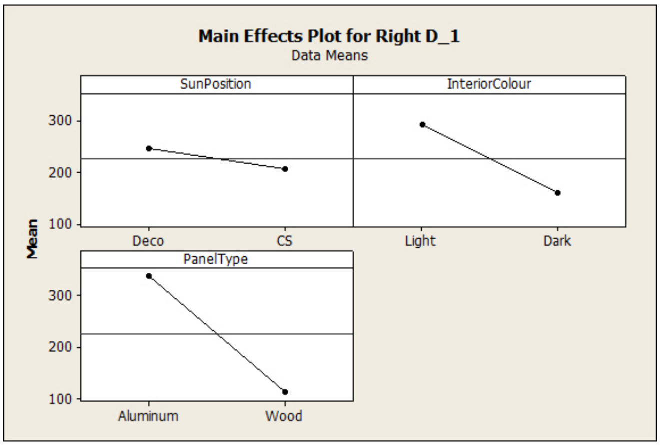
	Main Parameters			Parameter relation				Output Values				
	Sun Position	Light-ness	Panel Type	IxT	IxS	TxS	IxTxS	Lum1	Lum2	Lum3	Lum4	Mean
1	Right	Light	Aluminum	+	+	+	-	7395	7257	7425	7395	7368
2	Left	Light	Aluminum	-	-	+	+	7362	7382	7395	7316	7363,75
3	Right	Dark	Aluminum	-	+	-	+	7165	7276	7290	7244	7243,75
4	Left	Dark	Aluminum	+	-	-	-	7270	7303	7257	7303	7283,25
5	Right	Light	Wood	+	-	-	+	7362	7302	7316	7336	7329
6	Left	Light	Wood	-	+	-	-	7323	7349	7336	7290	7324,5
7	Right	Dark	Wood	-	-	+	-	7270	7277	7270	7270	7271,75
8	Left	Dark	Wood	+	+	+	+	7316	7415	7323	7395	7362,25
E	30,3125	-56,0625	7,1875	34,6875	12,6875	46,3125	12,8125					



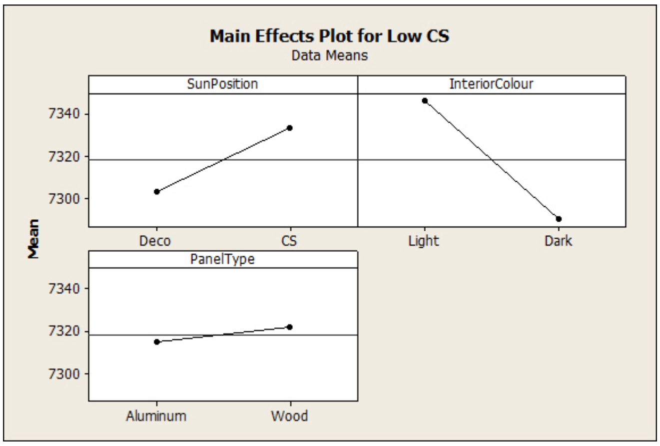
Normal probability plot of the effects (E) seen in the table above. The effect deviating from the probability curve is the effect of the lightness.

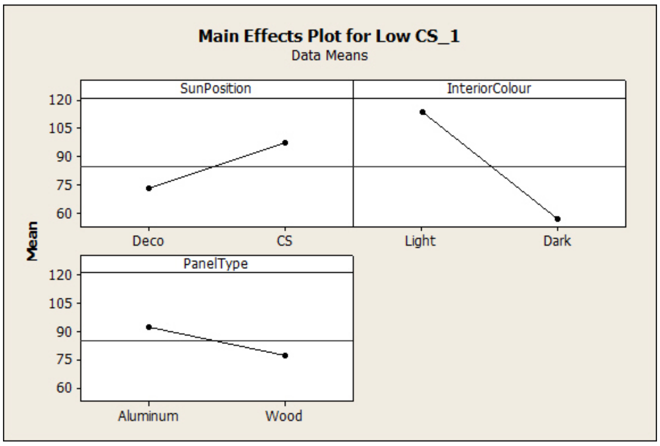
Appendix 8: Study on luminance dependency Results



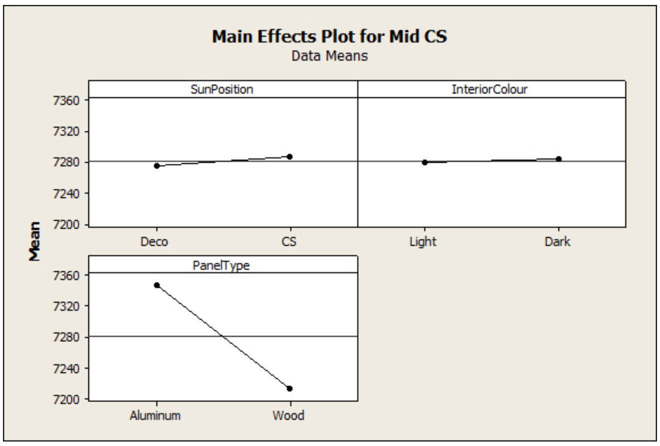


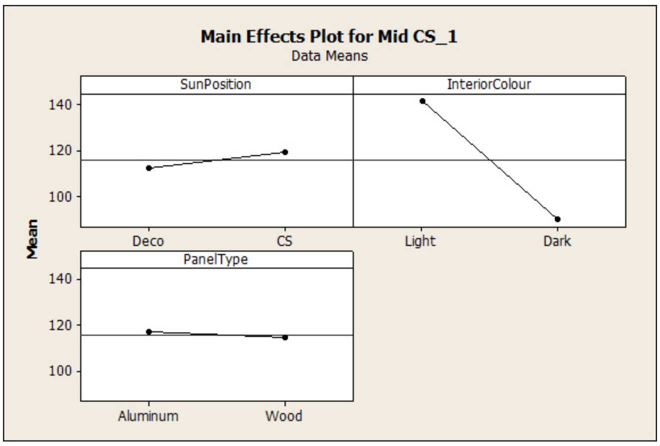
Main effects for deco panel area: Max Luminance to the left, Background luminance to the right





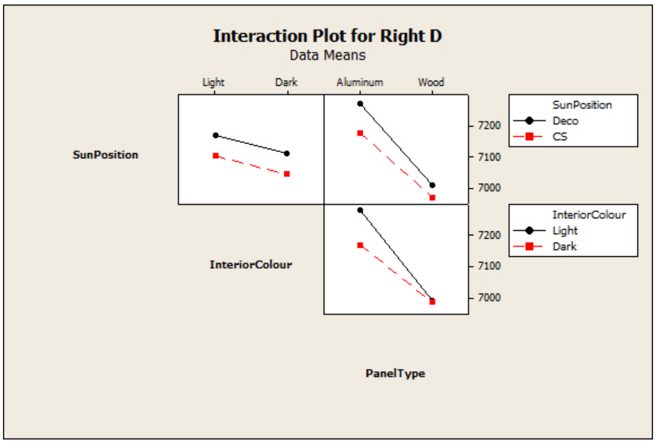
Main effects for lower centre stack area: Max Luminance to the left, Background luminance to the right

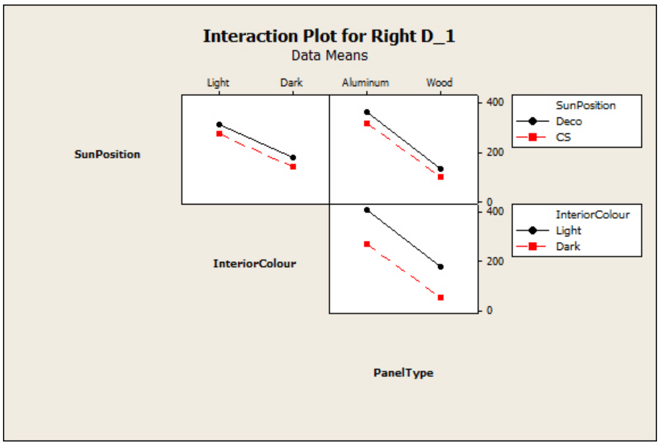




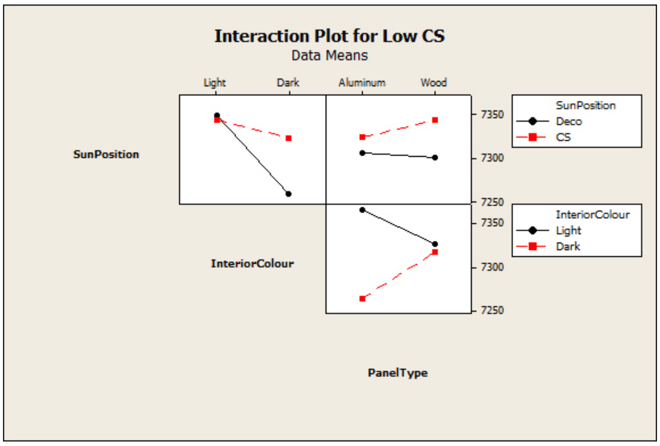
Main effects for centre stack area: Max Luminance to the left, Background luminance to the right

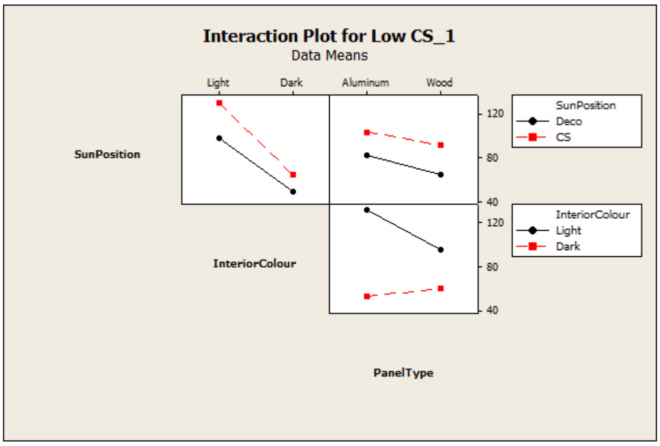
Appendix 8: Study on luminance dependency Results



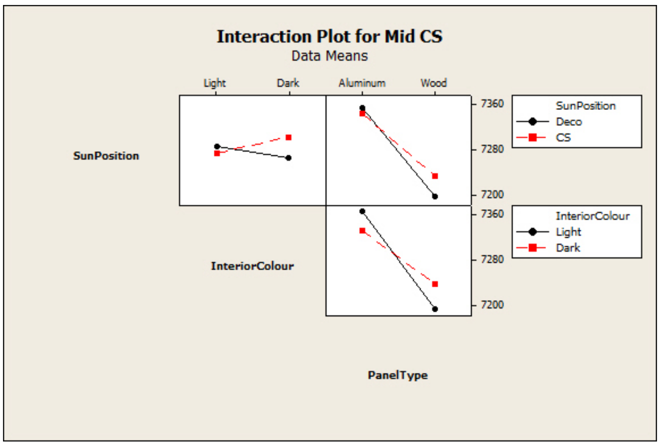


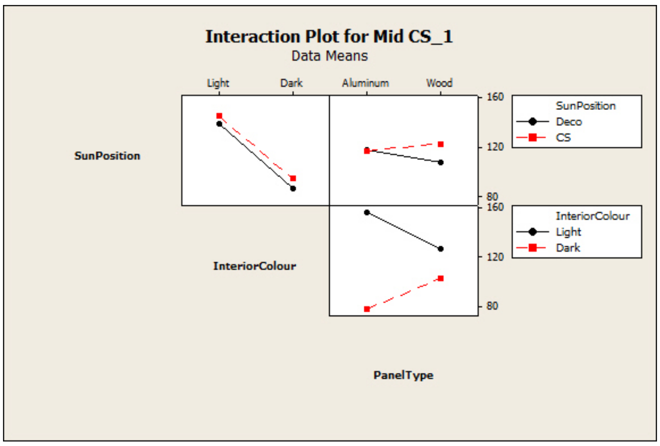
Interaction plot for deco panel area: Max Luminance to the left, Background luminance to the right





Interaction plot for lower centre stack area: Max Luminance to the left, Background luminance to the right

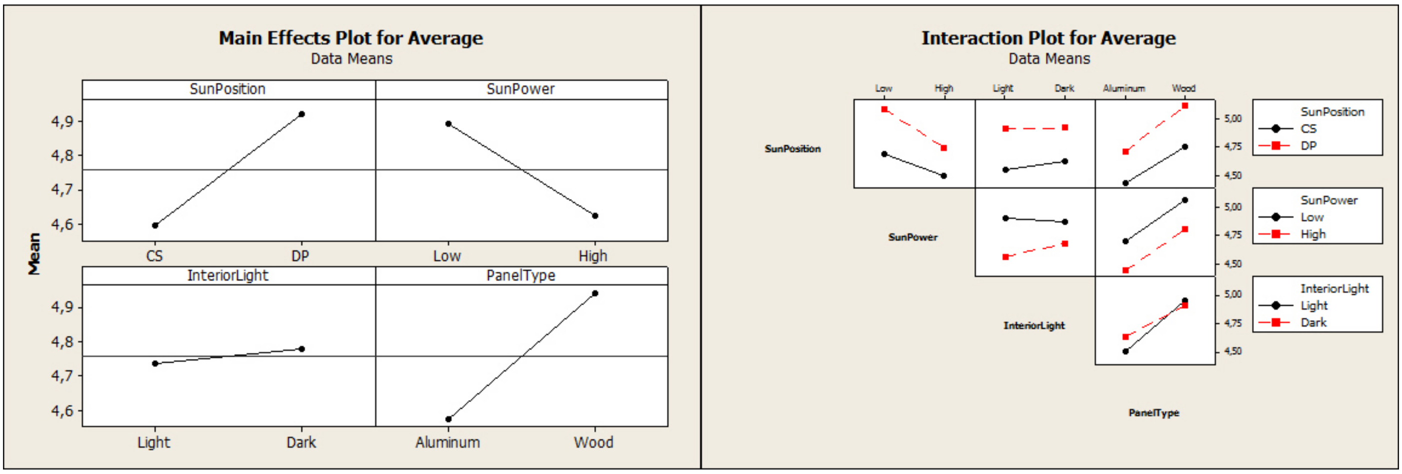




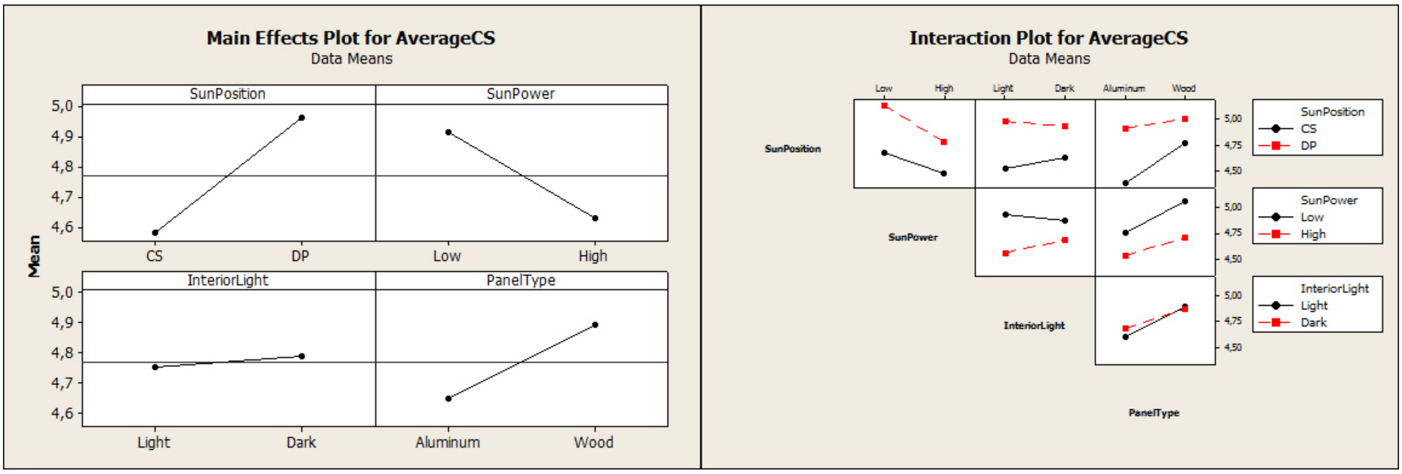
Interaction plot for centre stack area: Max Luminance to the left, Background luminance to the right

Appendix 9: Study of perceived reflections Results

Main effect and interaction plot for driving situation.



Main effect and interaction plot for looking at the centre stack.

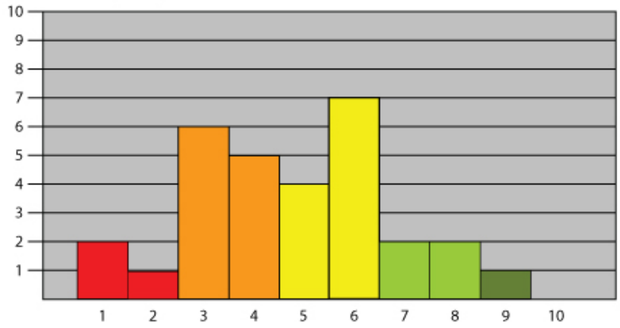


Appendix 9: Study of perceived reflections
Results

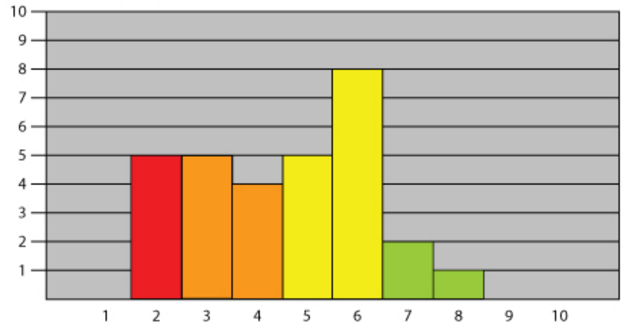
Data showing the number of participants rating on the different steps of the Volvo scale

High Power / Light on CS / Look at CS

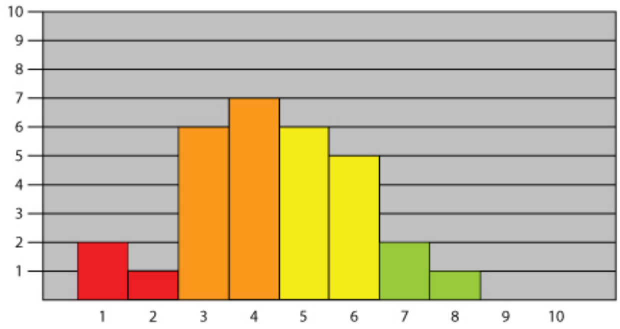
Dark surroundings / Wooden panels



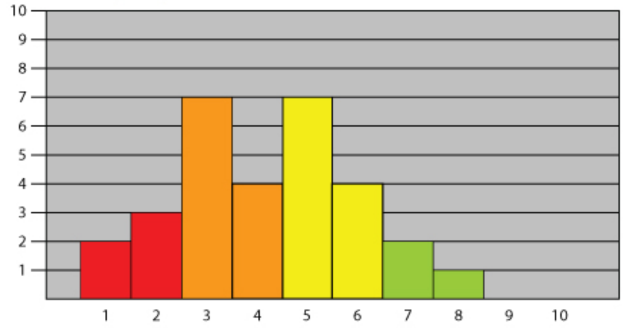
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels

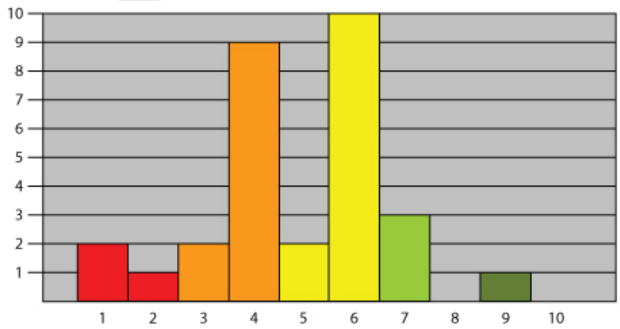


Light surroundings / Aluminum panels

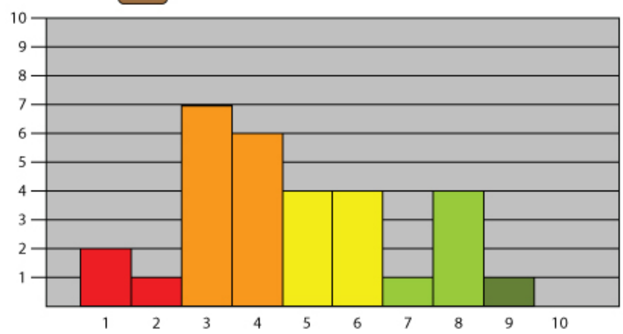


High Power / Light on DP / Look at CS

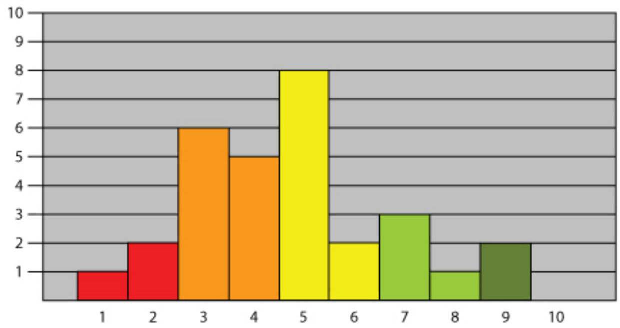
Dark surroundings / Wooden panels



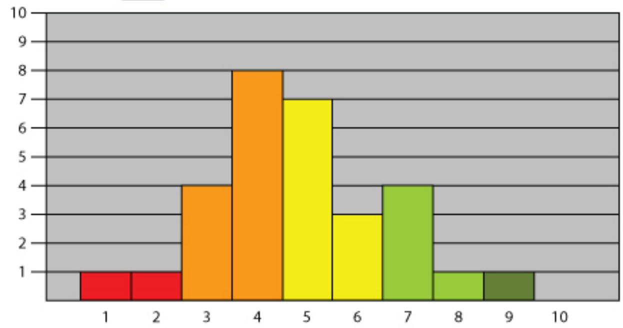
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels



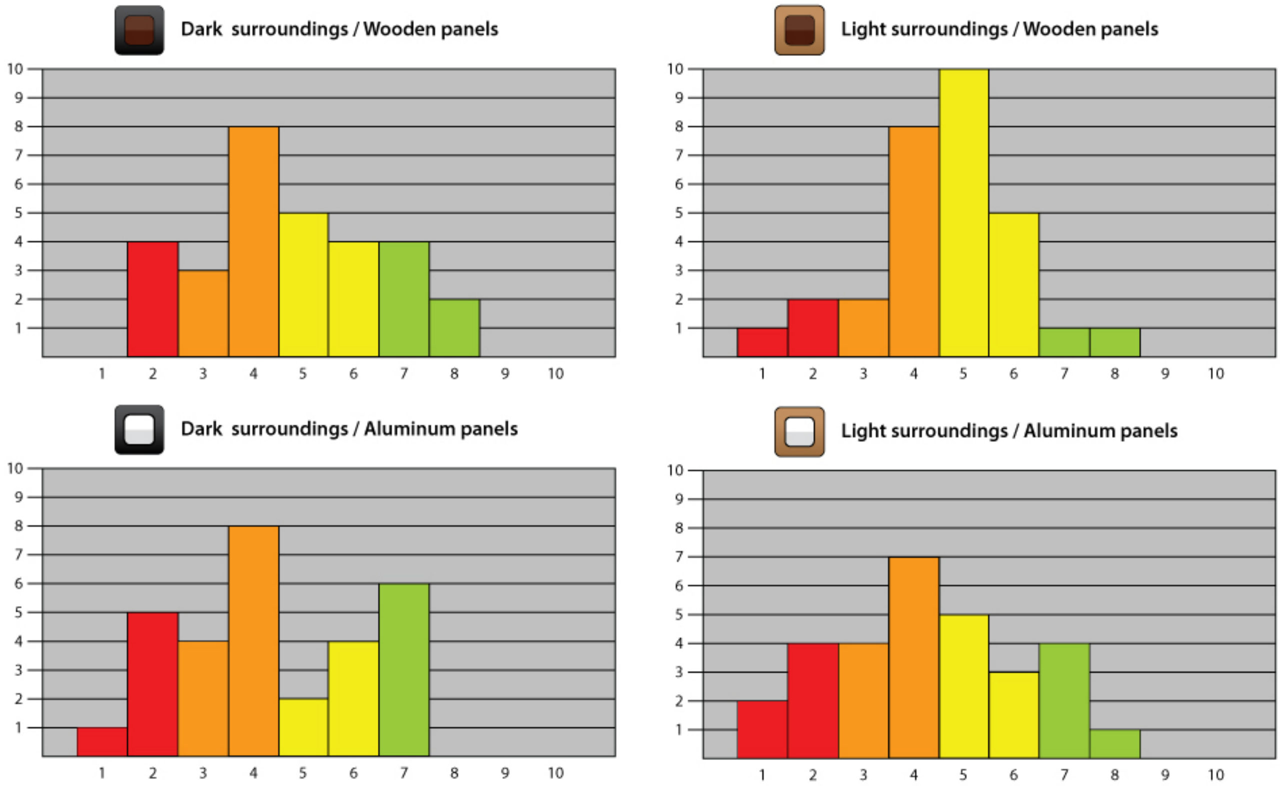
Light surroundings / Aluminum panels



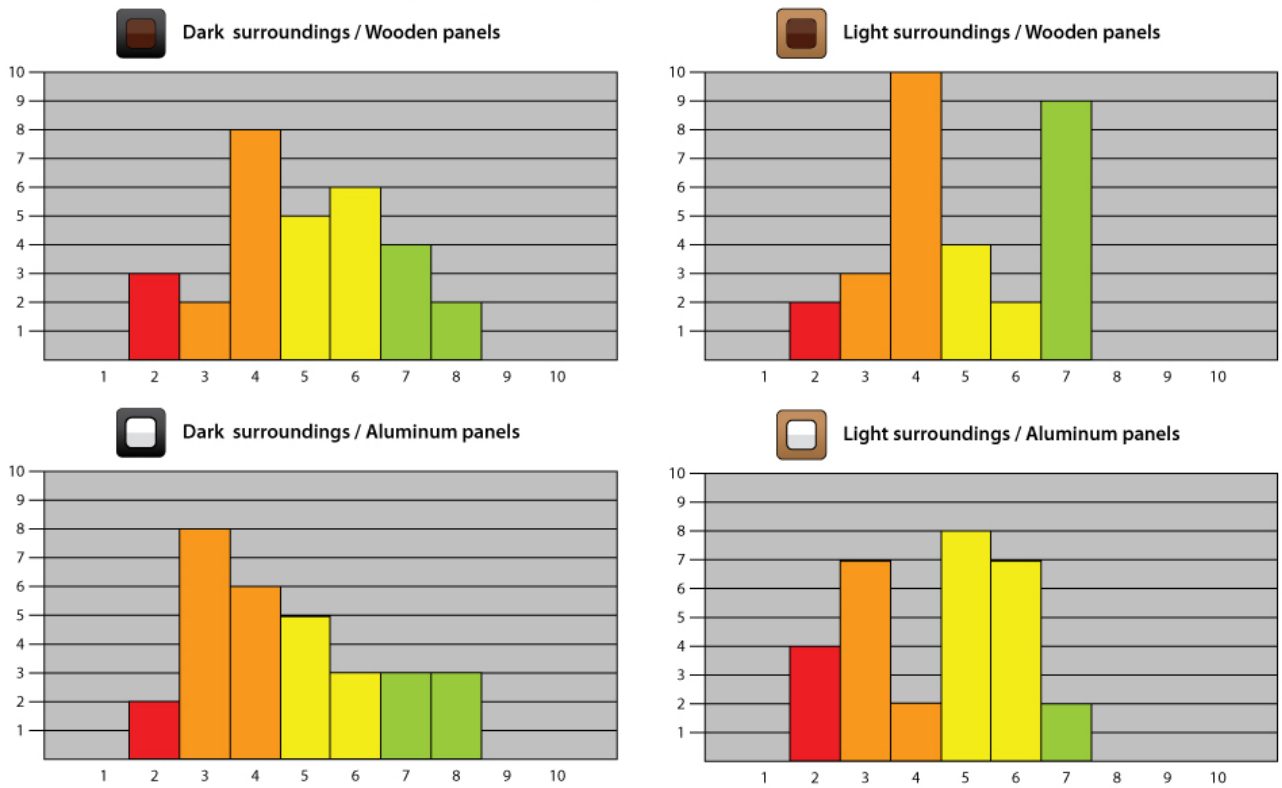
Appendix 9: Study of perceived reflections
Results

Data showing the number of participants rating on the different steps of the Volvo scale

High Power / Light on CS / Look Outside



High Power / Light on DP / Look Outside

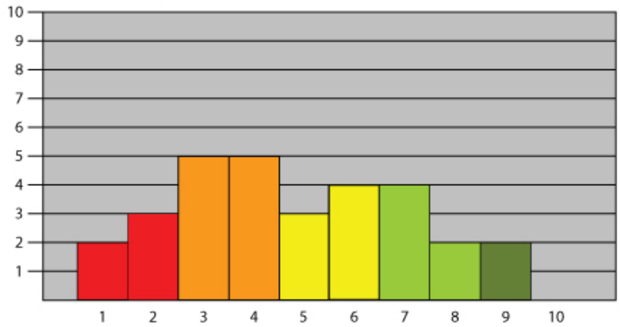


Appendix 9: Study of perceived reflections Results

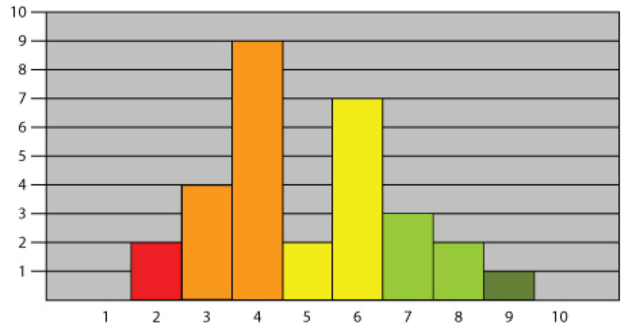
Data showing the number of participants rating on the different steps of the Volvo scale

Low Power / Light on CS / Look at CS

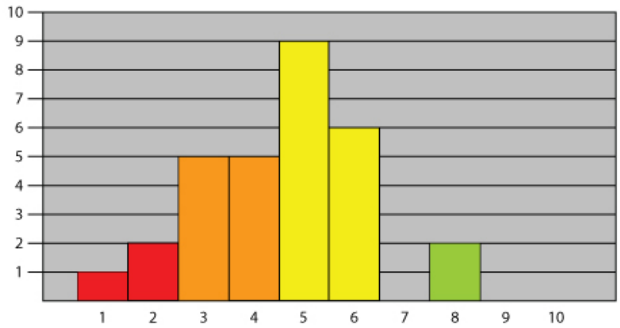
Dark surroundings / Wooden panels



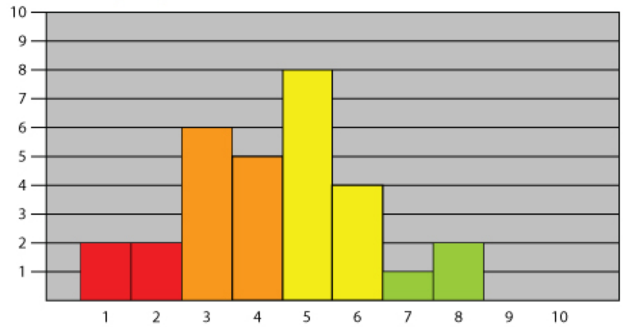
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels

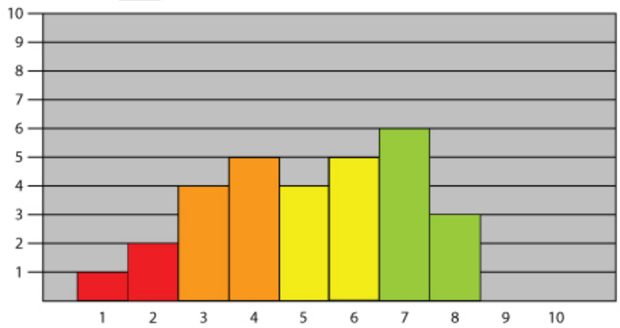


Light surroundings / Aluminum panels

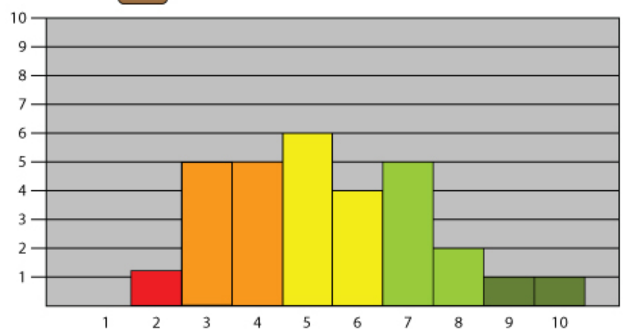


Low Power / Light on DP / Look at CS

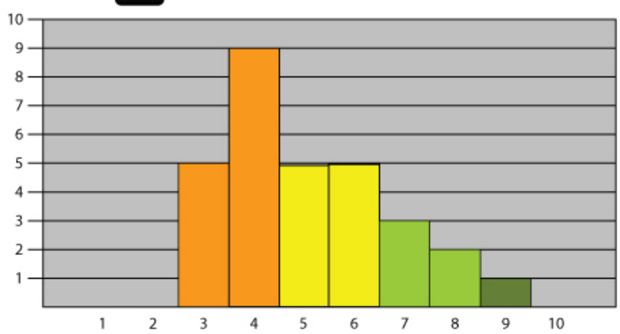
Dark surroundings / Wooden panels



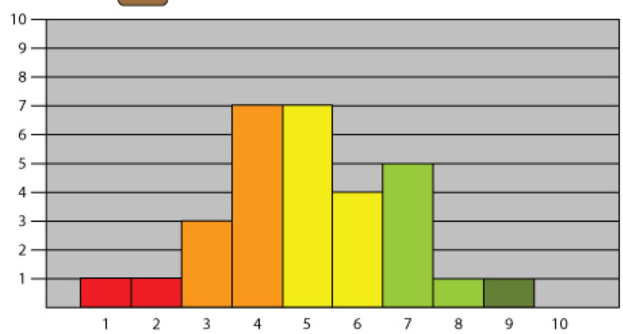
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels



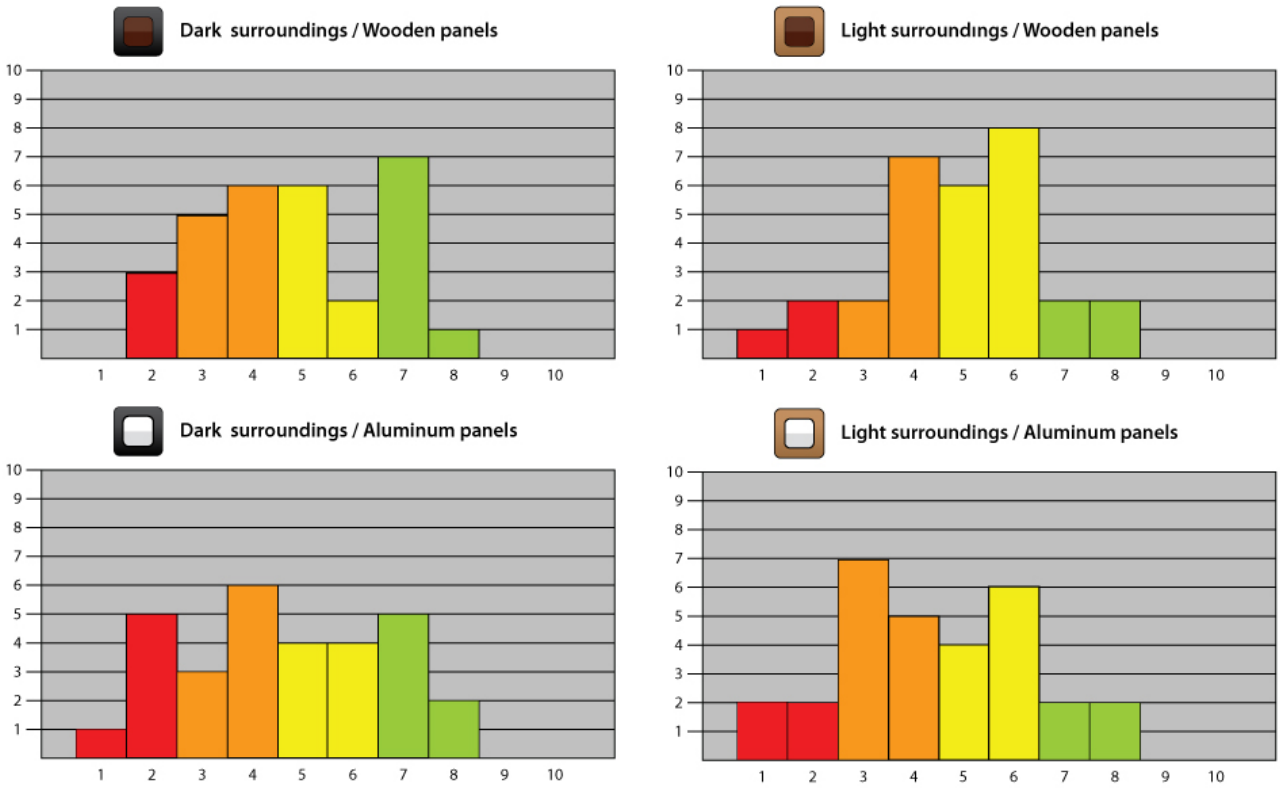
Light surroundings / Aluminum panels



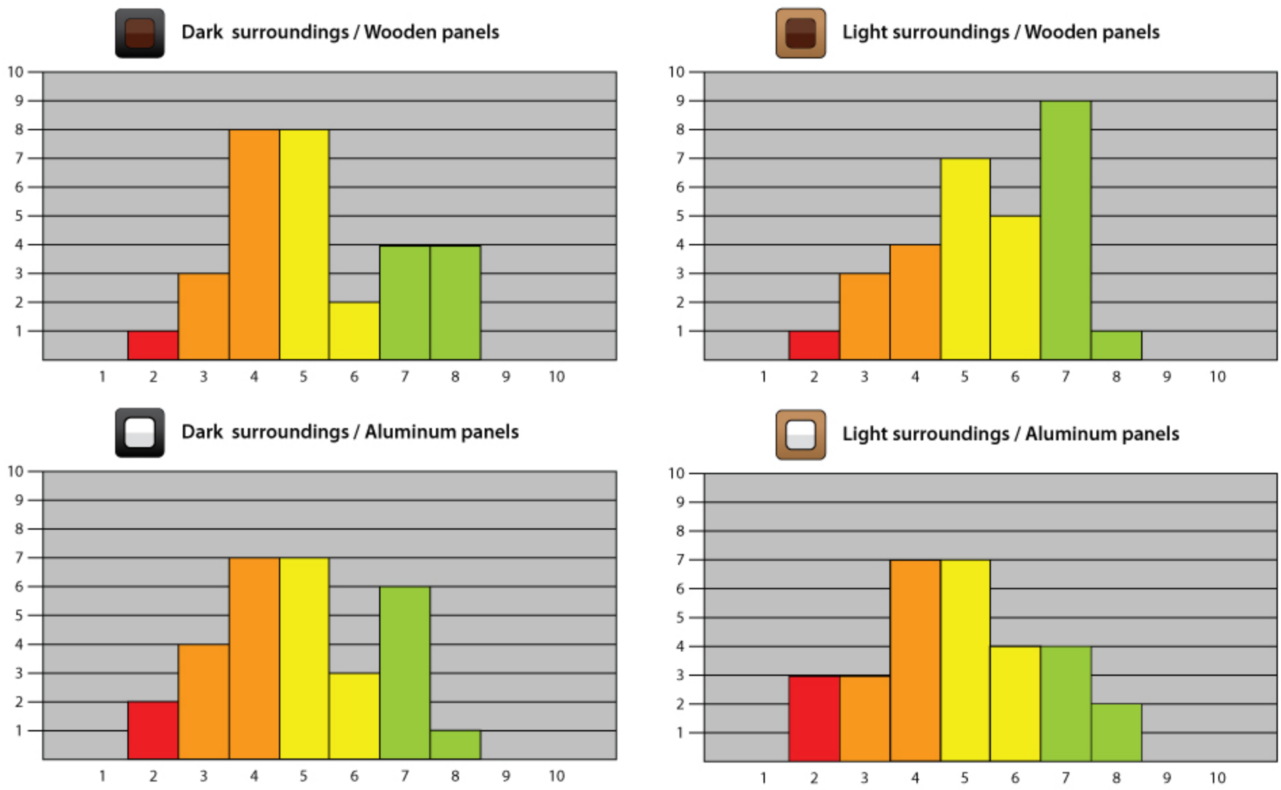
Appendix 9: Study of perceived reflections Results

Data showing the number of participants rating on the different steps of the Volvo scale

Low Power / Light on CS / Look Outside



Low Power / Light on DP / Look Outside

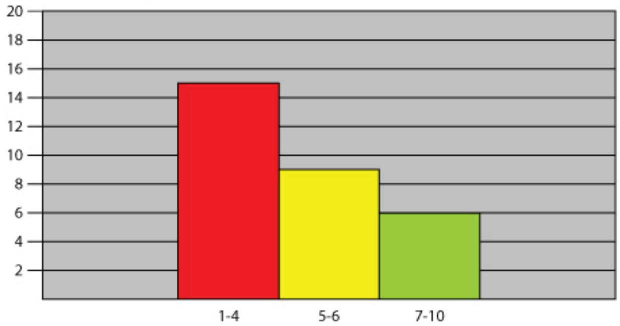


Appendix 9: Study of perceived reflections Results

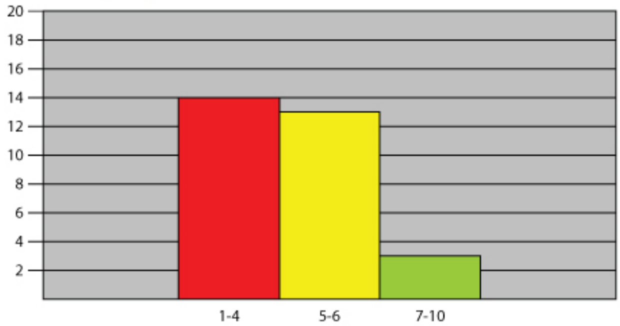
Data showing the number of participants rating on the different steps after grouping information

High Power / Light on CS / Look at CS

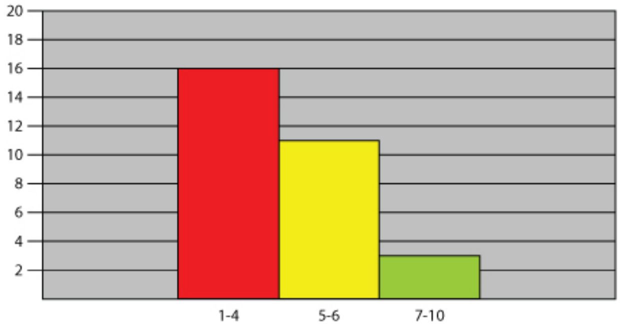
Dark surroundings / Wooden panels



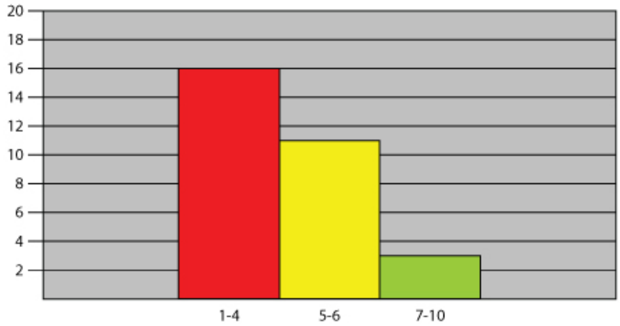
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels

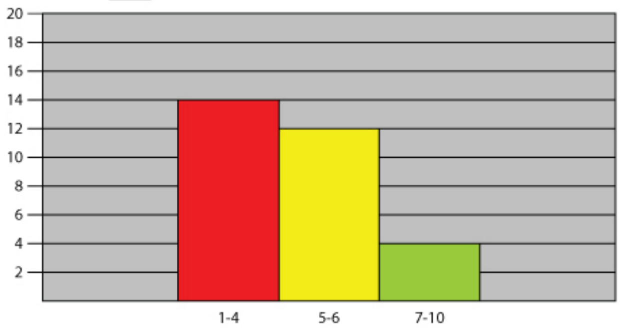


Light surroundings / Aluminum panels

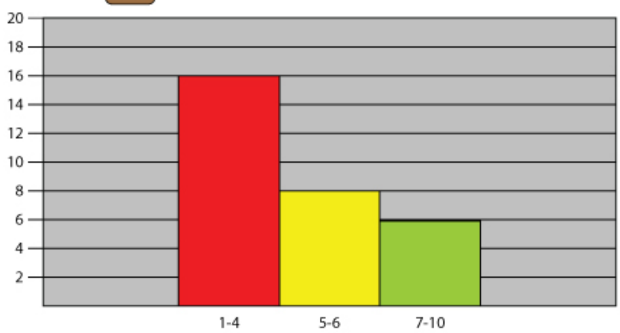


High Power / Light on DP / Look at CS

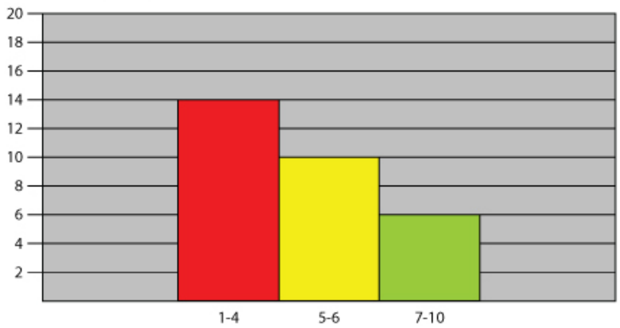
Dark surroundings / Wooden panels



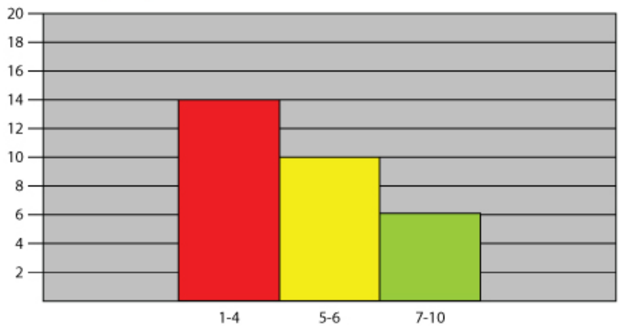
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels



Light surroundings / Aluminum panels

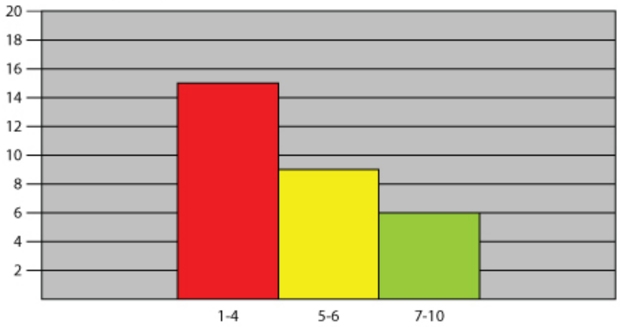


Appendix 9: Study of perceived reflections
Results

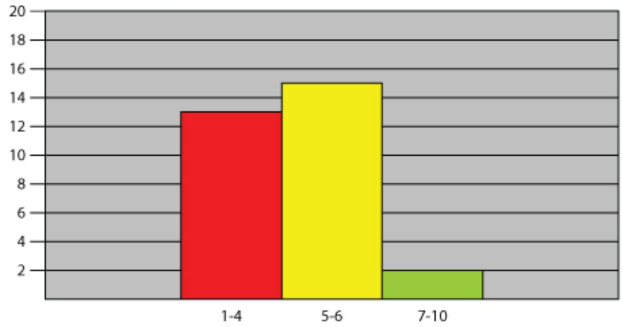
Data showing the number of participants rating on the different steps after grouping information

High Power / Light on CS / Look Outside

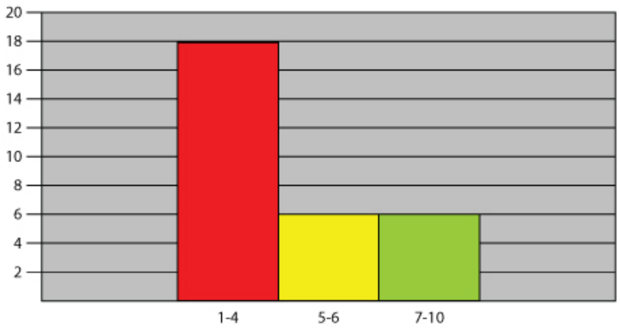
Dark surroundings / Wooden panels



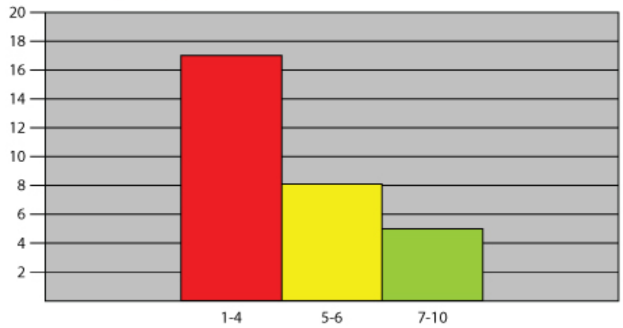
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels

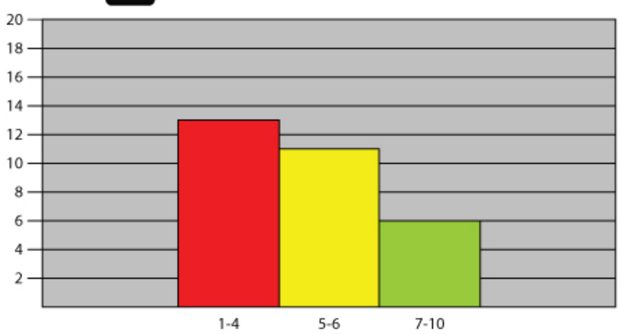


Light surroundings / Aluminum panels

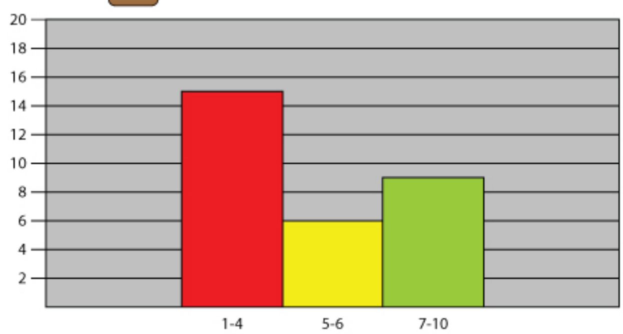


High Power / Light on DP / Look Outside

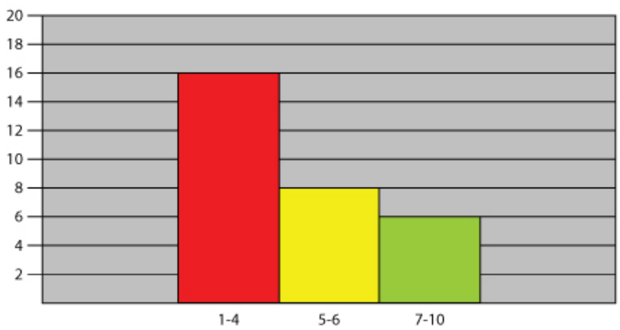
Dark surroundings / Wooden panels



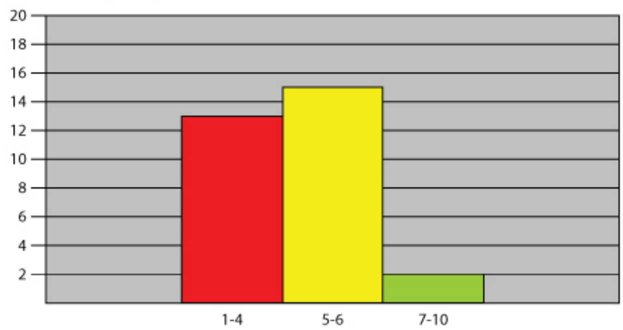
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels



Light surroundings / Aluminum panels

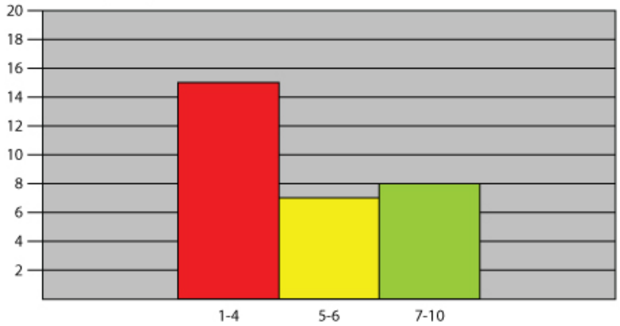


Appendix 9: Study of perceived reflections
Results

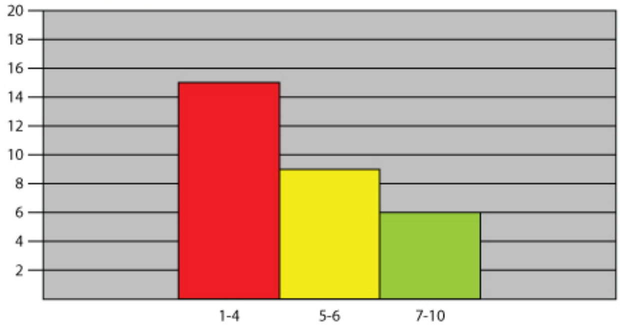
Data showing the number of participants rating on the different steps after grouping information

Low Power / Light on CS / Look at CS

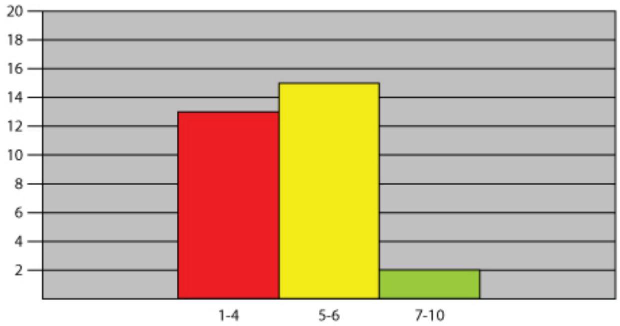
Dark surroundings / Wooden panels



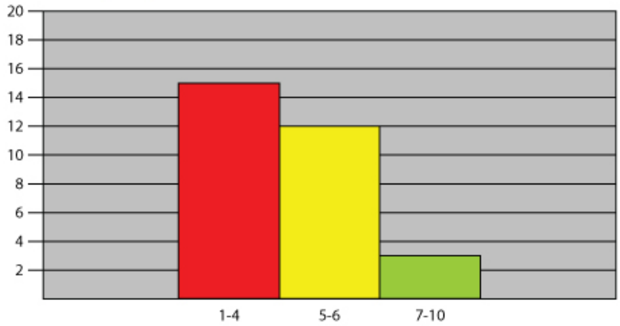
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels

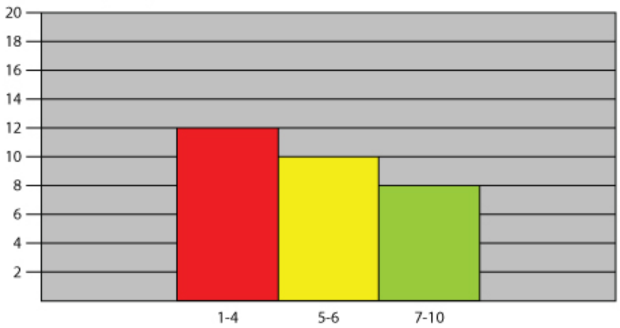


Light surroundings / Aluminum panels

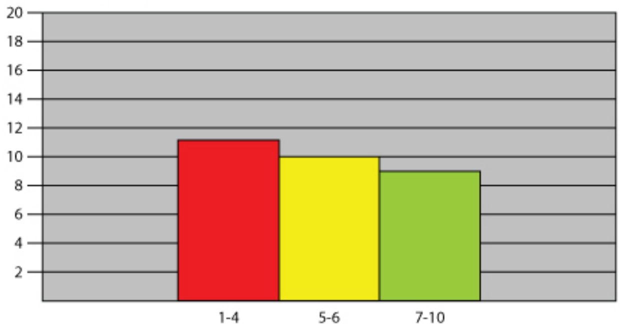


Low Power / Light on DP / Look at CS

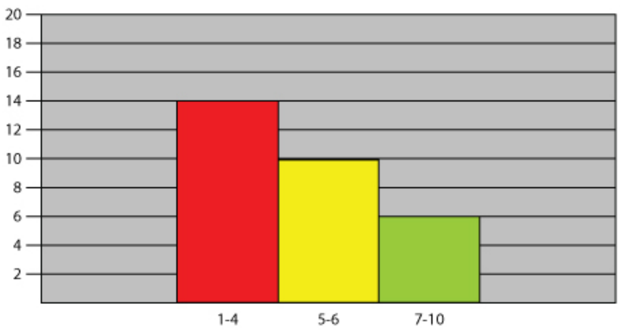
Dark surroundings / Wooden panels



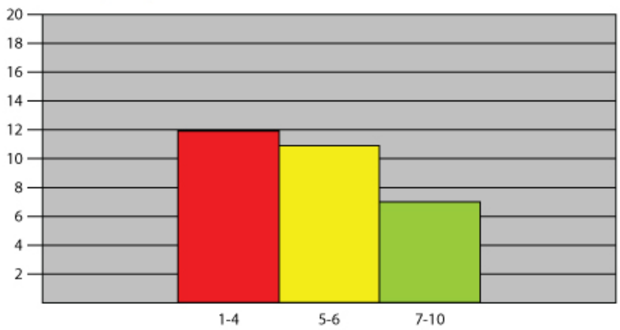
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels



Light surroundings / Aluminum panels

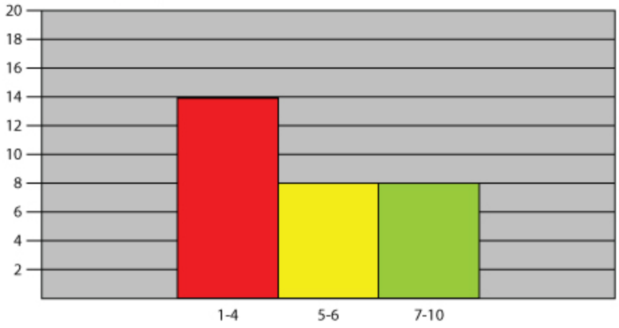


Appendix 9: Study of perceived reflections
Results

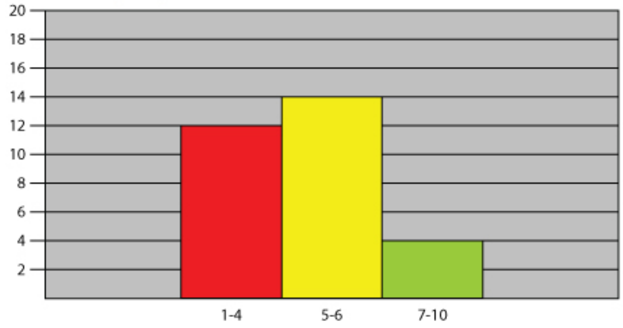
Data showing the number of participants rating on the different steps after grouping information

Low Power / Light on CS / Look Outside

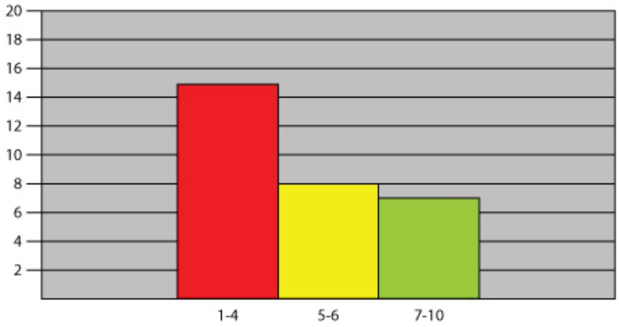
Dark surroundings / Wooden panels



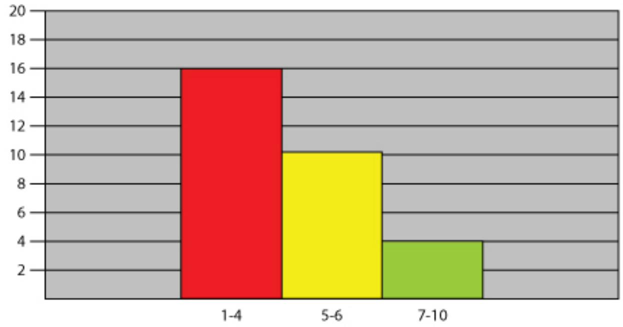
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels

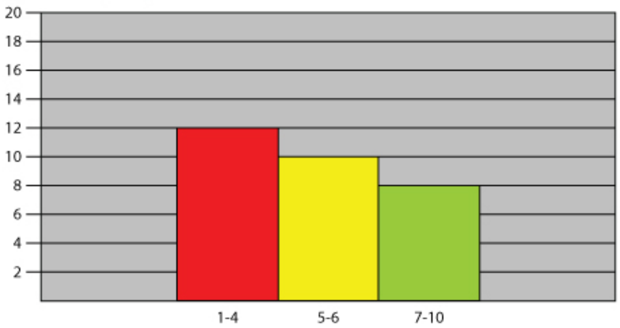


Light surroundings / Aluminum panels

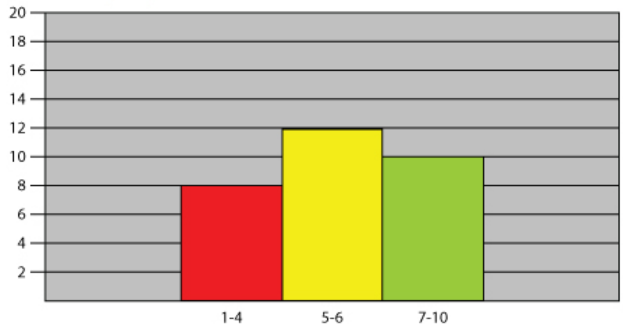


Low Power / Light on DP / Look Outside

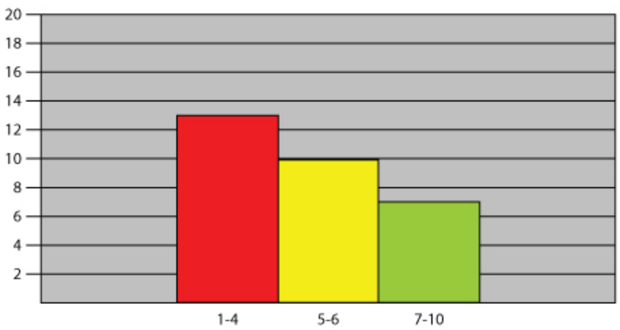
Dark surroundings / Wooden panels



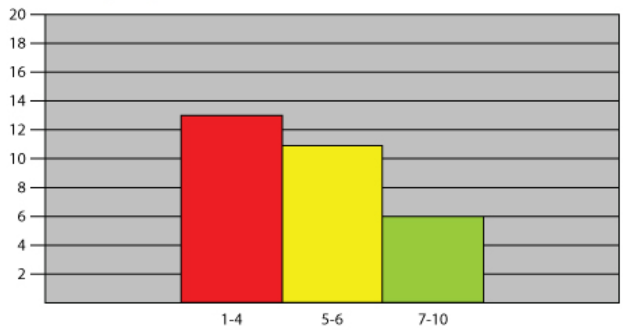
Light surroundings / Wooden panels



Dark surroundings / Aluminum panels



Light surroundings / Aluminum panels



Appendix 9: Study of perceived reflections Results

Comments on Aluminum panel		
Negative	**Neutral**	**Positive**
Aluminum worse	Aluminum spreads light.	Aluminium in dark interior is good. Not as sharp reflection.
Aluminum gives sharper reflection.	Aluminum spreads the light more.	Aluminum spreads the light better, more comfortable.
Aluminium have sharper reflection.	Aluminum spreads the light.	Aluminum spreads more, "warmer" reflection.
Aluminum in dark is the worst.	Aluminum lights up.	Aluminum panels better, spreads the light.
Aluminum spreads light everywhere, a bit more annoying.	Aluminum reflects more.	Aluminum does not reflect as sharp as wood. More even light.
Aluminum glares more.	Aluminum more reflective	Aluminum reflects softer.
Aluminum gives very strong reflection, prefer wood.	Aluminum scatters the light.	Aluminum better in light interior.
Aluminum reflects in the eyes.		

Comments on Wood panel		
Negative	**Neutral**	**Positive**
Wooden trim more directive reflection. Worse.	Wooden has a more point reflection	Wooden is better in black
Wooden is worse in dark car.	Wooden reflects a point.	Wooden reflections feels better.
Wooden more annoying due to direct reflection.		Wooden better in light interior.
Wooden panel worse		Wooden better.
Wooden worse as it has sharper light		
High annoyance from wooden panel. Sharper light.		

Comments on Black Interior		
Negative	**Neutral**	**Positive**
The reflections seems stronger in the black interior		Black feels better
Darker interior makes the reflection worse.		The reflections are more comfortable in dark interior.
The reflections seems sharper in dark interior.		Black is better as reflections becomes softer.
More reflections with dark interior.		Darker is more comfortable.
Dark interiors worst.		Black tones down the reflections.
Dark interior is worse due to higher contrast.		Black is better.
Stonger and sharper light in dark car.		Darker interior absorbs light
		Black interior absorbs light.

Appendix 9: Study of perceived reflections Results

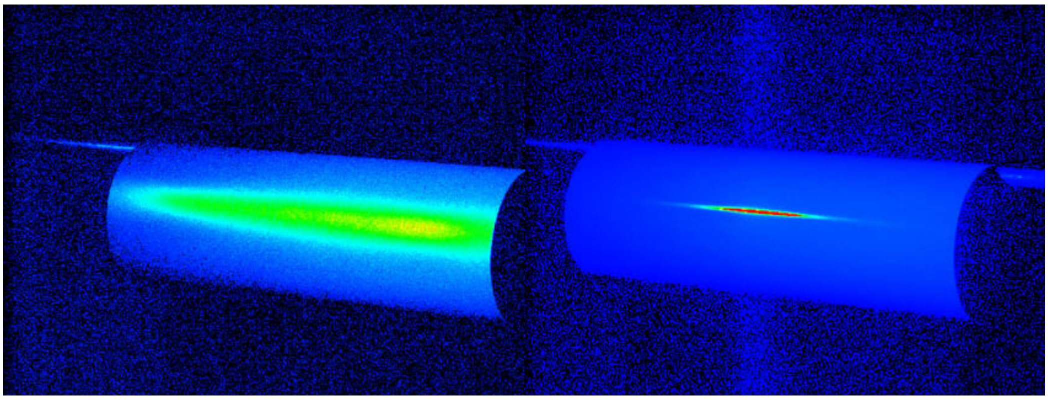
Comments on light interior		
Negative	**Neutral**	**Positive**
Reflections stronger in light.		Light interior feels better.
Reflections more annoying in light interior.		Light better than black overall.
Reflection area feels larger in the light interior		

Other reoccurent comments
- To large contrast with interior is bad.
- Looking at the reflections makes it better.
- Irritating with the reflections from the side.
- Gloss makes the reflections spotty.

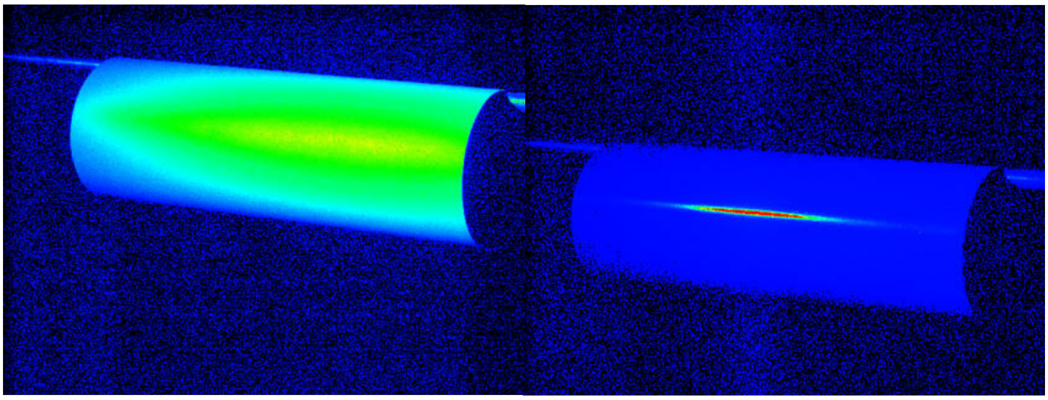
Appendix 10: Study of gloss, lightness and radius

How the glare size differs with different parameter settings

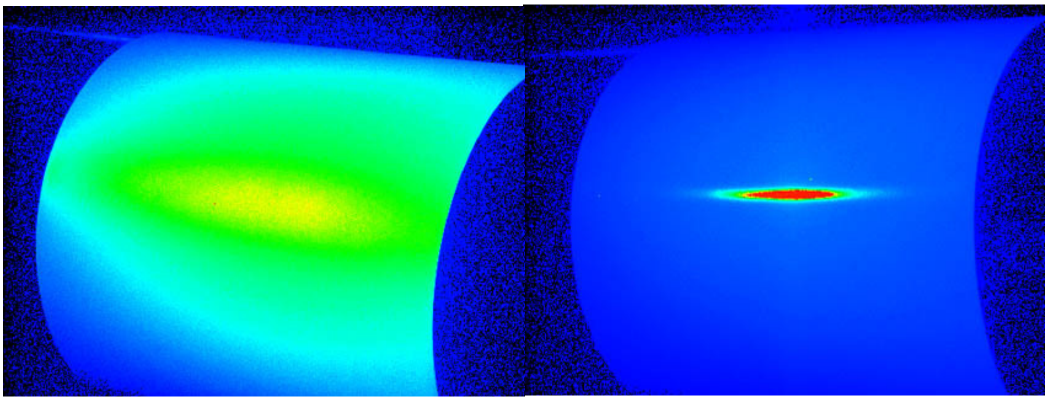
Gloss:25 Gloss:75



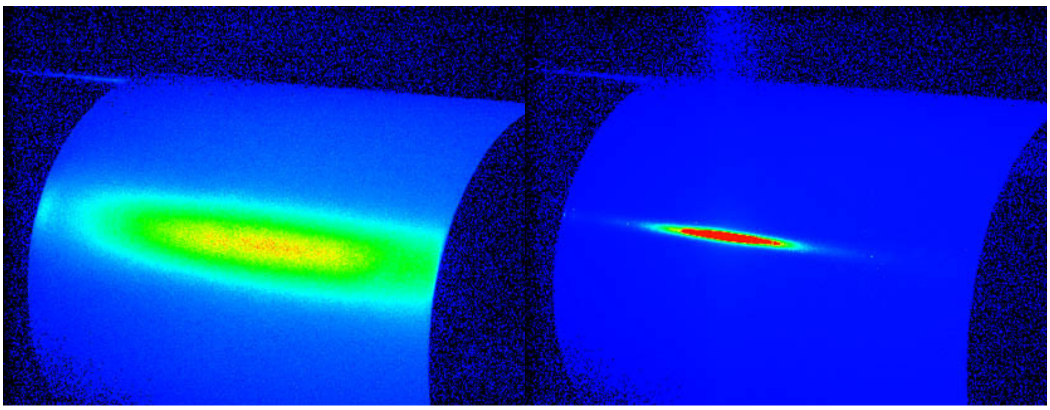
Lightness: 25
Radius: 50



Lightness: 75
Radius: 50



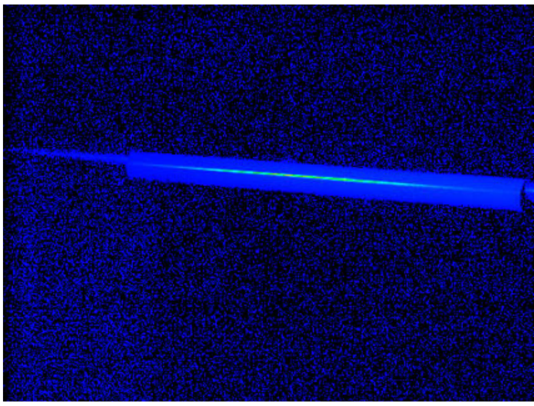
Lightness: 25
Radius: 130



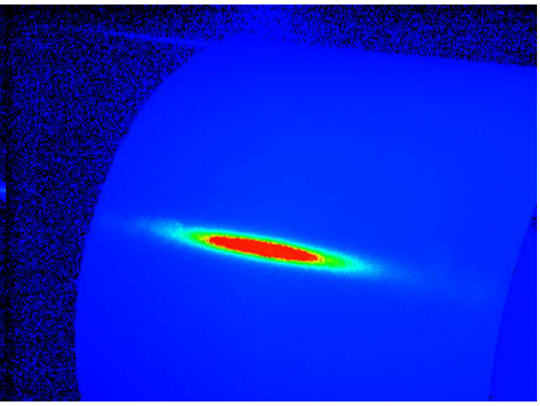
Lightness: 75
Radius: 130

Appendix 10: Study of gloss, lightness and radius

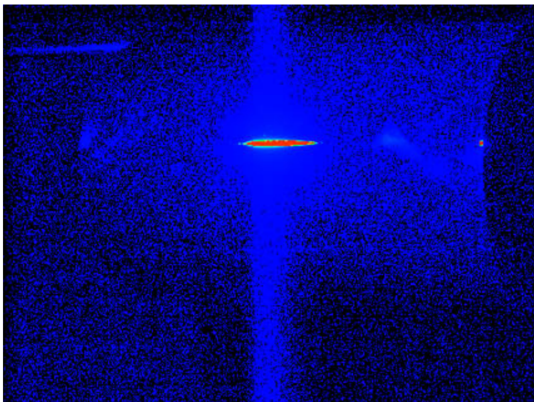
How the glare size differs with different parameter settings



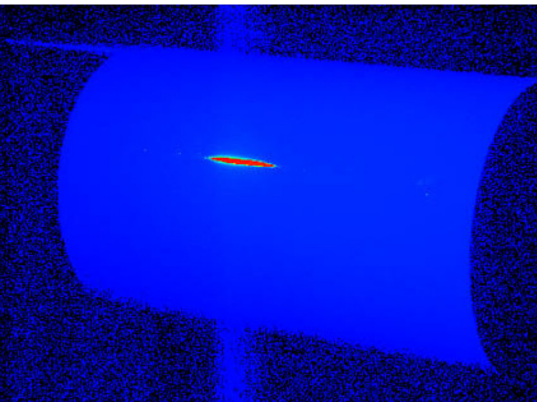
Gloss: 50 Lightness: 50 Radius: 10



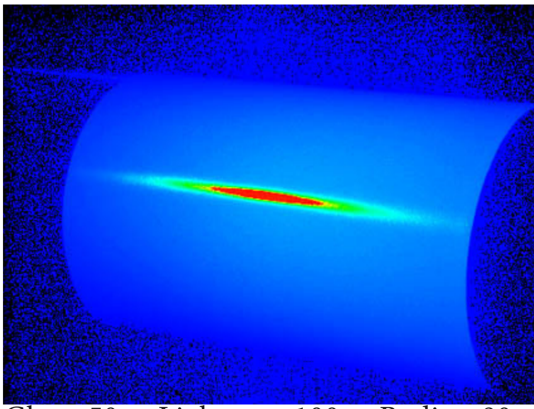
Gloss: 50 Lightness: 50 Radius: 170



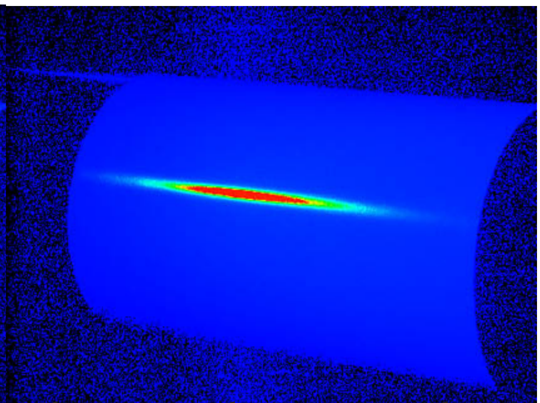
Gloss: 90 Lightness: 50 Radius: 90



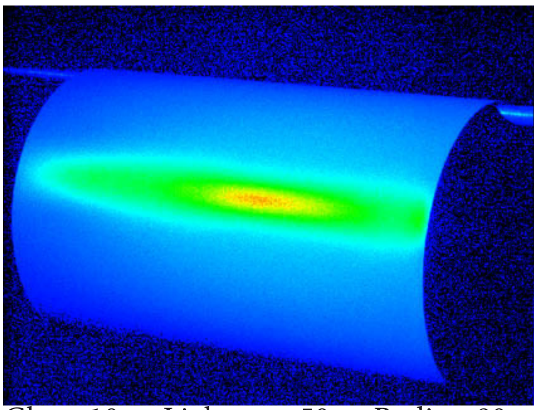
Gloss: 90 Lightness: 0 Radius: 90



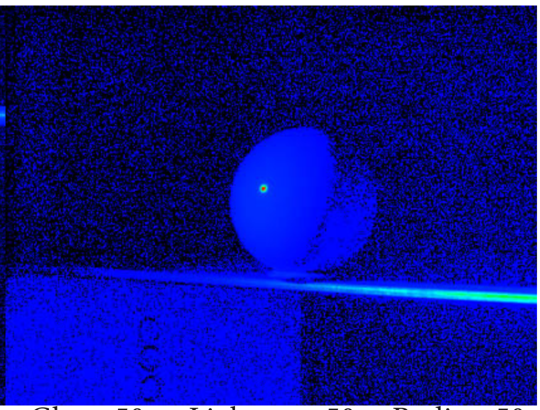
Gloss: 50 Lightness: 100 Radius: 90



Gloss: 50 Lightness: 50 Radius: 90



Gloss: 10 Lightness: 50 Radius: 90



Gloss: 50 Lightness: 50 Radius: 50

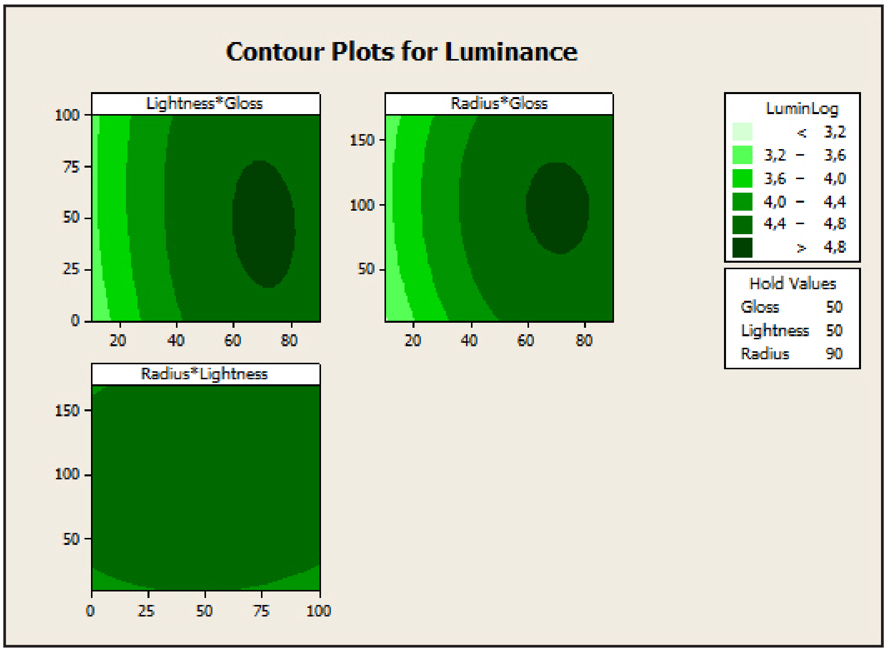
Appendix 10: Study of gloss, lightness and radius

Data showing the luminance for each cylinder setting

	Gloss	Lightness	Radius					Average
1	25	25	50	8482	3506	7676	3364	5757
2	75	25	50	49659	49802	49754	49754	49742,25
3	25	75	50	8529	5022	6160	4644	6088,75
4	75	75	50	49659	49802	49754	49801	49754
5	25	25	130	7060	6207	5023	4975	5816,25
6	75	25	130	50039	49943	49896	50086	49991
7	25	75	130	9000	6966	6823	7392	7545,25
8	75	75	130	49896	50891	49754	50086	50156,75
9	10	50	90	9382	6444	7392	8624	7960,5
10	90	50	90	49659	49802	50275	50086	49955,5
11	90	0	90	51033	50039	50323	49896	50322,75
12	50	100	90	49754	49754	50086	50038	49908
13	50	50	10	31653	34449	34022	32316	33110
14	50	50	170	50086	50039	50275	50086	50121,5
15	50	50	90	50086	49943	49754	49754	49884,25
16	50	50	90	49944	50275	50512	50512	50310,75
17	50	50	90	50039	50275	49896	50275	50121,25
18	50	50	90	49754	49944	49754	50086	49884,5
19	50	50	90	49896	49754	49896	50560	50026,5
20	50	50	90	50560	50086	50086	49659	50097,75

Response Surface coefficients (Using uncoded units, Log values) and the contour plot of the luminance.

Constant	2,43328
Gloss	0,054544
Lightness	0,00585173
Radius	0,00716034
Gloss*Gloss	-0,000367647
Lightness*Lightness	-4,56696E-005
Radius*Radius	-3,46939E-005
Gloss*Lightness	-3,28686E-005
Gloss*Radius	-1,14814E-005
Lightness*Radius	8,32046E-006



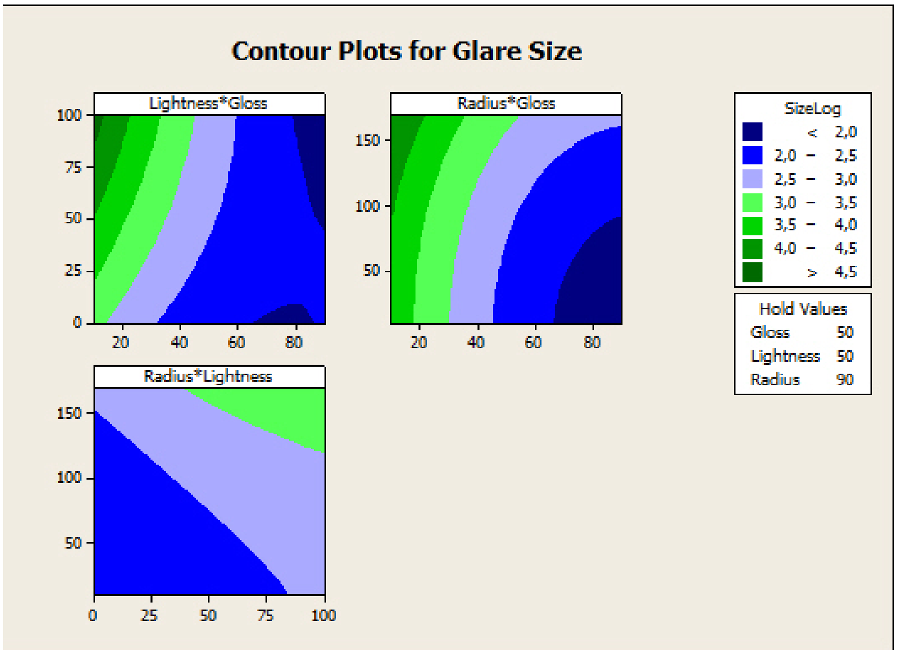
Appendix 10: Study of gloss, lightness and radius

Data showing the glare size for each cylinder setting

	Gloss	Lightness	Radius					Average
1	25	25	50	1920	2210	1120	2091	1835,25
2	75	25	50	141	105,8	139,75	101,2	121,9375
3	25	75	50	3450	7155	6500	6160	5816,25
4	75	75	50	88	96,2	113,1	87,4	96,175
5	25	25	130	3570	3720	4560	4420	4067,5
6	75	25	130	291,5	348,1	272,6	297	302,3
7	25	75	130	11811	14065	15400	13775	13762,75
8	75	75	130	351	286	312	348	324,25
9	10	50	90	2366	3403,66	2839,85	2470,65	2770,04
10	90	50	90	88,9	64,22	72,8	82,07	76,9975
11	90	0	90	76,5	71,63	59,8	78,3	71,5575
12	50	100	90	495	512,4	438,75	539,4	496,3875
13	50	50	10	118,3	140,8	160	155,2	143,575
14	50	50	170	630	633,75	705,6	658	656,8375
15	50	50	90	372,5	353,6	370,24	378,56	368,725
16	50	50	90	353,535	305,045	331,5	370,24	340,08
17	50	50	90	430,65	363,48	441,65	391,6	406,845
18	50	50	90	341,25	398,905	355,16	363,04125	364,5890
19	50	50	90	309,075	276,64	261,3	411,0744	314,52235
20	50	50	90	302,64	312	296,4	285,61	299,1625

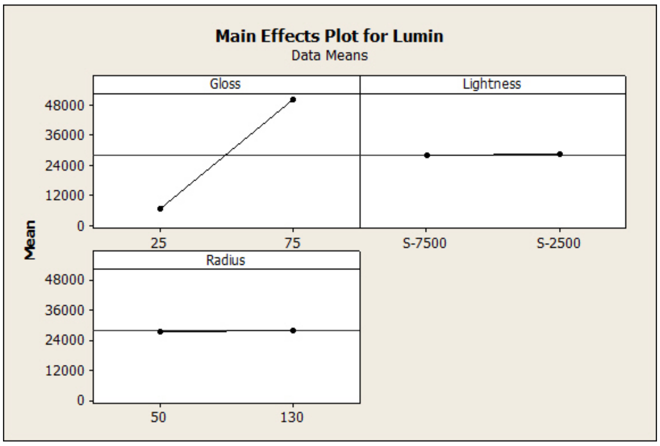
Response Surface coefficients (Using uncoded units, Log values) and the contour plot of the glare size

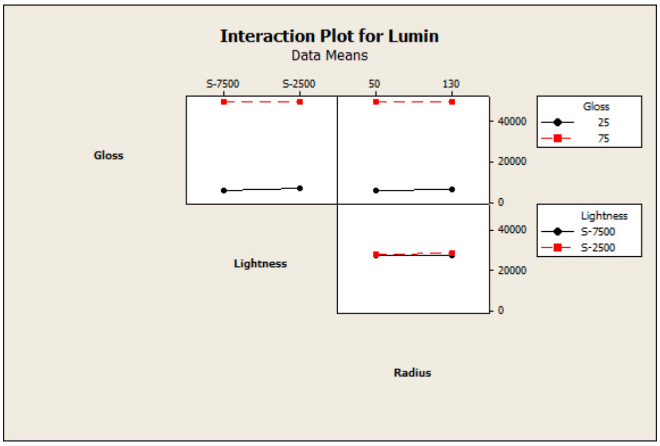
Constant	3,64796
Gloss	-0,0392413
Lightness	0,0141694
Radius	-0,00619495
Gloss*Gloss	0,000239347
Lightness*Lightness	2,02354E-005
Radius*Radius	4,85572E-005
Gloss*Lightness	-0,000219796
Gloss*Radius	2,12563E-005
Lightness*Radius	0,000019005



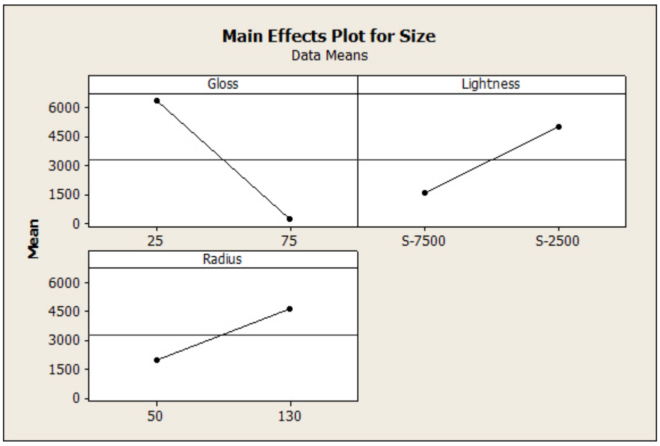
Appendix 10: Study of gloss, lightness and radius

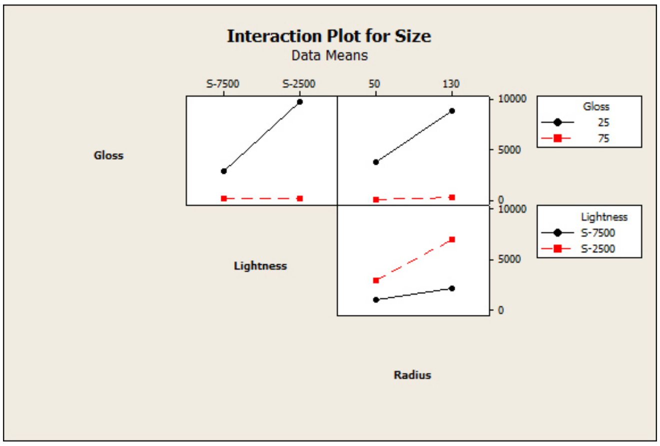
Linear functions showing the parameters affeting luminance



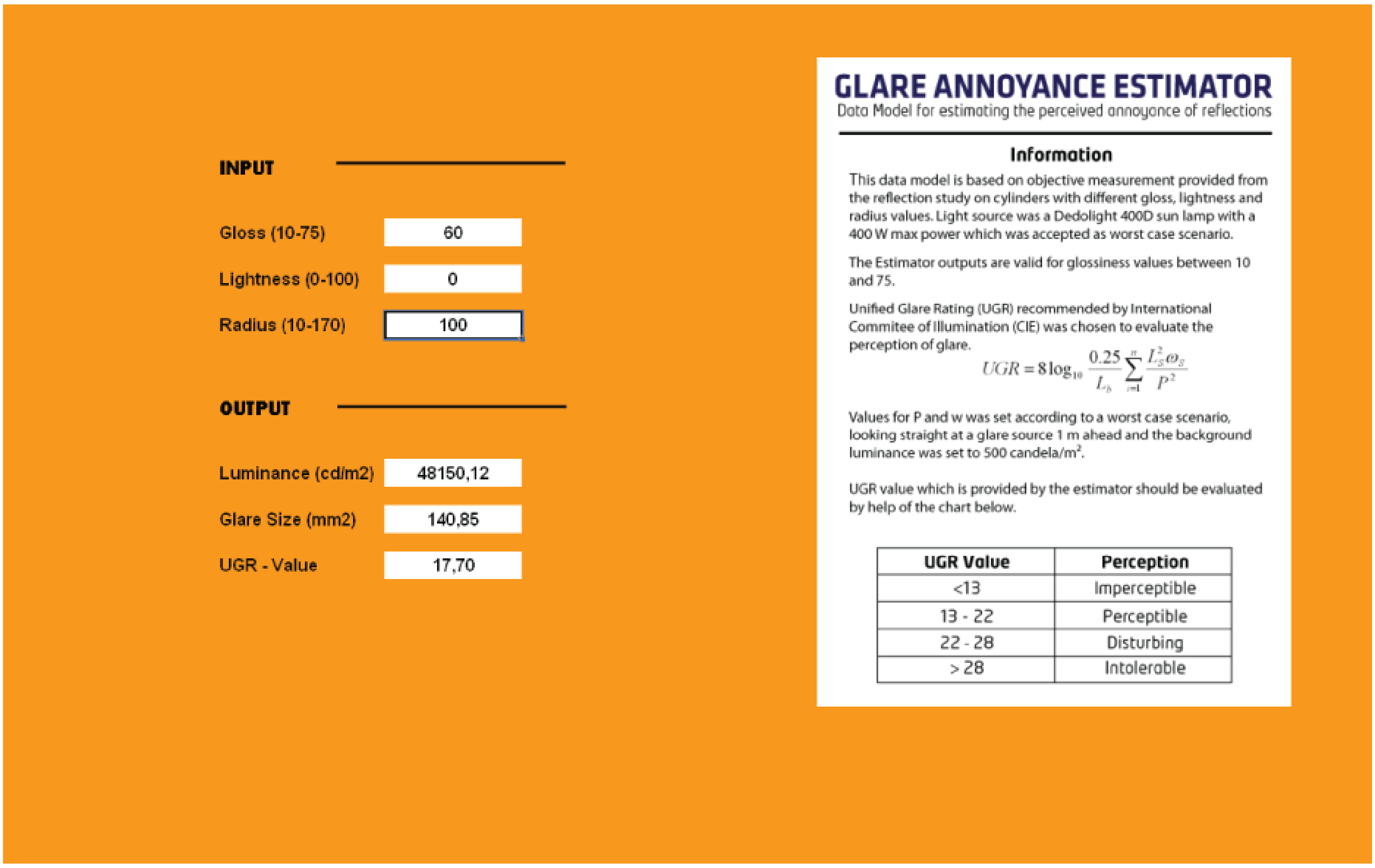


Linear functions showing the parameters affeting glare size

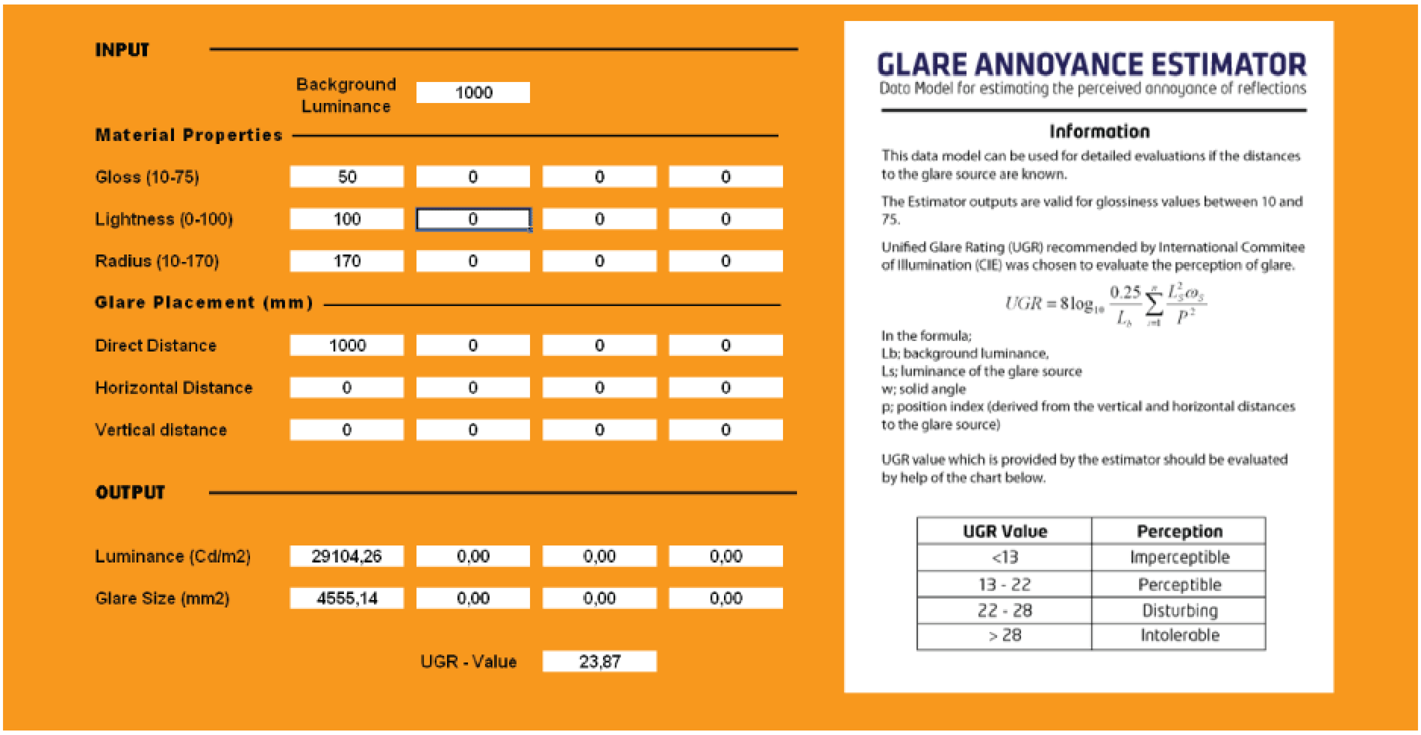




Appendix 11: Glare estimator



Simplified model for estimating luminance, glare size and UGR value for one glare source



Advanced model for estimating luminance, glare size and UGR value for a whole environment