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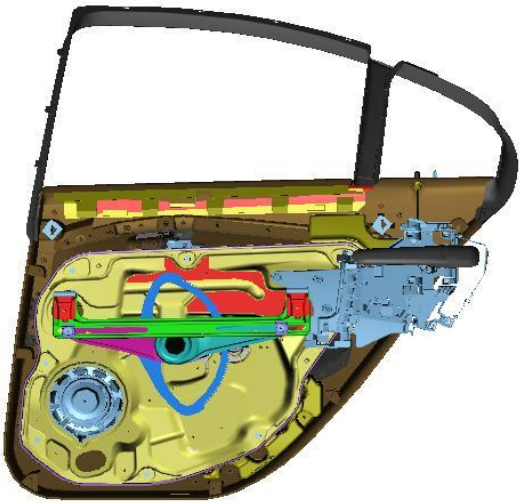

Opportunities with fixed glass in rear doors

Master´s Thesis in the Master´s programme Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden, 2012

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Cover:

Visual mock-up of a Volvo S80 rear door interior panel and its components

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Preface

This report documents the master thesis made for the institution of Product and Production Development (PPUX05) at Chalmers University of Technology in Gothenburg. The thesis was sponsored by Volvo Car Corporation at the department Interior Trim, the Door Panel group (93522) through the spring of 2012.

First we would like to thank our supervisor at Volvo Mattias Westerlund (Strategically responsible for the Door Panel group) who guided and supported us throughout this project as well as Lars-Ove Ohlsson (Manager of the Door Panel group) who took us in and made it possible for us to perform our master thesis. Thanks to Erja Olsson (Annual student leader) for helping us getting started with the project.

A special thanks to Per Hansson (concept leader for Door systems) and Fredrik Stråhlin (Strategically responsible/Concept engineer) who gave us a deeper understanding of car doors and their design as well as being reachable for our questions.

Thanks to Mikael Inghammar (Quality engineer) for providing us with quality aspects regarding car doors and Jamack Rezaie (Product manager) who provided us with contacts at the department of Market Intelligence. Ola Niklasson (Consumer researcher) was kind to grant us access to Volvo´s internal market research and Claes Lindgren was helpful regarding issues related to audio.

A warm thanks to Martin Tomingas (Quality action leader, Chongqing) who took time to distribute our survey to his contacts through China and USA.

We would also like to thank everyone else from Interior Trim, the Door Panel group (93522) for contributing to this project and made our stay enjoyable.

Lastly we would like to thank Dag Bergsjö (Assistant professor) at Chalmers University of Technology, the department of Product Development for supervising us during the semester.

Chalmers, Gothenburg, May 2012

Victor Bergström

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Abstract

This report presents the development of two concepts for an interior rear door panel in a car with fixed windows. The concepts were developed for Volvo Car Corporation in Gothenburg, Sweden. Needs and requirements were identified to design concepts that would be competitive from Volvo's standpoint and also differentiate them from their competitors. Performing a market study and analyzing the current market situation also resulted in a requirement specification.

The main function of the traditional rear door includes having an operable window, which means that the window can be rolled down to a certain extent. This projects main goal was to investigate the advantages, driving factors and possibilities to implement a fixed rear door window. Due to the conservative market, the development has included overseeing what functions that can compensate the need for an operable window.

Product development methods taught from Chalmers University of Technology in Gothenburg were applied to choose and design door panel concepts with fixed windows. The result of these carried along two final concepts where one of them included much storage capability and the other one was more technology inspired with multifunctional properties.

The authors' conclusions and future recommendations include an emphasis on being different from the competitors hence putting efforts in creating products that are unique for the automobile industry.

Sammanfattning

Denna rapport presenterar utvecklingen av två koncept av en bakre bildörrspanel med fast glas för Volvo Personvagnar i Göteborg, Sverige. Behov och krav identifierades för att utforma nya koncept som kan leda till differentierade och konkurrenskraftiga produkter från Volvos synvinkel. Därmed konstruerades en kravspecifikation med hjälp av en marknadsstudie samt en analys av det rådande marknadsläget.

Den huvudsakliga funktionen i den bakre dörren inkluderar idag att ha en manövrerbar fönsterruta. Projektets främsta mål var att undersöka fördelarna, drivande faktorerna och möjligheterna med att implementera ett fast glas i bakdörren. På grund av en konservativ marknad har utvecklingen inneburit att övervaka vilka funktioner som kan kompensera behovet av att ha ett öppningsbart fönster.

Produktutvecklingsmetoder från Chalmers Tekniska Högskola i Göteborg, tillämpades för att designa och välja dörrpanelskoncept med fasta glas. Resultatet av dessa frambringade två olika koncept där ett av dem inkluderar mycket förvaringsutrymme medan det andra var mer tekniskt inspirerat med multifunktionella egenskaper.

Författarnas slutsatser och framtida rekommendationer inkluderar en betoning på att differentiera sig från konkurrenterna och följaktligen att anstränga sig för att skapa produkter som är unika inom bilindustrin.

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1. Introduction

The report begins with presenting the background, aim, objective and scope of the project. The introduction chapter is thought to provide the reader with enough information to understand why the project was executed, what results were sought and what aspects around the project that were chosen to not be regarded. This chapter is followed by theory around the car door design and their included components to provide the reader with knowledge around the project objectives.

1.1 Background

Volvo Car Corporation is an automobile manufacturing company with headquarters in Gothenburg, Sweden. The first Volvo car was completed on the 14th of April 1927. The company founders were the SKF employees Assar Gabrielsson and Gustaf Larsson. Like today the guiding star of the car construction is safety and quality and the cars were initially designed to cope with Scandinavian climate and terrain (Volvo Personbilar Sverige Newsroom, 2012). Since 2010 Volvo Car Corporation is owned by the Zhejiang Geely Holding group based in China and the main production facilities are situated in Torslanda in Sweden, Ghent in Belgium and Chongqing in China. The product flora consists of 4 different series divided by the make of the car with a couple of variants within each series; Sedan, Estate, Sports Utility Vehicle (SUV) and Coupe/Convertible. Volvo Car Corporation employ around 20 000 people worldwide and the five largest markets are USA, Sweden, United Kingdom, China and Germany. The sales of 2010 were 373 525 cars delivered to end customers and the market share in Sweden is around 20 percent (Volvo Car Corporation, 2011).

The automotive industry being highly competitive, constant efforts of improvement, innovation and differentiation are required to maintain a competitive edge. The advanced climate and ventilation systems included in the modern Volvo cars have awoken the question of whether there really is a need to open the car door windows. Since the driver sometimes needs to reach out of the car to e.g. pay road tolls or parking fees the current opinion is that the glass of the front doors has to remain operable. However, since no such interaction is required from the back seat position the option of fixing the windows in the rear doors is still possible. Volvo C30 which is a two door coupe is already equipped with fixed glass in the back seat. Inoperable windows in a car without rear doors are accepted in public but to implement the same principle in a car with four doors or more is somewhat different and more controversial.

The space occupied by the window opening mechanism can be put to other uses if replacing an operable window with a fixed one. There are also internal advantages and driving factors with implementing fixed glass such as reducing cost, weight and enhancing storage capability. The weight and cost that will be saved are in detail described in section 4.1.1. The storage area that becomes available is illustrated in Figure 1 and can roughly be said to be the space between the yellow and the grey part.

The car door consists of three parts; the interior panel that is red in Figure 1, the yellow part is the door module and the grey part represents the exterior panel. The door module contains a speaker and window motor which makes the window operable among other things. If removing the option of rolling down the windows, the door module can either be shaped like a bowl towards the grey exterior part or simply be removed. If the door module can be removed, the red interior part can instead be pushed more against the exterior. The parts will be described more in detail in the theory chapter of the report.

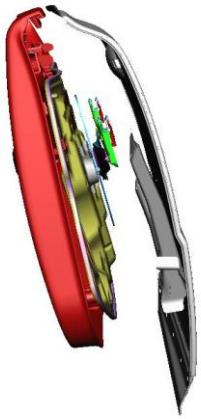

Figure 1 Rough visualization of the space freed by window fixation

Combining weight and cost reduction as well as enhancing storage capabilities might lead to competitive advantages and increased customer satisfaction provided that general acceptance of inoperable windows in the rear doors of Volvo cars is established.

Volvo does not put themselves in the same category as Toyota, Nissan, Renault, Peugeot, Hyundai, Citroën or Skoda since they do not produce as many cars each year. These companies also afford to sell their vehicles at a much cheaper price than Volvo and their main competitors BMW, Audi, Mercedes, Lexus and Acura. Volvo does not have the same manufacturing capacity as the cheaper brands and can therefore not afford to sell the vehicles at an equally cheap price. Volvo and the more luxurious brands rely more on prestige rather than volume (Volvo Car Corporation, 2012). Figure 2 shows a breakdown of the companies that make many cheaper cars versus few but more luxurious. The brands that are on the left side of the white arrow show companies that manufacture a large amount of less luxurious vehicles compared to the ones on the right side of the arrow. Volvo´s goal is to lean more towards the right side of the arrow indicating that they would produce luxurious and high quality products. Note that Acura is not present in Figure 2.

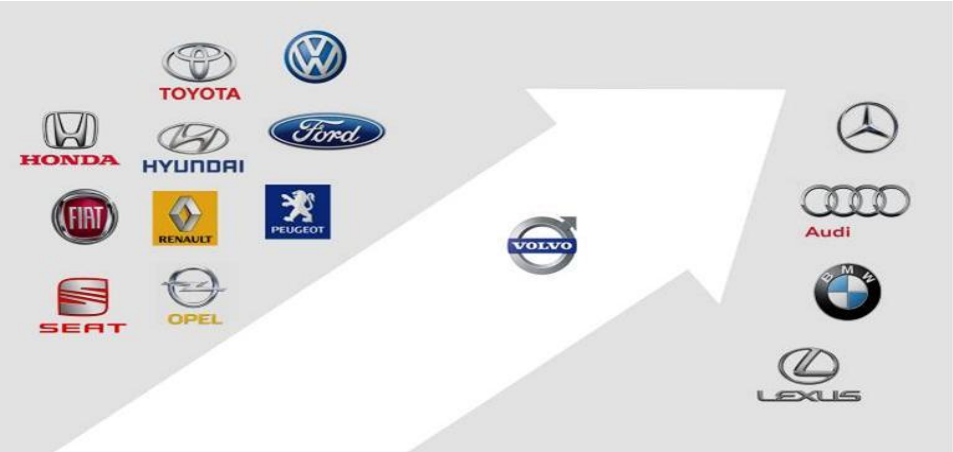

Figure 2 Volume VS Prestige (Volvo Car Corporation, 2012)

1.2 Aim

When purchasing a car with four doors the customer more or less takes for granted that the windows are operable in the front and the rear doors. By removing the option to roll down the back seat windows there is a risk that the customers perceive a loss of functionality. Furthermore, outside of Sweden Volvo cars are considered to be luxurious and exclusive and fixed rear windows might be considered as a feature of a more economical car. Such perceptions would damage the brand image and probably have negative effects on sales. The satisfaction on the other hand, of customers that have already purchased a vehicle with fixed rear windows is not likely to be heavily affected since a rational need for opening the rear windows is not usually present in modern cars.

The aim of this project is hence to evaluate the possibilities of fixing the back seat windows in order to make place for other functional solutions. The utilization of the created space must be perceived as equally or more convenient for the customer than being able to roll down the window. Since operable windows is a feature that is deeply rooted within the mind of the average driver, the most challenging aspect of the project is to generate solutions that convey the value created in place of the movable glass.

1.3 Objective

The objective is to develop concepts for the rear door interior panel that justifies the fixation of the window. The concepts shall vary to fit the different price ranges of the different Volvo cars and could be made as optional features within car purchase. Modular solutions should be sought in order to facilitate production and assembly. The result of the project will hence be a redesigned rear door interior interface along with different applicable panel modules. A target of two concepts ranging from low to high price shall be developed and each concept shall be modeled virtually.

1.4 Scope

The concepts created will serve as functional descriptions of new door panels. Internal and external requirements will be regarded when designing the concepts but since the concept design is to merely demonstrate the functionality of the concepts, not all requirements regarding for

example assembly and choice of material will be taken into account. The designed concepts will hence not be ready for production when finalized.

The project scope is set to parts that are directly affiliated with the interior panel of the rear doors only (see section 2.1.2). The possibility to move components from other parts of the car into the rear doors and thus create space somewhere else will not be investigated.

Parts of the car indirectly affiliated with the door interior panel will not be subjects for redesign. Some parts constraining interior panel design will be assumed to be modifiable. The rear side door outer panel and the impact member (see section 2.1.3) as well as the door opening mechanism mounted to the door module (see section 2.1) will however be considered as a fixed input and constraint. Parts that are not connected to the doors will neither be redesigned in any way.

Only cars with four doors or more will be considered. Inoperable glass in the back seat of cars without rear doors is common on the market. The innovative idea behind the project presented in this report is to remove the window operability on cars with rear doors to replace it with something that the customer might consider more valuable. The case of the concepts developed being applicable to three-door cars as well will in that case be regarded as a bonus.

Alternative ways of opening the rear door windows will not be constructed in detail. Possibilities that do not require the glass to slide within the door will be briefly discussed if an essential need for somehow opening the rear windows is identified during the project.

The assembly process of the complete car will not be redesigned within the project frames. The manufacturing and assembly of the new door features will be regarded separately and an adaption to the production line at Volvo Car Corporation’s facilities will not be done.

Pricing or market launch decisions will also be omitted throughout the project.

2. Theory

As mentioned in chapter 1, this part of the report presents the most important facts concerning the design of a car door. Initially there will be an explanation of how a car door is constructed and the current available features. Throughout the report different body types of cars will be continuously mentioned as well as different Volvo car models which will also be explained in this chapter. It also provides the reader with terminology and knowledge needed to fully comprehend the project methodology, results and conclusions presented in the report.

2.1 Rear door structure

The rear doors are made out of three main parts; interior panel, exterior panel and a door module which is mounted in between the interior and exterior panels. Each main part will be explained further in the succeeding sections. Figure 3 shows the rear door on the Volvo car model S80 with transparent exterior panel and visible door module.

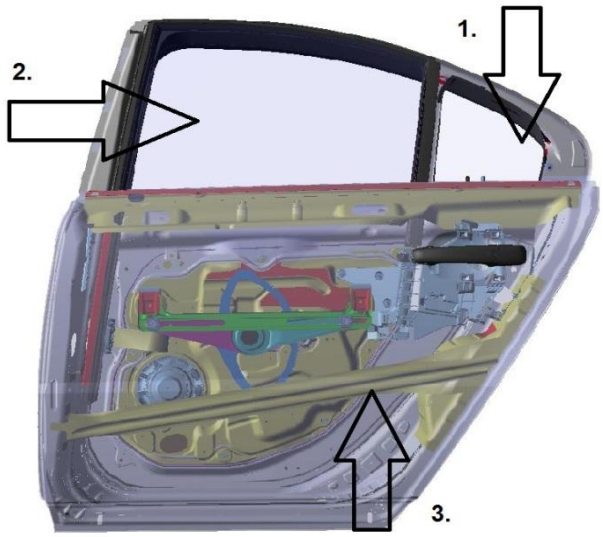

Figure 3 Rear door with transparent exterior panel

The interior panel is visible in Figure 5. The door module, which is visible in Figure 4, contains the components related to the function of movable windows (#2 in Figure 4) as well as the speakers (#3 in Figure 4). A multifunctional bracket containing a guiding track for the glass window and the door opening mechanism (#1 in Figure 4) and other components such as electric wires not shown in the picture are also included in the door module. The yellow fundament in Figure 4 is called the carrier plate on which the components mentioned above are mounted.

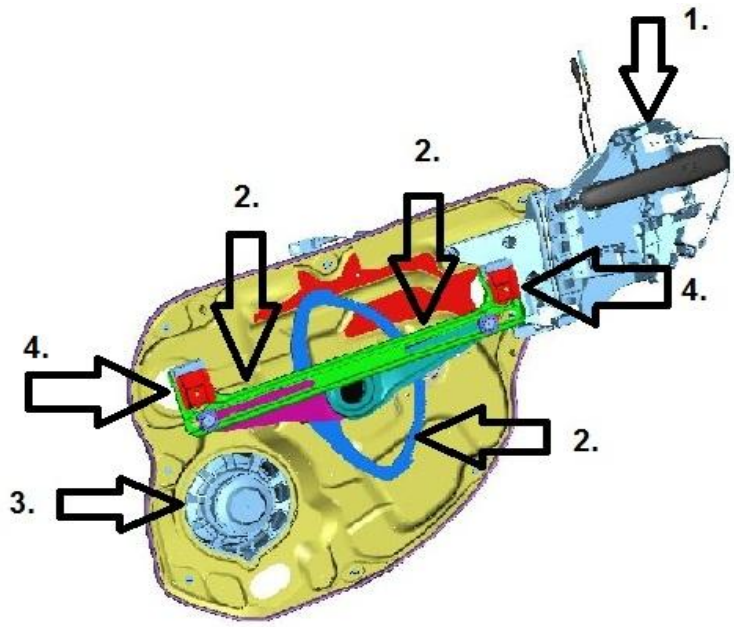

Figure 4 The door module and its main components

The window elevator in Figure 4 has to be aligned with the glass window and thereby constrains the structural options regarding the plate and also splits the space between the exterior and the interior panel. The glass window is attached to the elevator with clipping mechanisms (#4 in Figure 4). The blue gear like component and the arms extending from it (#2 in Figure 4) has on door modules present in models newer than the S80 been replaced with a wire mechanism to minimize weight and to save space. Rear doors of lesser size usually only have one clipping mechanism for window attachment which in that case is placed in the middle of the window elevator.

Figure 5 The rear door interior panel

Quarter glass (#1 in Figure 3) is present on some car models depending on their design. The quarter glass is non-movable and is separated from the movable glass (#2 in Figure 3) with a

vertical ledge. It exists on some models because the door geometry prevents a glass spanning the whole window area to slide down properly between the door panels. The door geometry is in turn, constrained by the wheel housing placed behind the rear door which leads to that the glass window has to be split in one movable and one non-movable part to be operable to a maximum level. The rear door window however, is also constrained to completely slide down between the panels because of the impact member (#3 in Figure 3). It is therefore not possible to open the rear door window to its full extent.

2.1.1 Carrier plate structure

The main reason why the included components of a car door are mounted on a carrier plate is because it promotes and eases the assembly and thus saves time. The components included in the door module are separately assembled before reaching the Volvo production plant. Instead of having to mount each component separately, the production staff needs only to fit and assemble the carrier plate and then connect the wires necessary. The geometry of the plate with different ribs and protrusions is designed to promote stiffness as well as strength. If the carrier plate was made flat, it would possess lower resistance to bending which could lead to component damage and quality issues such as rattling sounds while driving.

Various holes are also manufactured into the carrier plate surface. They function as handles during assembly as well as passage routes for wires and cables. These holes have to be sealed off against air and water. Terminology commonly used when describing car door design includes a wet and a dry side. Because the window when opened slides between the interior and exterior panel of the door it is not possible to completely seal the slide opening against water. In case of the windows getting wet, water will leak in behind the door exterior panel. The area between the door module and the exterior panel is therefore called the wet area. The wet area is depicted as the space to the right of the yellow door module in Figure 6. Components mounted in the wet area thus have to be waterproof. The surface of the carrier plate facing the interior is sealed off by a rubber strip at the outer edge of the plate and different plugs sealing the various holes manufactured in the plate. Hence, the area between the door module and the interior panel is referred to as the dry area.

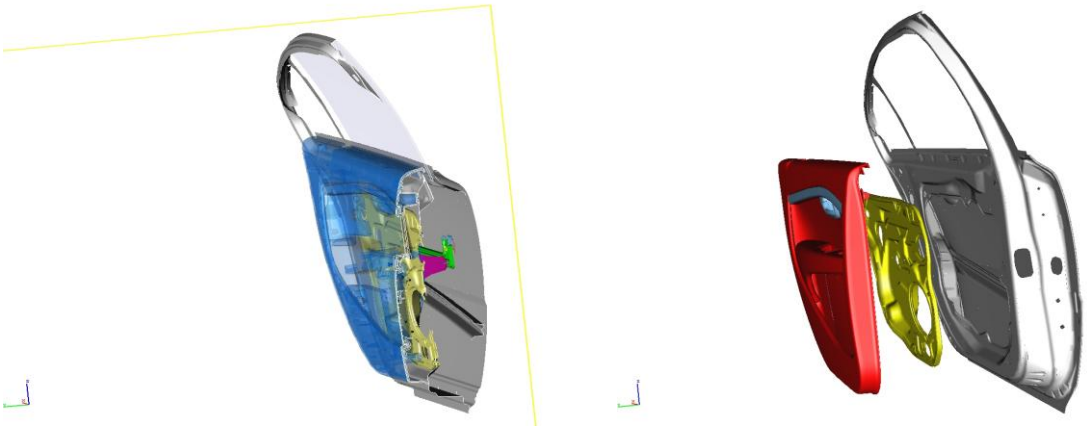

Figure 6 Rear door components visualizing the wet and dry area

2.1.2 Interior panel structure

The interior rear door panel mainly consists of four parts. An interior panel carrier which is the yellow part in Figure 7, an upper insert and a door pocket which are the red and the details black in Figure 7, and an armrest which is the blue part in Figure 7. The insert, the pocket and the armrest are mounted onto the panel carrier which in turn is mounted to the exterior panel of the rear door.

Figure 7 Rear door interior panel and its' main components

The upper insert includes the interface to the door opener and the pocket includes a stowage compartment as well as the speaker attachment. The armrest attachment is positioned between the two inserts. Figure 7 also includes two impact absorbers which are the green details. They are mechanically spring loaded devices that smoothens and dampens an eventual collision.

2.1.3 Exterior panel structure

Figure 8 represent the rear door exterior panel. The part presented in blue color is called the outer plate and the yellow part is referred to as the inner plate. The impact member is the red device in Figure 8. It is located at different positions in car doors of different models. The purpose of the impact member is to absorb and distribute forces in case of a side collision and it is made out of the metalloid Boron. Crash tests and simulations at Volvo usually govern the outcome of where the impact member will be mounted. Some cars on the market provide the possibility to open the rear door window to full its extent. On Volvo cars on the other hand, they can only be lowered to a certain degree. This is due to that the impact member blocks the path of the glass window. Cars with the possibility to open the rear door windows to their full extent might either lack the impact member or have it positioned in another way than what can be seen in figure 8.

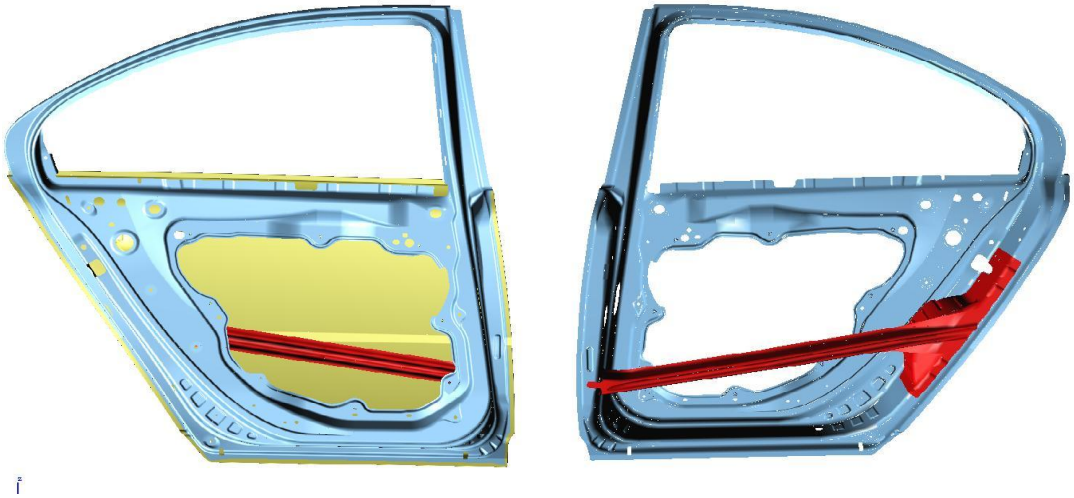

Figure 8 Rear door exterior panels

2.2 Kano model

The Kano Model is an effective tool used within Product Development and it helps to prioritize and identify which qualities and characteristics that are important to consider when satisfying the customers' needs (Process Excellence Network, 2012). As can be seen in Figure 9, there are three different customer preferences; dissatisfiers, satisfiers and delighters. Dissatisfers or hygiene factors are requirements that a customer expects to be fulfilled within a product that they consider purchasing. If these requirements are not fulfilled, the customer is very unlikely to buy the product in question. Requirement fulfillment will not however, satisfy the customer but only qualify the product for purchase. An example of a dissatisfier can be the possibility to steer your car. Satisfiers on the other hand are requirements that a customer expects the product to fulfill but as the level of fulfillment increases, the customer gets more and more satisfied. Example of a satisfier can be that the car handles really well. Finally, delighters are product characteristics that the customer does not look for when buying a product but leads to high customer satisfaction. Product characteristics categorized as delighters have the ability to positively surprise the customer. A possible delighter could be that the steering wheel of a car has ventilation that automatically keeps the drivers hands at body temperature.

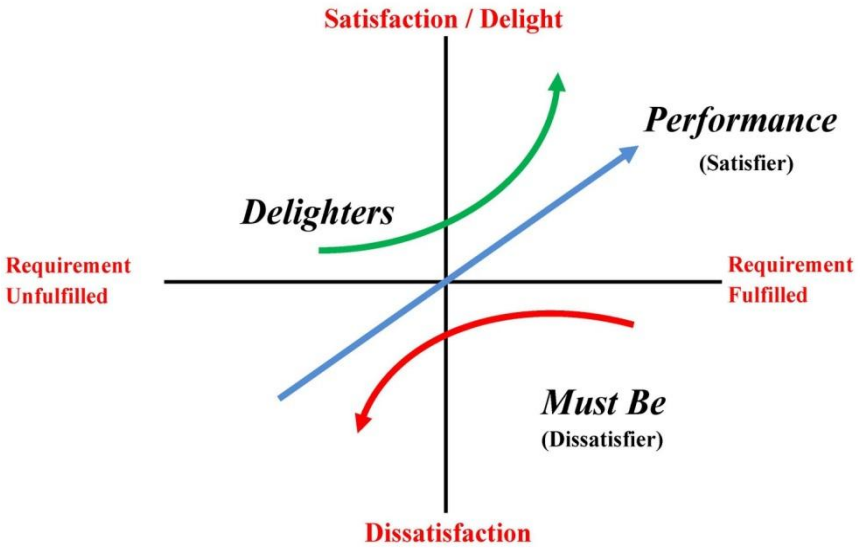

Figure 9 The Kano Model (Process Excellence Network, 2012)

A majority of car owners expect to have a movable window. It is a necessary quality that has to be included in the car i.e. a hygiene factor. Lack of a simple function or feature such as a movable window can create frustration but fulfilling simple requirements does not impress either. It is perceived as a basic requirement and is often taken for granted. Therefore it is very important to design concepts with capability of delighting and surprise the customer and thus compensate the need for a movable window.

2.3 Car body types

In the later sections of the report different Volvo car models will be mentioned. This section aims at providing the reader with insight on how the Volvo car models are designed and what separates them.

2.3.1 Pillar formation

Cars are designed with A, B, C and D pillars. Each pillar supports different functions and depending on the car body type, the combination of these pillars can vary. Generally speaking, the pillars main function is to hold together the roof and the body of car. The A pillar, which is seen in Figure 10, is the part of the body that supports the roof where the windshield is anchored. It is placed in front of the front doors. This pillar helps during head-on collisions by distributing forces through the vehicle body. The B pillar also supports the roof but is placed between the front and the rear door where the safety belt mechanism for the front seat is hidden. It also helps during side impacts by distributing forces away from the car occupants. The C pillar which is located behind the rear doors is attached to the rear windshield (Barlett, 2012). Similar to the B pillar it also hides the safety belt mechanisms but for the back seat. The D pillar can be found in the rear cargo space where the trunk lid is attached. They are however only found on four-door cars where a large space is required for the luggage.

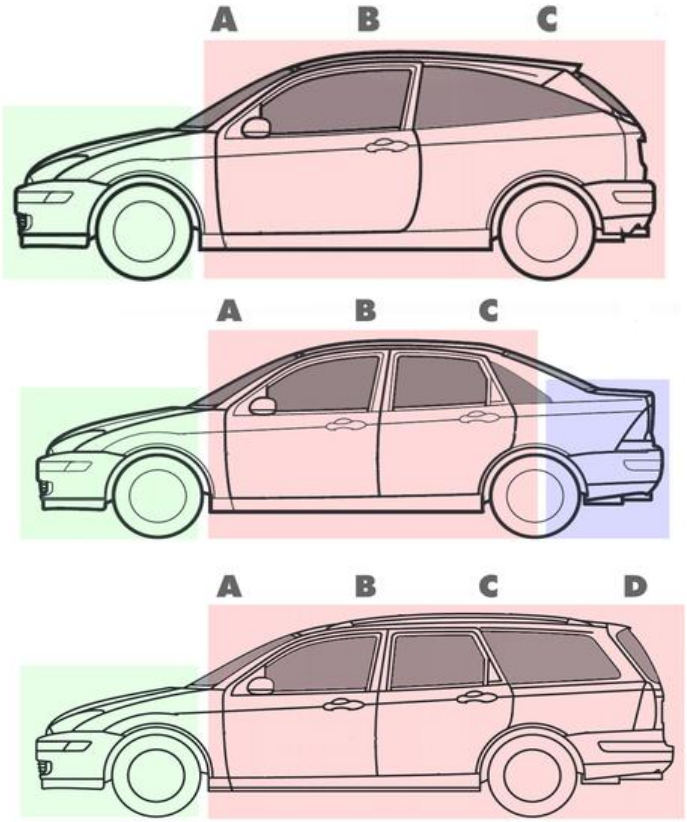

Figure 10 Pillar formations (Wikipedia, 2012)

2.3.2 Volvo models and body types

When this report was written Volvo Car Corporation offered a total of 12 different cars in their product portfolio. The cars were categorized into four body types and within each body type there are different car sizes. Each body type is characterized by letters and the different sizes are characterized by numbers. Table 1 shows a summary of the Volvo car models.

Body type / **Size**	**Coupe/ Convertible**	**Sedan**	**Estate**	**SUV/ Crossover**
30	C30			
40		S40	V40	
50			V50	
60		S60	V60	XC60
70	C70		V70	XC70
80		S80		
90				XC90

Table 1 The Volvo models categorized by body type and size

A coupe is defined as car often with sporty shape and three doors including a trunk such as the Volvo C30, visible in Figure 11. A convertible is similar to a coupe but also includes an operable roof system which lets the driver open the roof of the car. At the time of the report being written, Volvo offered one convertible called the C70. The coupe and the convertible are supported by A, B and C pillars as can be seen in the top of Figure 10.

Volvo offered three sedans of different sizes, S40, S60, and S80. A sedan is defined as a body form that has A, B and C pillars like the coupe/convertible but also has four doors as well as a trunk lid. The pillar formation of a sedan is seen in the middle of Figure 10 and a Volvo S60 is visible in Figure 12

Volvo also offered four estates including the newest addition called V40. An estate is constructed out of A, B, C and D pillars like the bottom pillar configuration of Figure 10 and is thought to satisfy the need of a more spacious cargo area than a sedan. Except for the V40 Volvo also offered the V50, V60 and V70 and the latter of these models is depicted in Figure 13.

The last body type of Volvo cars is the SUV/Crossover. The Volvo XC90 (Figure 14) was the largest of the Volvo models and combines the maneuvering of an all-terrain vehicle (ATV) and a passenger car – hence called a SUV. They are designed with five doors including one in the luggage compartment, with five to seven seats. Just like the estate the SUV equips an A, B, C and D pillar. Lastly, Volvo also offered two crossover vehicles, XC60 and XC70. This type of vehicle is a combination of a SUV and an estate and is thus called a crossover.

Figure 11 Volvo C30

Figure 12 Volvo S60

Figure 13 Volvo V70

Figure 14 Volvo XC90

3. Method

Following chapter explains how the project was carried out. The methodology used in the different steps of the project is described in detail in separate sub-sections divided throughout the chapter. Chapter 4 presents the results generated through exerting the methodology described in this chapter. Discussion regarding the methods used can be found in chapter 5.

Upon initiation the project was divided into four main phases to be carried out in a somewhat linear order. The methodology for each phase was also determined. However, as the project proceeded more knowledge was gained regarding the construction of the rear doors, the different markets and about Volvo cars in general which led to added activities. Applied tools and methods are in general taken from the context of the product development master degree education but also from the mechanical engineering bachelor education at Chalmers. The four main project phases were: 1. Acquaintance with door construction, 2. Market analysis, 3. Concept generation and evaluation and 4. Concept design. The logic of the phase sequence follows:

1. Understand what parts that can be removed and what can be fitted into the interior door panel in their place.
2. Understand who purchases the car, who is sitting in the back seat and what features they want the car to possess.
3. Generate and design concepts that the customer wants and that can be fitted into the door.
4. Create models of the concepts

Each phase is individually described in detail in the following sections.

3.1 Acquaintance with door construction

To familiarize with the Volvo cars in general and the door structure in particular, two different scopes where used; a holistic view and a detailed view.

3.1.1 Holistic Scope

The holistic view was thought to capture the wide range of aspects surrounding the rear doors. Shorter interviews were carried out with staff from every department that could be affected by an interior redesign of the rear door. The departments visited were:

- Safety
- Ergonomics
- Quality
- Product Planning
- Door Module
- NVH (noise, vibration and harshness)
- Cost- and weight distribution
- Body and exterior engineering
- Exterior trim and sealing

- Glass and Mirrors
- Manufacturing Engineering
- Infotainment – Audio and Broadcasting
- Design

In order to better understand Volvo Car Corporation as a company, a guided tour through the plant in Gothenburg was attended as well as a couple of exhibitions and workshops. Material available at the Volvo headquarters concerning each car model such as brochures and strategic presentations, were also studied in detail to fully comprehend values, beliefs and visions within the company. The holistic acquaintance was also done to discover as many positive aspects as possible connected to fixating the rear door windows. The positive aspects found are presented in section 4.1 titled *Driving Factors For Fixed Glass.*

3.1.2 Detailed Scope

The detailed scope of the rear door acquaintance was centered on the parts of the rear door that were directly connected to the interior panel. Initially to understand the structure of the door several models were studied in Volvo´s internal product development management database (PDM), Team Center visual mockup where complete car models can be displayed and parts can be removed and repositioned as the viewer chooses. Visits at Volvo workshops were also done to study actual doors and their components.

Findings from this particular phase of the project are documented in the theory chapter since the findings are fundamental for comprehension of the project execution.

3.2 Market analysis

As earlier stated, the objectives of the market analysis was to grasp who purchases Volvo cars, who is likely to sit in the back seat and what possible extra features they would like in the rear door. The methods used in the market analysis phase was a survey, focus group workshops, competitive benchmarking, retailer visits and studies of secondary research performed by the market intelligence department at Volvo Car Corporation. Each method and why they were chosen for the project is described separately in the following sections. These sections are divided into two main parts where the first treats primary research and the second describes secondary research. The complete results from the market analysis can be found in section 4.2.

3.2.1 Primary research

In short, primary research means research carried out by the project executors themselves which serves a purpose which is directly connected to the project in question (McQuarrie, 2005). The primary research carried out in this project was focused on backseat behavior, views on window operability and possible new car features. The research also aimed at generating ideas for concepts that would be created at a later stage of the project. The different steps that were taken during the primary market research are depicted in detail in the following sub-sections.

3.2.1.1 Survey

A survey was put together in the early stages of the market analysis to capture some data on backseat behavior and general views of rear door window operability. It was also used to gather ideas to be used in the concept generating phase of the project. The reason why a survey was decided to be done was to get as much general information as possible regarding window operability and backseat behavior. Since an electronic survey opens up possibilities to reach people in other countries at a much faster pace than for example distributing the survey by mail (McQuarrie, 2005), electronic distribution was the allocation method of choice. The survey was spread by e-mail for the whole duration of the market analysis phase and in the end of the phase the survey had reached 330 people from different countries. The sample participating in the survey consisted of people that were somehow connected to the authors of this report. Either through the international network of Volvo Car Corporation employees, people from Chalmers University of Technology, old colleagues, friends and family and so on. The sample could thus be said to be chosen out of convenience and is therefore categorized as a non-probability sample (McQuarrie, 2005). The survey can be seen in total in Appendix H.

3.2.1.2 Focus group Workshops

Four workshops were held with Volvo personnel as well as people outside of Volvo to generate creative input for concept generation. Focus groups were used for this purpose because they provide the opportunity to sit down with people of different opinions and backgrounds to brainstorm ideas and to hold developing discussions around these ideas. Focus groups are probable to lead to new and unexpected approaches to concepts (McQuarrie, 2005). Approximately twenty Volvo employees were invited from departments that were thought to contribute and usefully affect the development. Three workshops were held with an evenly distributed amount of participants. Seven persons not under any contract with Volvo Car Corporation were also invited to one workshop that was carried out after office hours. An interior door panel of a Volvo S80 was used to visualize the interface to which the ideas would be attached to the surrounding door structure. The door panel was also thought to provide the workshop participants with knowledge about the interior design of the doors and how the space available was utilized with the present window configuration.

The workshops started off with a presentation on what the project aimed to achieve as well as the participants' role in the master thesis project. After the presentation each attendant was asked to write down any idea they had on rear door functions or designs on post-it notes. When every idea had been written down the post-it notes were gathered, similar ideas were grouped together and the workshop participants were then asked to rate the ideas which they liked the most. The ideas with the highest ratings were then openly discussed in group to explore further add-ons and to establish a more detailed view on how the ideas could be transferred into concepts.

3.2.1.3 Competitive analysis and Retailer Visits

Car models of competitive brands that already implement a fixed rear door glass were investigated by visiting retailers selling these models as well as scanning the automotive benchmarking

database A2MAC1. This was done to gain a broader understanding of what features that are currently available on the market and also worked as a source of inspiration. The investigated car brands were Mercedes, BMW, Audi, Volkswagen, Citroën, Toyota and Renault. Shorter interviews were also carried out with retailers of cars that in some way had already implemented fixed rear door glass. The interviews were done to gain insight on how the customers perceived cars without rear door window operability and what customer segment was most likely to buy such a car.

3.2.2 Secondary research

Secondary research, which is studies of research done by others than the ones that are carrying out the project and possibly for other reasons than that of the project described on this report (McQuarrie, 2005), was used for general knowledge around how the market looks in different countries in terms of customer demographics, opinions toward Volvo's cars and the main consumer segments. The main objective was however to determine who is likely to ride in the back seat and to categorize each Volvo car model with four doors or more with respect to likely back seat passengers.

Through access to the market intelligence database of Volvo, numerous amounts of reports and data regarding customer research was obtained. The reports were browsed through to determine their applicability within the project scope. The ones thought to contain relevant information were then completely read through and any helpful information was extracted to serve as a basis for evaluating ideas and creation of concepts.

3.3 Requirement Specification

The purpose of a requirement specification is to ensure that customer demands and necessary product properties are taken into account when designing and manufacturing a product. These specifications are designed to fit the needs and requests given from customers, employers and other stakeholders.

From interviews, the market analysis and by studying existing requirement specifications created by Volvo´s departments of interior and exterior trim; an updated requirement specification was made for the application of a fixed rear door window (see Appendix A). The specification was not used to evaluate and develop the concepts within the frames of this project but it was thought rather to serve as a basis for further development of the concepts should a decision be taken to continue with the idea of fixed windows.

3.4 Concept generation and evaluation

Finding innovative solutions to new door panels was one of the main goals of this project. The survey described in section 3.2.1.1 helped generate many solutions for space utilization and were an effective method for providing different ideas. The focus group interviews also contributed with even more promising ideas. These methods were beneficial and worked well in connection to the concept generation phase.

The first step of this particular phase of the project was to organize the ideas gathered through the primary market analysis and to quickly screen the ones not applicable with implementation of rear door window fixation. The second step was to combine ideas into concepts fitting the categorization of likely back seat passengers that was established through the secondary market research. In order to combine ideas into a basic version of a concept the door panel was divided into eight areas as seen in Figure 15.

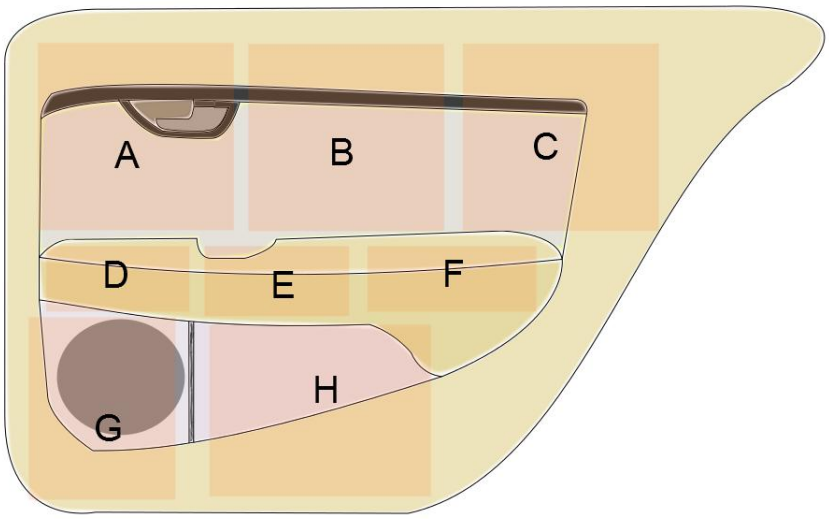

Figure 15 Divided areas of the door panel

By splitting the panel into different areas a morphological matrix approach could be used. A morphological matrix is a method commonly used for methodical concept design. Each function that a product is supposed to include is listed within a matrix (Ulrich & Eppinger, 2007). Possible solutions or ways to achieve desired functionality is also listed with each corresponding function. After all functions have been identified and a satisfying amount of solutions has been listed in the matrix, concept generation starts by combining one solution for each function into a complete concept. This method is usually utilized when the functionality of the product to be developed is clear. The development of the product described in this report was however more open-ended since deciding what functions that should be included in the product was part of the development. The morphological matrix was anyhow used but with the slight modification of listing door panel areas instead of functions.

The ideas gathered in the primary market research were categorized into eleven function categories with different alternatives for each function. A table with the several function categories and the related alternatives is found in Appendix B. Basic concepts were then generated by putting one function category in each of the door panel areas in Figure 15. A morphological matrix was used when assigning a function category to each panel area. The morphological matrix can be seen in Appendix C. An example of one possible idea of a concept

generated through the matrix is visible in Figure 16. Note that the concept in Figure 16 is a rough and initial version of a concept and the way of combining ideas through this methodology was an attempt to structure the initial concept design and to retrieve schematic images of how the concepts could be designed.

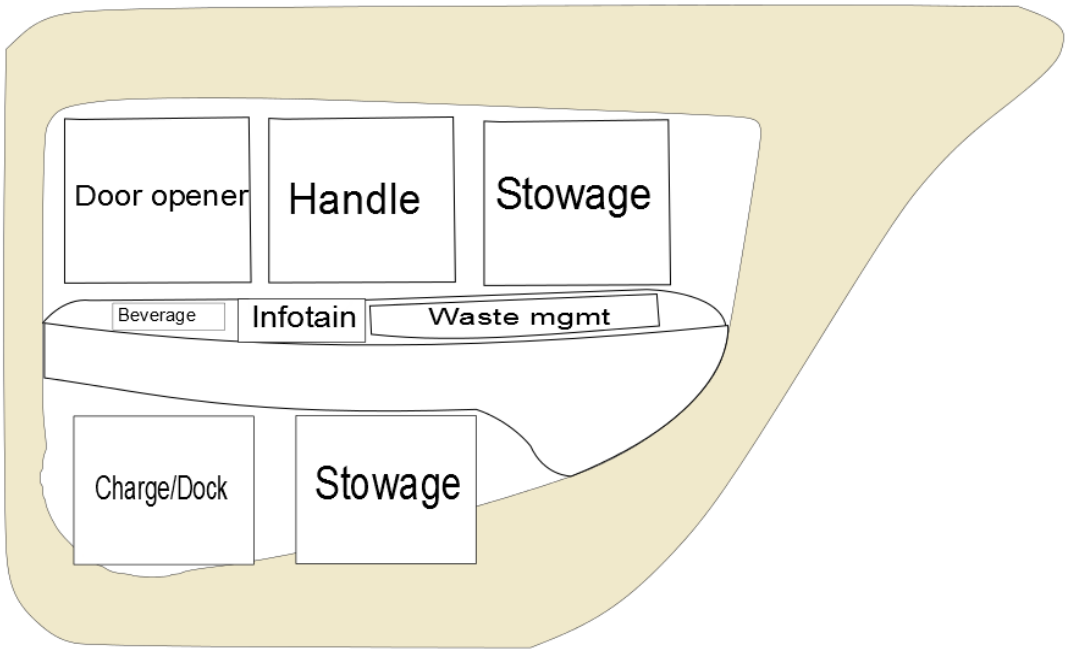

Figure 16 Example of schematic concept

The function categories *Door opener* and *Handle* had to be present in each concept and had to be placed in area A, B, D or E for ergonomic purposes explained in the requirement specification visible in Appendix A. Also the speaker needed to be placed in either area G or H. Once the Door opener and Handle had been assigned to one of these panel areas the remaining areas could be filled with any of the remaining function categories. The process of combining the functions into concepts was executed by considering the categorization of likely back seat passengers of each Volvo model and trying to suit each concept to a certain kind of passenger. The categorization of passengers and the Volvo models associated which each passenger category can be seen in section 4.2.1.4.

The applicable concepts were then developed to a degree that would bring the possibility to compare them in relation to each other but also in relation to the current rear door configuration including window operability. The comparison was done to eliminate, screen and finally to score each concept. Three different matrix types were used for this purpose; an elimination matrix, a Pugh matrix and a Kesselring matrix. The elimination matrix is used to quickly narrow the amount of concepts that are to be further developed. To pass through the elimination matrix each concept

has to pass an amount of criteria (Ulrich & Eppinger, 2007). The criteria can be chosen from the requirement specification and are supposed to be of great importance for the possibility of product success. If any of the concepts does not fulfill any of the criteria in the elimination matrix the concept shall be eliminated from further development which means that the idea for the concept will be dropped or the aspects leading to the elimination has to be redesigned until the concept pass through the matrix. Since the purpose of using the matrix is to quickly screen the concepts it might however be a wiser choice to drop the eliminated concepts and to focus on the ones that pass through. The criteria used for the elimination matrix were:

- Realizable
- Safe
- Economically feasible

The Pugh matrix also uses criteria to evaluate whether a concept should be further developed or not (Ulrich & Eppinger, 2007). The Pugh matrix provides the opportunity to compare the concepts to a reference solution to find out if they are better or worse than the reference. Each concept is compared to the reference within each criterion, the scores are then added up and the concepts retrieve a relative rank. The robustness of the matrix can be checked by switching the reference. If the result varies to a great extent depending on what reference is used, the criteria should perhaps be reconsidered. The Pugh matrix does not regard the fact that some criteria might be more important to consider than others. Furthermore it does not take into account that differences in concept performance might be hard to estimate depending on the level of development of the concepts participating. Providing each concept is developed to a degree that makes concept comparison possible as well as the criteria chosen for the comparison are thought to be relevant, the Pugh matrix can be useful to rank the concepts relatively and to focus the development efforts on the concepts with the higher rankings (Ulrich & Eppinger, 2007). Three Pugh matrices were used during this project. The first one compared all the generated concepts against window operability. The second and the third matrices were used one time for each back seat passenger category to choose one concept for each category. The reference in the latter two matrices were the highest scoring concepts for each passenger category in the first matrix

To score and to select what concept will be the concept of choice, a Kesselring matrix can be a useful tool. The same criteria as in the Pugh matrix can be used but they should each be given a weight of importance (Ulrich & Eppinger, 2007). Instead of comparing each concept in relation to each other, the concepts are given ratings in each separate criterion. The rating is then multiplied with the weight of the criterion to retrieve a criterion score for each concept. The scores are then summarized and a quantitative ranking is thus established. Usually the concept with the highest score is chosen for further development but another choice is to combine the positive aspects of several concepts if applicable to create one, superior concept. The method of combining concepts is called cross breeding (Ulrich & Eppinger, 2007). Cross-breeding means that two or more concepts that are strong in different aspects are combined with the intent to bring out the positive

characteristics of the concepts and eliminate the negative aspects. Cross-breeding is usually implemented in combination with the above described matrices since they highlight eventual strengths and weaknesses of each concept included in the evaluation process.

Since this project aimed at developing more than one concept, the Kesselring matrix was used to establish which concept would be suited for premium price cars and which ones that would be better suited for less expensive models.

The criteria used for the screening and scoring matrices were chosen from a list of attributes included in Volvo's differentiation strategy. More information about the criteria used can be found in the next section. The concepts that scored the highest in accordance with the strategic differentiation attributes were cross –bred as described above and then developed further in the concept design phase of the project which is described in section 3.5. All evaluation matrices are visible in Appendix D, E and F.

3.4.1 Evaluation criteria for screening and scoring

In addition to that each concept had to meet the requirements of the elimination matrix they should also comply with Volvo's corporate strategy. This was done by utilizing attributes used by Volvo that compare themselves with their competitors. Attribute performance of each competitive brand is ranked in a system made visible in Figure 17

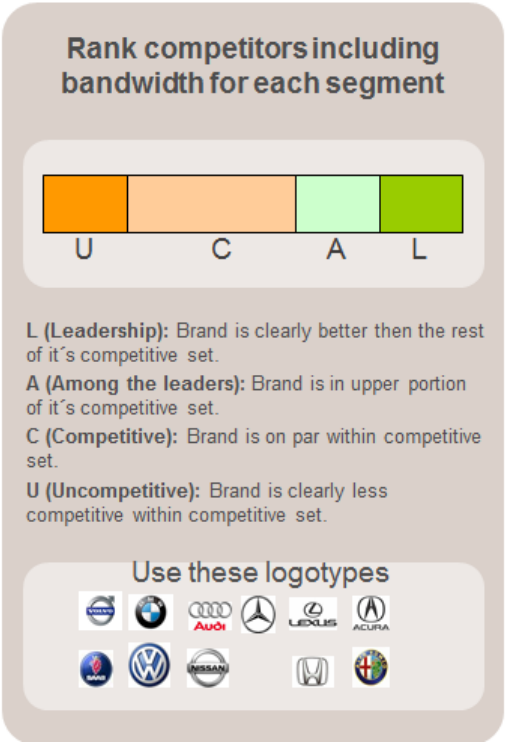

Figure 17 Attribute ranking system

An example of attribute performance ranking is visible in Figure 18. Note that Volvo state their own current attribute performance in the ranking but also a target attribute performance ranking.

The example of Attribute X in Figure 18 show that Volvo currently is ranked as *Among the leaders* in Attribute X but the target is to establish *Leadership* regarding performance in Attribute X

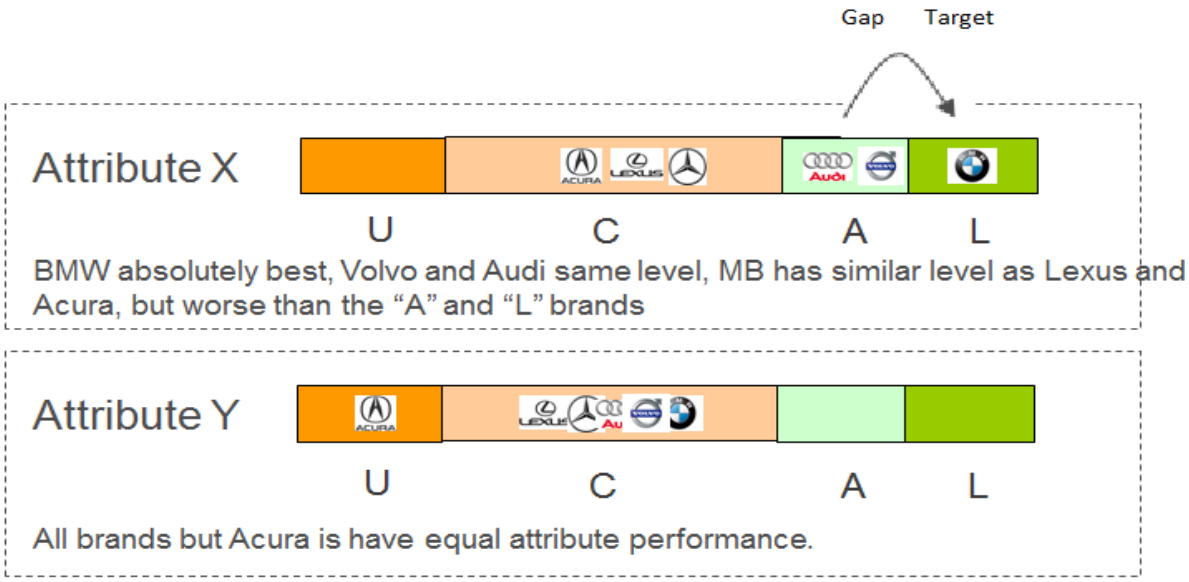

Figure 18 Attribute ranking example

The attributes chosen as criteria for the evaluation matrices were the ones applicable to a rear door panel. The weighting of the criteria in the Kesselring matrix (see section 3.4) was done by considering how large the gap was between current attribute performance rank and the target. The attributes used as concept evaluation criteria were:

1. **Infotainment and Connectivity:** Refers to what eventual features regarding audio, display and connecting features there are in the car. Connecting feature implies possibility to connect portable devices such as an Mp3-player to the car infotainment system.
2. **Perceived Quality:** Refers to how exclusive the car is perceived to be.
3. **Daily Life Usage:** Refers to functionality and flexibility in stowage of items brought inside the car.
4. **Solidity:** Refers to the robustness and stability of the parts included in the car.

The actual attribute ranking for Volvo in relation to their main competitors as well as Volvo's target position is confidential and can thereby not be published in this report.

Each door panel concept were compared and ranked according to the attributes above but also with three additional criteria thought of as important by the project executors. These were weight, passenger value and driver value. Passenger value refers to how valuable each concept is for a passenger occupying the rear seat. Driver value refers to how valuable the concepts would be if no rear seat passengers were carried.

3.5 Concept Design

The concepts that emerged from the evaluation matrices were designed into virtual models. These concepts were further developed in collaboration with the prototype workshop at Volvo in order to come up with ideas how the functionality of the concepts could be implemented with different

technical solutions. The design of the concepts was then done with surface modeling in CATIA V5 and the models were created in accordance with the surrounding parts of the rear door design. This was done by first modeling a frame common for the concepts and also containing the attachment points to the interior door panel carrier. The frame also included the attachment for the interior door opener. The frame alone and also attached to the interior panel carrier is visible in Figure 19.

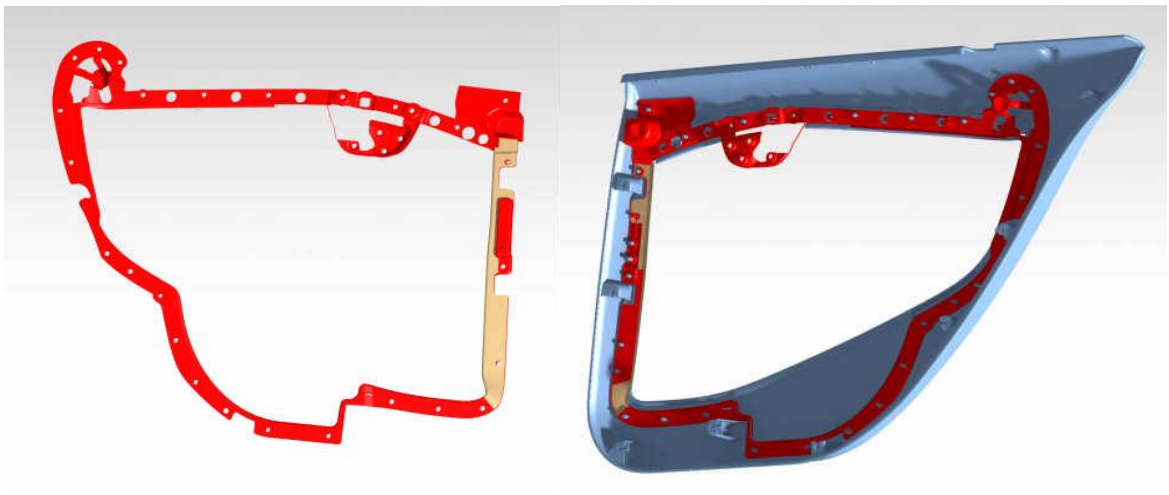

Figure 19 Common frame used in concept design

To fully utilize the space made available by fixing the windows, a geometry enfolding the space between the interior and exterior panel was created. This geometry was also designed considering the impact member and the multifunctional bracket containing the glass guide and the door opening mechanism. This geometry was used as outer limits when designing the interior panel concepts and is visualized in Figure 20. The surface behind the geometry in Figure 20 represents the exterior panel with an offset of 20mm to make room for an eventual need for extra isolating material.

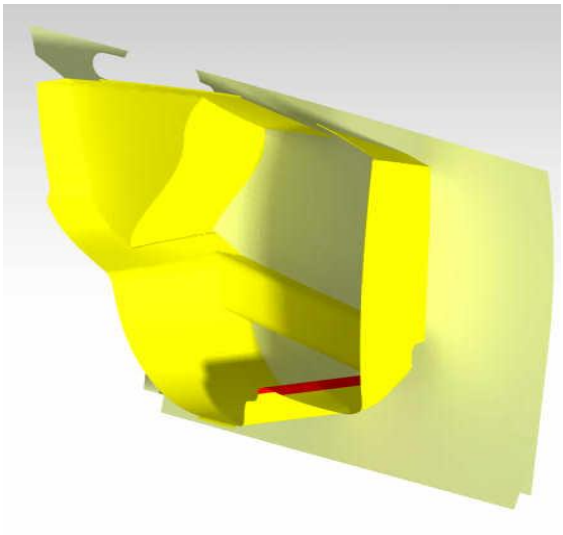

Figure 20 Limiting geometry used in concept design

The concepts were then designed to fit into the frame and the limiting geometry. The concepts were also designed to fit into the left-hand rear door of a Volvo S80.

4. Results

This chapter presents the results that were generated by following the different steps presented in chapter 3 with the knowledge presented in chapter 2 as background. To link the results of the project with each phase described in the previous chapter, this part of the report follows the same logic as chapter 3 and is thus divided into sections with the same titles and chronological order as in the methodology chapter. Note that the header of the phase previously called acquaintance with rear door in this chapter is referred to as driving factors for fixed glass. This because the results of the rear door acquaintance phase besides knowledge around door design also were a number of positive aspects regarding fixation of rear doors as mentioned in section 3.1.1. Discussion regarding the results from the different phases of the project is presented in chapter 5.

4.1 Driving factors for fixed glass

The door acquaintance inquiry and partly the market analysis both gave rise to some positive aspects related to removal of window operability. As previously mentioned, initially in the project the drivers behind an eventual decision of fixing the rear door windows were cost- and weight reduction. Additional drivers found are also described in the following sections.

4.1.1 Cost and weight reduction

By removing the components related to operational windows, savings regarding cost and weight can be achieved. Table 2 summarizes the direct cost savings as an effect of removing the components related to window operability. MFB stands for the multi-functional bracket which is the device that helps opening the door and also includes a glass channel to guide the glass down between the panels.

Deleted components	**Part price (incl. 1st Tier assembly)**	**Weight reduction**	**Tool reduction**
Window regulator complete, MFB including seal	**-250 SEK/car**	**-2250 g/car**	**-2 MSEK**
Glazing, rear, Quarter glass	**-315 SEK/car**	**-2000 g/car**	**-**
Rear door structure & seals	**-240 to -520 SEK/car**	**-2800 g/car**	**-**
Power switches in front and rear door	**-40 SEK/Car**	**-400 g/car**	**1,2 to 4 MSEK**
Sum	**-845 to -1125 SEK/car**	**-7450 g/car**	**-0.8 to 2 MSEK**

Table 2 Cost and weight saving related to window fixation

By reducing the weight of the car the amount of fuel consumed per kilometer is also reduced. This benefits customers since they need to buy less fuel as well as Volvo Cars since less consumed fuel means less emission of carbon dioxide which can lead to marketing advantages.

4.1.2 Water management

Fixing the rear door windows gives the possibility to completely seal off the area between the door panels from water. The wet area described in section 2.1.1 can thus be eliminated and the complete space between the panels is transformed to a dry area. By doing so the requirements on the components contained between the door panels will not need to be as strict regarding protection against corrosion. Protecting electrical components will neither be necessary. Furthermore no regard needs to be taken for draining eventual water that leaks in between the panels.

4.1.3 Freedom in design and Volume management

Movable rear door windows constrain the design possibilities of the rear door. Fixating the windows opens opportunities to shape the interior panel in different ways that were not possible when constrained by the alignment requirement of the sliding glass. In other words fixating the windows will give panel designers more freedom when modeling their design concepts. The window insert can also be designed with less constraints as well as the door exterior. One possibility could be to remove the quarter glass described in section 2.1. Since the glass window does not need to slide between the panels the quarter glass and the sliding window can be combined into one part. The dividing vertical ledge can then be removed and a glass spanning the entire window arch could be implemented with visual benefits and a lesser amount of components.

Like freedom in design the space created by fixing the windows opens up possibilities to utilize the free volume in any desirable way. The concepts designed in this project are two examples of volume management.

4.1.4 Assembly

The assembling process would not have to include the handling of a movable glass window. The mounting of the glass to the window elevator requires the assembly workers to slide down the glass so that it fits the glass guide but also reaches the clipping mechanisms on the window elevator. If the glass does not need to slide between the door panels no such fitting will be required and the assembling of the glass will be easier in the rear doors.

4.1.5 Speaker attachment

Door modules in cars manufactured before 2006 were made out of steel but since then the material has been changed to plastic mainly to reduce weight but also due to difficulty of pressing the steel to a desired shape for optimal flexural rigidity and to fit components and cables. The plastic carrier plate starts to oscillate when certain frequencies come out of the rear door bass speakers. The oscillation starts when the speaker frequency gets close to the self-frequency of the

carrier plate causing resonance. The window motor placed on the dry side of the door module amplifies the oscillation of the carrier plate straining the material which can be seen in Figure 21.

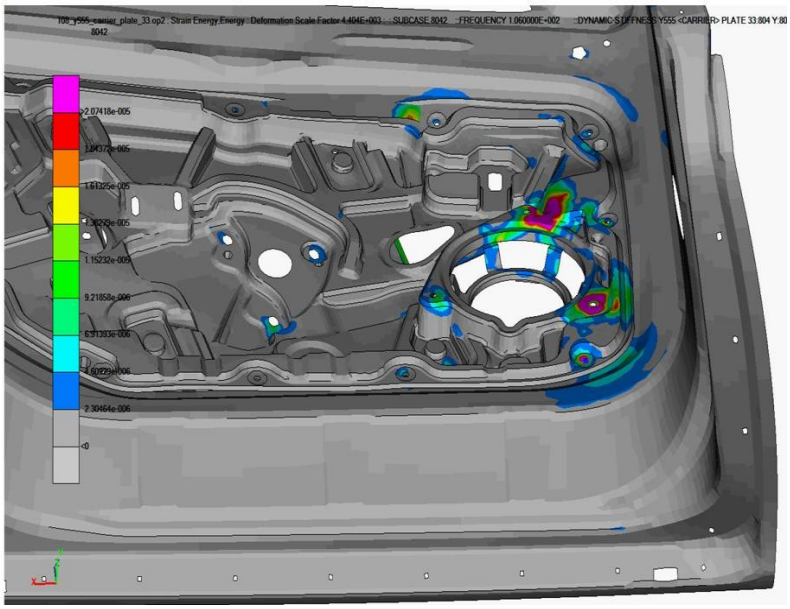

Figure 21 Strain in the speaker attachment caused by resonance amplified by window motor

Because of the oscillation and strain around the speaker attachment the sound quality drops by 5-6db. By removing the components related to window operability the speaker fundament could be made more stable and the losses in sound would be minimized. More space also adds the opportunity of modifying the speaker attachment, reinforcing the area around the bolt holes and possibly adding a fourth bolt to the existing three, making the attachment even more rigid and stable.

4.1.6 Solidity

The function of operable windows in some cases lead to quality problems. The window elevator and the glass window have been causing rattling and squeaking sounds when closing the rear doors or when driving on a bumpy road. These sounds are a major cause of customer complaints which are costly to fix and also damages the brand image of Volvo. If the elevator were to be removed, the rattling and squeaking noises would be eliminated and the door structure in total would be more solid since complex, moving parts are removed along with cabling related to the window operability.

4.2 Market analysis

The market analysis includes results from secondary and primary research. The secondary results are presented first and contain general customer information as well as likely backseat passengers. A summary of the secondary market research can be found in section 4.2.1.4. The results from the primary research focused on possible rear door features and backseat behavior follow as well as different possibilities of window configurations that does not require the glass to slide between the door panels.

4.2.1 Secondary research

Following sub-sections provide the results from the studied reports from the market intelligence database. As mentioned earlier, the reports were studied to identify who is most likely to ride in the back seat of each Volvo model.

4.2.1.1 Customer Demographics

The tables that initially were included in this section are compiled out of Volos´s market intelligence databases; NCBS and NVES. They are extracted from Demographics and Buying Behavior-reports and are confidential. They will therefore not be included in any report version distributed outside of Volvo Car Corporation. The results gained from analyzing the tables of customer demographics that were used in later phases of the project will however be summarized in section 4.2.1.4

The confidential tables contained the age, life state and marital status of Volvo customers for each of the five most important markets. The statistics were divided between different Volvo models and provided insight of what concept would be most suitable to replace window operability in the different car models.

4.2.1.2 Main consumer segments

The main customer profiles of Volvo are categorized into various consumer segments. The model used for the segmentation is called Volvo Automotive Consumer Segmentation or VACS and divides the customers into eleven segments. Out of these eleven, six of the consumer segments stand for 80% of the sales and therefore the focus will lie on these six. Each segment is generally categorized with respect to the life-stage of the consumer and their attitude toward cars. Life-stage implies whether the consumer does not have any children (pre-family), if they have children living at home (parents) or if the children have left their parental home (post-family or empty nesters). Attitude toward cars imply the degree of involvement in the automobile market and also whether they see their car as personal enjoyment or just as a means of transportation. The actual consumer segment profiles are confidential and can therefore not be included in the published report. The key results used in the later phases of the project will however be presented with slight modifications allowing publication in section 4.2.1.4

4.2.1.3 Consumer segments' vehicle distribution

This section showed statistics regarding each consumer segment in relation to Volvo car models sold. For each car model the amount of cars purchased had been divided according to what segment each customer belongs to. This provided information regarding what consumer segment were more likely to drive a specific Volvo model. Like in the previous sections, these statistics are confidential but the key results are described in section 4.2.1.4.

4.2.1.4 Secondary research summary

The information gathered from section 4.2.1.1 and 4.2.1.3 showed that the mean age and life stage vary to a great extent in China related to the other main markets. A majority of the

customers in China are in the family stage of their life. The family life-stage shows a strong presence in the other markets as well even though the post-family consumers make up the majority of the customers in the other main markets except for Germany. The family and post family segments on average make up a total of 86.55% of the five main markets. The pre-family segments in China, however constitutes as much as 21% of the Chinese market which is a significant amount related to the other markets which contained few pre-family consumers.

Summarizing the information from the three previous sections, the Volvo models with four doors or more (C30 and C70 excluded) for the published report modified main consumer segments are as follows:

- **Pre-family life-stage:** S40, S60 and V50
- **Family life-stage:** S80**,** V50, V70, XC70 and XC90
- **Post-family life-stage:** S40, S60, S80, V70 and XC70

Hence the models with four doors or more where children are most likely to ride in the back seat of the car are generally V50, V70, XC70 and XC90. The models where any back seat passenger is likely to be absent or less likely to be juvenile are S40, S60 and S80. Note that the categorization of likely back seat passengers does not include V60 and XC60 since no numbers regarding these models were present in the market intelligence database reports.

The concept generation phase (section 3.4) was thus carried out considering these two categories:

1. **Back seat carrying children:** V50, V70, XC70 and XC90
2. **Back seat carrying adults or no one:** S40, S60 and S80

The department of ergonomics also complemented with confidential information about rear seat passengers that complied with the information above. The majority of back seat passengers in sedans that were children sat mostly in S80, S60 and fewer in S40. But estates carrying children in the back seats were the above mentioned V70, XC70 and XC90 as well as the V50. Back seats that carried adults in sedans were S80, S60 and S40 as well. Lastly, the estates which were most likely carried adults in the back seat were XC70, V70 and V50. This result showed that estates carry more children in the back seat than adults and the sedans carry more adults than children in the back seat. This strengthens the reason to why the two categories above were considered.

4.2.2 Primary research

Following sub-sections contain the results obtained from the market research performed by the project executors. The knowledge gained from the primary and secondary market research where combined and used as a template in the concept generation phase presented in section 4.4.

4.2.2.1 Research Survey

The survey was intended as a complement to the data and information obtained from Volvo's own market intelligence database. The goal was to research Volvo's five largest markets. The majority of the questions were closed and a few were open. Out of the 330 respondents, 198 (59%) were from Sweden, 64 (19%) from USA, 34 (10%) from China, from Germany and United Kingdom 1% each, Italy 2% and others were 7% mainly from Belgium. See Figure 22 for the nationality proliferation.

The majority of the survey respondents drove either estates (29%) or sedans (26%). Of all the car owners most had both front and back seat passengers (38%). Front seat passengers (21%) were more common than back seat passengers alone (4%). Having no passengers at all was also regular (20%).

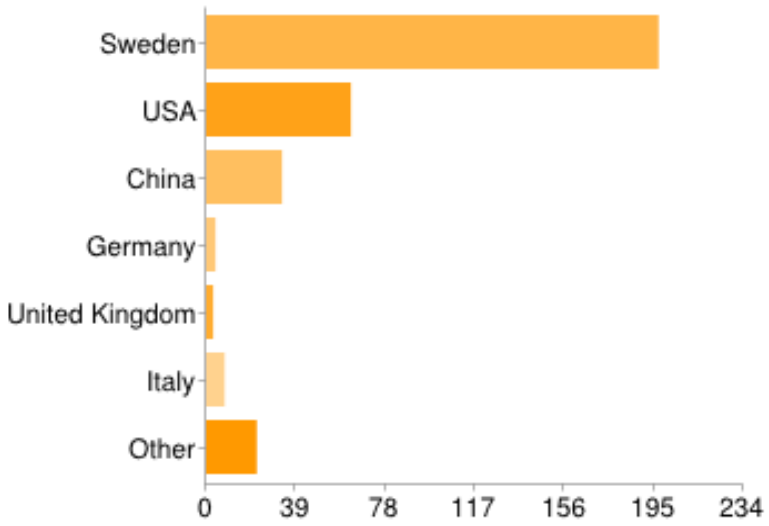

Figure 22 Nationality proliferation

When the respondents were asked to tell who usually rides as a passenger, the most common answer were spouse (68%), children (41%) and friends (36%) as can be seen in Figure 23. Note that the respondents were allowed to choose multiple answers to the question which lead to that the percentages below exceed 100%.

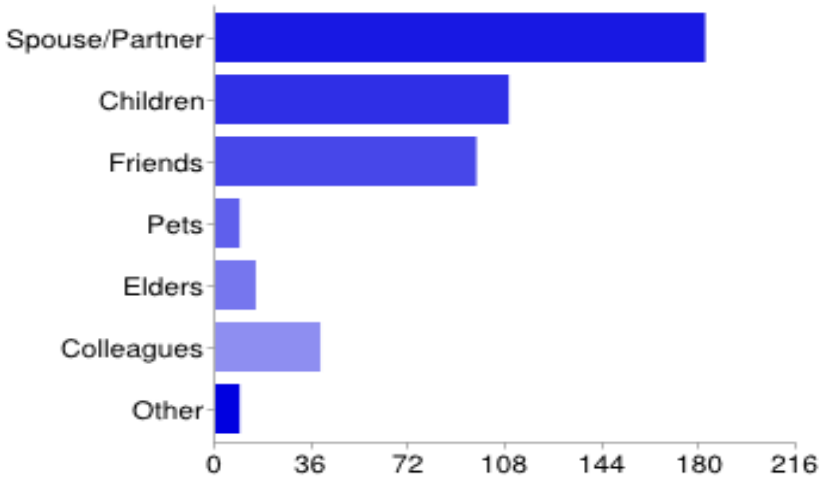

Figure 23 Usual passengers

The most frequent response to the question regarding what personal belongings the passengers bring along into the vehicle were phone (89%), wallet (78%) and clothe (53%). The diagram of Figure 24 also shows that bringing some sort of food, snacks or beverages into the car is quite common. The percentages exceed 100% because of the same reason as mentioned before.

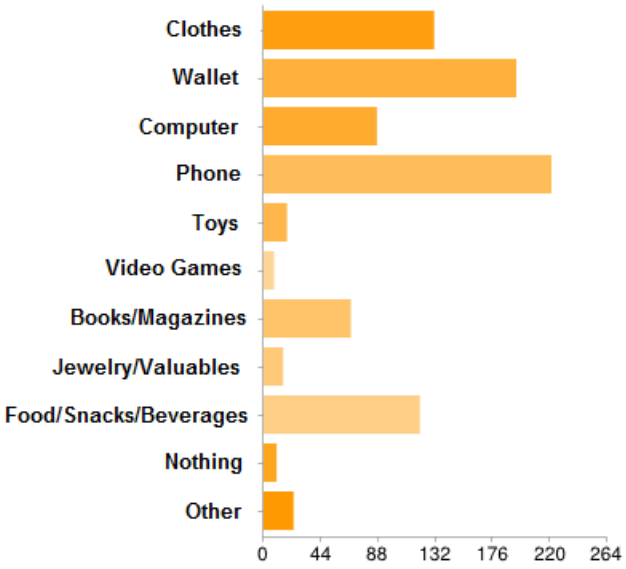

Figure 24 Items brought into car

The answers on the question regarding passenger activities, depicted in Figure 25, showed that listening to music was the most common activity (49%) followed by doing nothing at all (43%) and other which mostly included conversation (36%).

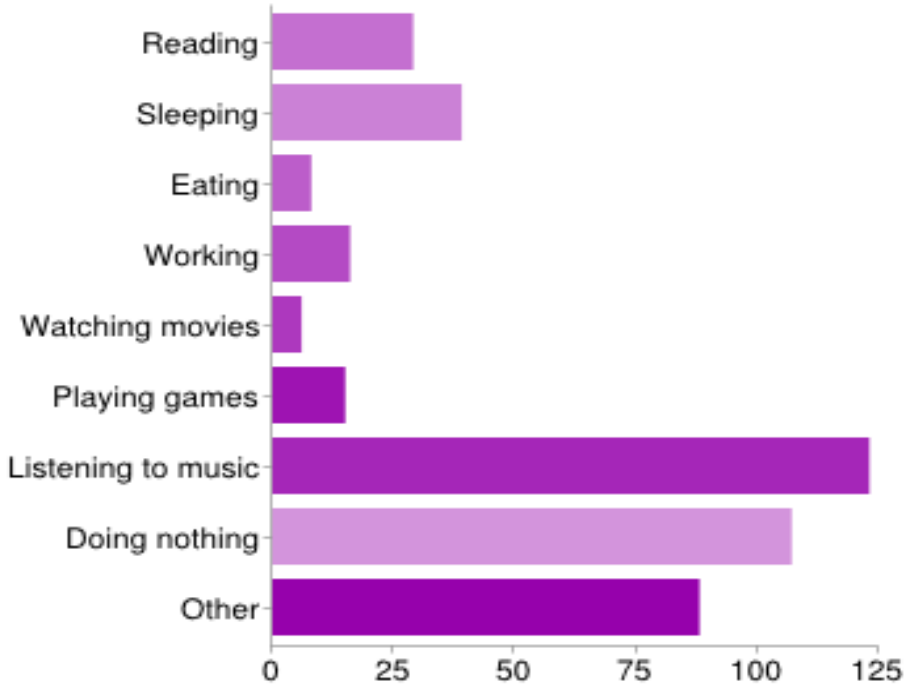

Figure 25 Passenger activities

One of the open questions included in the survey was if passengers felt limited to do anything while riding in the car. 184 (80%) said no and 66 (20%) said yes. The ones who answered yes mentioned trouble regarding sleeping well. Some said that there was nothing to do in the car. Laptop and cell phone usage is not facilitated due to lack of a charging station in the back seat. Garbage disposal on current car models is not well designed because it can't contain much litter, noise could be a hinder while listening to music and there is no controllable radio and audio system in the back seat. Internet connection is not established and there is not enough space in the car to store items and nothing to carry them either like for example a table. Many passengers also mentioned that they get car sick while reading and watching movies while riding as a passenger.

A supplementary question was if the respondents could add any function or feature to the car where they spend the most time, what they would choose. Many would like an autopilot, Wi-Fi connection, fridge, coffee machine, inflatable pillow, footrest and adjustable seats for long-distance travel. Other features commonly mentioned were sun visors, better storage for items, movable tables like on airplanes, flexible cup holders, power stations for re-charging electrical gadgets, audio control and ear phone plugs. To be able to speak with the car was regarded to be an exquisite feature as well as water and ice repellant glass, a blow dryer, better trash cans or a vacuum cleaner, automatic parking functions, USB-hub, warm arm rest and floor, massage functions, TV etc.

The main reason for opening the rear door windows showed to be in order to get fresh air followed by interaction with people outside the car (see Figure 26). Given the question if it is necessary to be able to open the rear door windows, 80% answered yes and 48% of these thought that the rear door window should be operable all the way down.

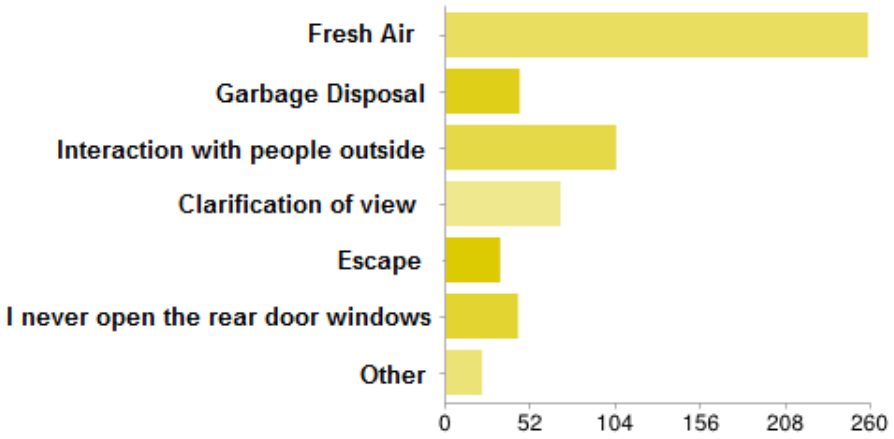

Figure 26 Reasons for opening rear door windows

4.2.2.2 Focus Group Interviews

The outcome of the focus group interviews brought innovative ideas to the table. Letting participants with different technological backgrounds interact with each other resulted in a variety of multifunctional feature possibilities. The ideas were categorized and analyzed for further development and the complete list of ideas generated through the focus groups can be seen in Appendix I. Participants from different groups at interior and exterior trim, climate and safety were involved in these focus groups. Most of the participants had the same ideas and solutions to functions that they would like to include. The majority wanted an item carrier, infotainment system, lighting mechanism, increased comfort and storage compartment and a better air conditioning system due to the fixed windows. The group discussions also gave an opportunity to see the reactions towards the idea of implementing fixed windows in the rear doors. Initially almost every participant reacted negatively to the idea of fixed windows but as the discussion went on, the general opinion shifted toward being more liberal to window fixation providing other features could be added to the door panel.

4.2.2.3 Competitive analysis and retailer visits

The benchmarking investigation of competitive premium brands and models which implements fixed rear door windows is described in this section.

One of Volvo´s competitors, Citroën offer a five door car with fixed rear door windows. It is one of few vehicles on the market that offers this unless it is a coupe. The Citroën DS4´s (Figure 27) design of the door is different from what the market is accustomed to. The designers have managed to position the rear door handles on the back of the doors (#1 in figure 27).

According to the retailers, having a fixed glass is mainly due to styling purposes. Other probable causes could be cost savings and weight reduction. But as this research clearly points out, implementing fixed glass in the rear doors leads to saved space. In this model, the designers have not put in any functions in the doors except for creating a more spacious stowage compartment. Other noticeable things are the above mentioned door handles position and that the speaker is

pressed deeper against the exterior. It is unknown to why they have chosen not to add more functions since fixing the windows theoretically creates more playing room and freedom in design.

The retailers also mentioned that the buyer of this seem to be design oriented and show a high interest in technology. The salesman did not mention that Citroën fixed the windows to create space since it, according to him, probably lies beyond their knowledge. That statement should however be regarded as a personal opinion not necessarily representing the reality.

Figure 27 Citroën DS4 and its rear door (Automotive Benchmarking, 2012)

The market analysis indicated that there are different ways to open a rear door window. It can either be done mechanically or electrically. Toyota Aygo in Figure 28 and Citroën C1 are two four door cars with tilting rear door windows. Both are mechanically driven where a knob is pushed to tilt the window outwards (#1 in Figure 28). The old BMW 3-series used to have a similar mechanism to open the windows but it have been replaced by electrically driven components. One disadvantage with opening the window with this kind of tilt is that it involves a greater chance for jamming fingers.

Figure 28 Toyota Aygo and its window tilting mechanism (Automotive Benchmarking, 2012)

Volvo's main competitors are Mercedes, BMW, Audi, Lexus and Acura. Similar to Volvo, they offer a wide range of different vehicles in different sizes. These competitors are perceived as premium brands with advanced design, technology and high quality to offer to their customers at a high price. By looking at Figure 29 you can see the Mercedes S-class 350 backseat interior. The design is elegant; a table is included in the back of the front seat and has an embedded air conditioner. On the door there are buttons to adjust the position of the seat. These positions are possible to save

in different slots if there are many different passengers. It is also possible turn on the seat heaters using buttons in the interior door panel.

Figure 29 Interior of Mercedes S-class 350

The rear doors of Audi A8, visible in Figure 30, and the new BMW 5-series, visible in Figure 31 have sun visors in the rear door windows.

Figure 30 Rear door of Audi A8

Figure 31 Rear door of BMW 5 Series

Volkswagen Golf Plus has a table similar to the Mercedes model but has a cup holder integrated into the table. The rear doors also have two speakers on each side as well as one removable ashtray. Volkswagen Passat has a remarkably large storage compartment and two speakers in the rear doors.

There are also cars that completely lack storage compartments in the rear doors. Volkswagen CC only has a cup holder in the back seat middle arm rest. The door which is depicted in Figure 32 only has a button for opening the window. Volkswagen Tiguan has a table in the back seat as well and has adjustable cup holders in the middle arm rest.

Figure32 Rear door of Volkswagen CC (Automotive Benchmarking, 2012)

Some cars also have compartments that are hard to reach which is the case for the estate Citroën C5 (#1 in figure33). It is placed in the lower central portion of the rear door. The legroom makes it hard to reach.

Figure 33 Rear door of Citroën C5 (Automotive Benchmarking, 2012)

Modern cars also have older functions as the mechanical window opening mechanism. The Citroën C3 has a roll able window opener in the rear door similar to the Volvo 240. But in the front seat the C3´s front windows are driven electrically.

4.2.2.4 Alternative window configurations

As stated in the project scope in section 1.4, a brief discussion about different window configurations was to be included in the report. Figure 34 lists different possibilities for window configurations that do not require the glass window to drop between the door panels. In the category fixed glass there are two possibilities; glued glass and inserted glass. Two different ways of opening the window is also included in Figure 34; Tilted glass and Turned glass. General comments around each alternative are present under the window configuration images in Figure 34. Black-Off refers to the black frame in the window seen in the images depicting glued glass and tilted glass. This is used to hide the attachment arrangement fixing the glass window to the rear door.

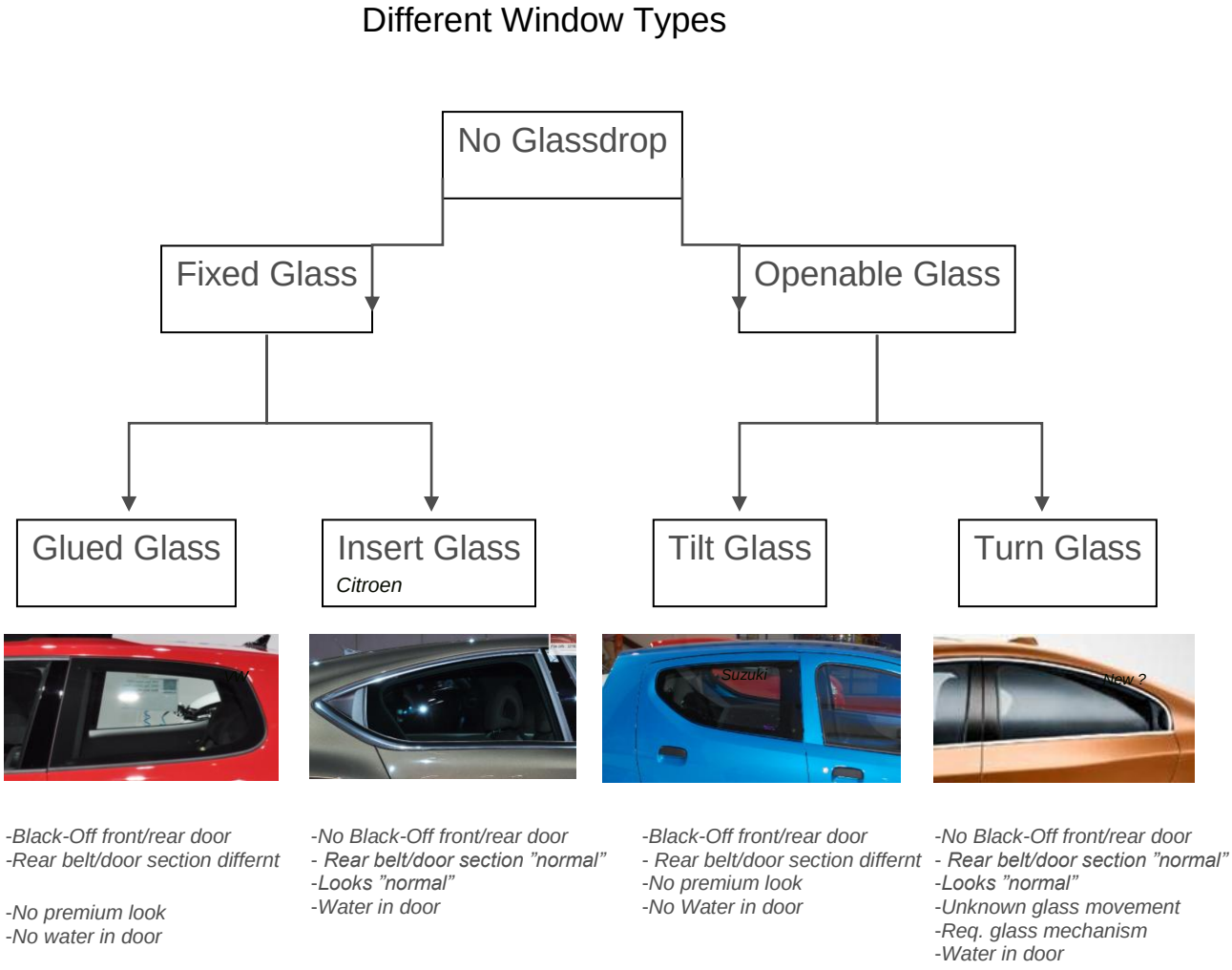

Figure 34 Different window types (Anders Nordström, Dept 93140 VCPVOS PVÖS34 Concept Engineer

4.3 Requirement specification

The requirement specification was used to compile all the important requirements and requests presented from different stakeholders. It was divided into 12 categories (see Appendix A for the detailed requirement specification) and covered the most important aspects of the door panel. All requirements that were identified from the market studies and stakeholders are briefly shown below.

Attribute requirements

The purpose of the attribute requirements is to set a limit to where different components shall be placed. The appearance of the door panel depends much on how the different components are related to each other. The armrest is constrained to a certain height as well as the door opener and the position of the door handles.

Safety requirements

To complement Volvo´s safety requirements, no components are allowed to come loose upon accidents and sharp edges have to be avoided in order to reduce the risk for injury. These

requirements are designed to fit the user in the safest way possible. Electrical and material constraints have also been considered to enhance passenger safety.

Security requirements

Avoiding break-ins and vandalism can be done by designing the interior door panel in a way that prevents visibility of stored items from outside the car.

Endurance requirements

Door panels must be sustainable from different points of view. No deterioration, rattling or fatigue cracks are allowed during the cars life-span and the door panel must withstand a high amount of cycles of fully closing and opening. To design the components strong enough to withstand high and varying forces is therefore a must.

Design for recycling

Materials and substances that are harmful to the nature and people occupying the car are to be prevented from use. Products must be environmentally friendly and promote recycling from a sustainable point of view.

Weight requirements

Since weight reduction was one of the most important criteria to fulfill, components that will be added or removed shall not increase the weight of the door panel.

Manufacturing requirements

Facilitating and promoting manufacturing is key. Complexity has to be reduced in the assembly of the windows. Creating designs that allows one person to mount and assemble the door panel or automated assembly is required. Safety of the operators has also been considered and the designs shall not allow the components to have sharp edges or anything that can cause harm while assembling.

Maintenance requirements

The installation, service and repair time must be kept at a minimum and without damaging surrounding parts. Defects that are noticeable shall be easily maintainable with replaceable mountings that are designed for reinstallation or removal. The interior of the door panel shall be easily maintained and not leave stains or a colour change even when cleaning with water.

Packing requirements

Parts and components shall not be too close to each other due to the risks of scratching, tearing and rattling. They are to be prevented from moving by constraining part to a certain degree.

Cost

The main idea with cost was that each part shall be designed to minimize their cost. Cost of maintaining and repairing must be considered and should result in a minimum amount of workers, tools and service time. A more complex product often leads to a costly manufacturing process. Instalment can also be difficult if the geometry is too complex.

Material

Right choice of material needs to be applied to reduce risk of loosened parts during use and assembly. Materials that are hazardous are required to be excluded.

Aesthetics

The interior door panel must be aesthetically appealing to the customer. The design must have functions and features that have much to offer and must be perceived as exclusive.

4.4 Concept generation and evaluation

This section describes the results of the concept generation phase and the process of how the final concepts were chosen.

Twelve rough concepts were generated with help of the morphological matrix as explained in section 3.4. Schematic images of these concepts can be found in Appendix G. Three out of the twelve concepts were disregarded since they were disqualified from further development in the elimination matrix.

The nine remaining concepts were evaluated in different Pugh matrices (see Appendix E) where three concepts scored substantially higher than the others. These three remaining concepts were scored in the Kesselring matrix (see Appendix F). Two of them were cross-bred as explained in section 3.4 resulting in a total of two concepts with beneficial characteristics that were further developed. These two concepts are described below.

4.4.1 Multifunctional armrest

The concept presented in this section is thought of as the more expensive of the two in accordance to the objective presented in section 1.3. The schematic design of the concept as initially generated with help of the morphological matrix, can be seen in Figure 35.

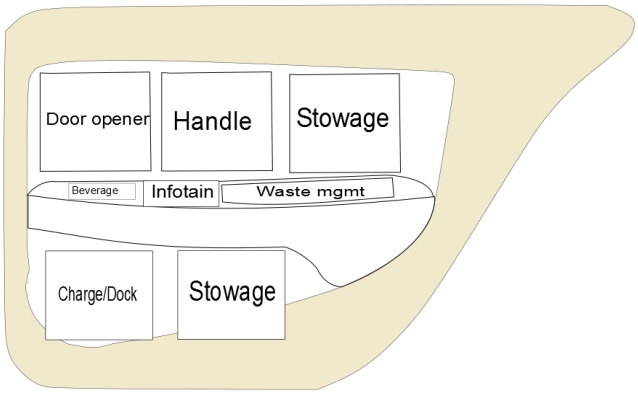

Figure 35 Schematic design of the concept Multifunctional armrest

Scoring high on the criteria regarding infotainment and connectivity as well as passenger value and perceived quality, this concept scored the highest of all the concepts in the Kesselring matrix. The idea is to use the space created between the interior and exterior door panels to deepen the arm rest and add several functions to it. The space between the panels would also be used for cabling to connect the armrest with the infotainment system in the car. The cables would have to be led through the inner plate of the exterior panel, on through the B pillar and then on to the infotainment system. The armrest should contain a cup holder, a touch screen and a closeable compartment for smaller waste. An interface to plug in earphones and USB-compatible devices shall also be included in the armrest. A basic sketch of a slightly more developed version of the concept can be seen in Figure 36.

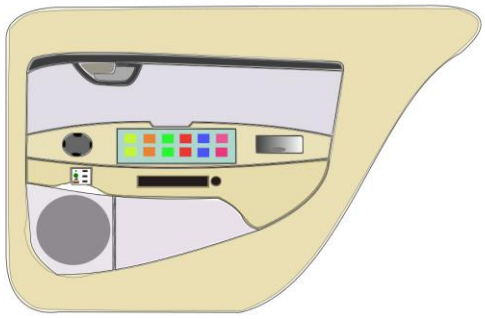

Figure 36 Primary sketch of the concept Multifunctional armrest

The area below the armrest is thought to be utilized as a docking station for portable devices such as tablets and laptops. The portable device is supposed to be plugged in at the docking station to charge the batteries and at the same time connect the device with the infotainment system of the car. The touch screen in the armrest shall be used to control the docked device and its screen is supposed to be projected onto the monitors attached to the neck rest of the front seats. For Volvo

models without neck rest monitors, the screen could simply be integrated with the touch screen in the armrest. Charging or docking could in such a case be acquired through a retractable USB-chord coming out of the armrest. Other possible features to add to the concept could be to include a cooling mechanism in the cup holder.

4.4.2 Multiple storage compartments

The concept was schematically designed according to Figure 37.

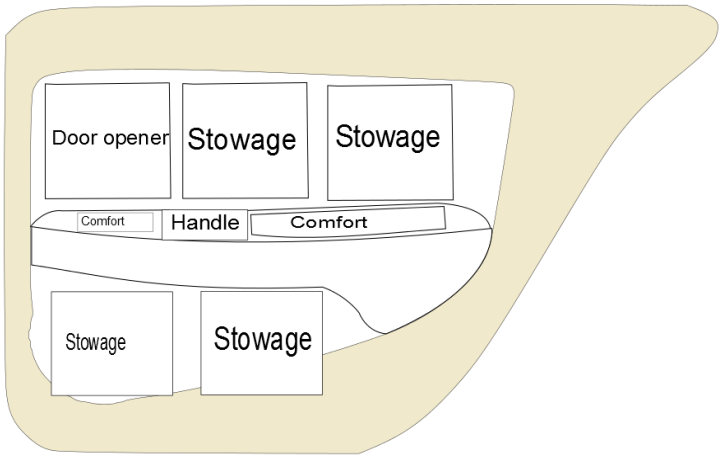

Figure 37 Schematic design of the concept multiple storage compartments

This concept was thought to fit the Volvo models sold at a somewhat cheaper price in the product family. The concept scored high in the criteria concerning daily life usage, solidity and weight reduction but was also thought to be of better value to the driver in relation to the competing concepts because of the extended storage capacity. The idea is to fit in storage compartments of different sizes wherever possible in the door panel. A more developed sketch of the concept is shown in Figure 38.

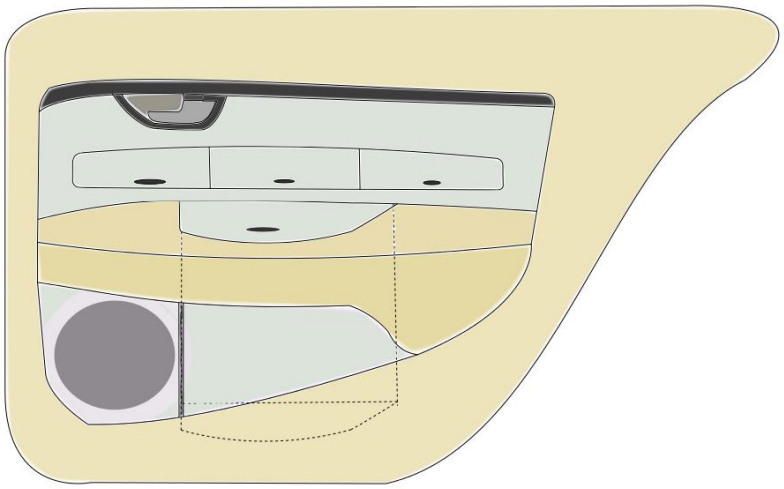

Figure 38 Primary sketch of the concept Multiple storage compartments

A big closable compartment is to be placed behind the arm rest as illustrated in Figure 38. This compartment can be used for different purposes. It could be used as a waste basket with a removable container or a fridge containing bottled and canned beverages. It could also be used simply as a large storage compartment. In that case some inner lighting that activates when the hatch is opened should be included in the design for adequate vision of the stored items. Another possibility is to implement all these ideas as modules which can be optional choices when purchasing a vehicle from Volvo.

The compartments above the armrest are thought to be used to store smaller items like keys, cellphones, sunglasses and wallets. One of these compartments could also, in the near future, be equipped with an inductive charging device for cellphones as the technology behind inductive charging develops. The choice to of using closable compartments is due to security requirements stated in the requirement specification (see Appendix A). The area below the armrest will be similar to how it is on current Volvo cars with an open compartment next to the speaker. Since the speaker can be moved toward the exterior, the storage compartment beneath the armrest will be extended to include the possibility of storing items under the lower edge of the speaker. No part of the panel can however obstruct the speaker since that would have a negative effect of the sound quality.

4.5 Concept design

This section contains the result of the concept design phase that the two concepts described in the previous sections went through. The chosen concepts were further developed and models to visualize the design of the concepts were created.

4.5.1 Multifunctional armrest

Figure 39 depicts the concept model of the multifunctional armrest.

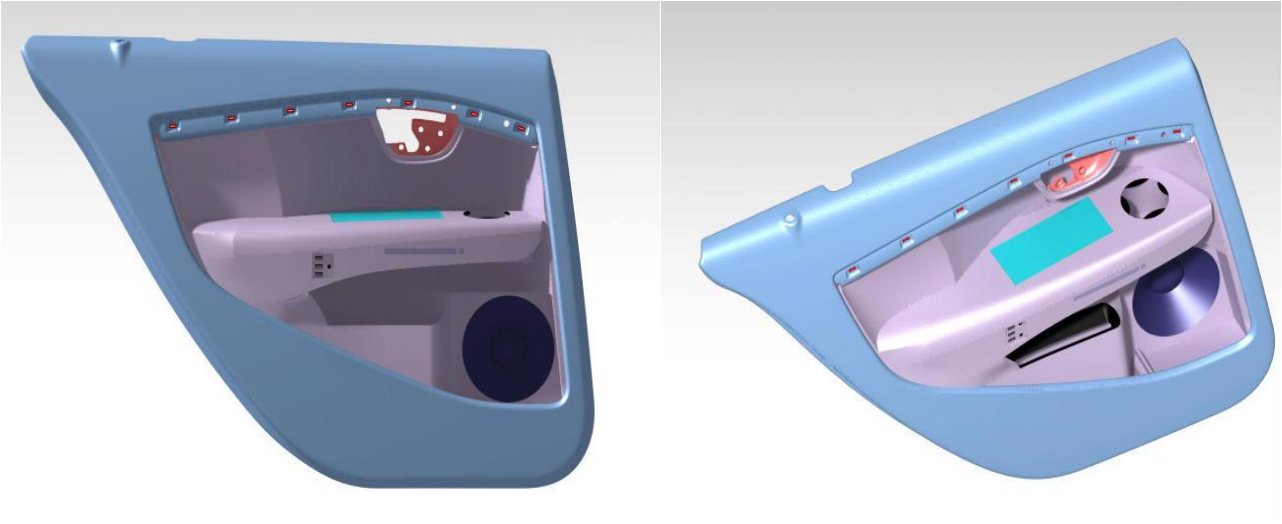

Figure 39 CAD-model of the multifunctional armrest

Just as the basic design depicted in Figure 36, the armrest contains a touch screen and a cup holder on the top surface and a DVD/CD-ROM as well as an interface for plug in of USB and earphones on the surface facing the passenger. The closable compartment for smaller waste is not included in the model but could be placed in the rear of the armrest. Below the armrest is a compartment thought to be used as a docking station for portable devices. The black detail surrounding the compartment beneath the armrest is a fixating device which will prevent the device docked to move and hit the walls of the compartment when for example driving on a bumpy road. The speaker has been moved 70mm toward the exterior panel which gives room for additional storage in front of the speaker. Small items such as keys, a wallet, a phone or sunglasses are thought to be stored in this area. Views and opinions regarding this concept will be discussed in Chapter 5.

4.5.2 Multiple storage compartments

The CAD-model of the concept is visible in Figure 40

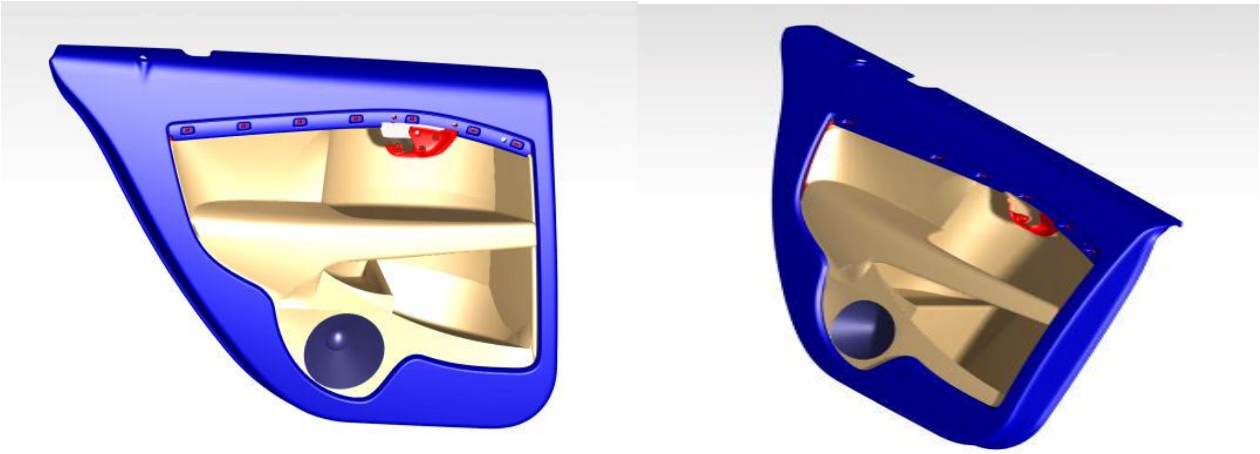

Figure 40 CAD-model of the Multiple storage compartments

As can be seen in Figure 40, the speaker has been moved to the rear of the door panel to make room for a large storage compartment in the front. The speaker has instead of being placed 70mm closer to the exterior been kept at its' original position of depth in order to use the speaker attachment as a basis for a smaller compartment above it. The storage capability within the door panel has thus been divided into two areas. The smaller one is thought to carry smaller items such as the ones mentioned in the previous section. The larger one is supposed to carry whatever items the passengers or the driver wish to bring into the car. The compartments can be reached either from above, through the handle of the armrest or from the side, by reaching below the armrest. The smaller compartment could be used as an inductive charging station for cellphones by placing an induction plate in the bottom of the compartment. The larger compartment could be customized to fit certain items such as, bottles, smaller umbrellas, books or magazines. But for now it is designed as one big compartment that can carry any item that fits into it. The basic sketch of Figure 38 includes additional storage capability above the armrest but such features have not been included in the CAD-model since it would restrict the passenger from reaching the compartment below the armrest from above. The lid behind the armrest in Figure 38 has neither been included since it would require a sealing wall beneath the armrest which would neglect the passenger of entering the compartment from the side. This would in turn impair the ability to reach eventual smaller items in the bottom of the large storage compartment. Views and opinions regarding the multiple storage compartments concept can be found in Chapter 5.

5. Discussion

As mentioned in the title of chapter 4, the results gained in the project will be discussed in this chapter. The chapter is included in the report to provide the reader with nuanced opinions and views on the execution of the project as well as its' results. Note that the structure of this chapter is not divided under the same chronology as chapters 3 and 4. The discussion is instead focused on opportunities with fixed windows, views on the chosen methodology, pros and cons regarding the final concepts and a general discussion on window operability. The final two chapters following this one contain the conclusions of the project and recommendations for future work respectively.

5.1 Fixed window opportunities

Volvo has early differentiated themselves from their competitors by specializing on safety issues. This project aimed to create unique products that would differentiate and diversify Volvo even more from other existing products on the market. By contributing to the door panel group at Volvo Car Corporation, a solid foundation for further development of the concepts related to fixed rear door windows have been established. The generated door panel concepts have a design and functionality not present on the market today

Volvo has a small market share worldwide but has their largest share in Sweden. Knowledge is limited for the market regarding fixed windows. Becoming one of the first to explore the possibilities could be a major advantage. The mindset of the regular customer can be changed and increase the perceived customer value. For Volvo it is also key to reduce the weight and cost to enhance quality assurance.

There exist financial resources to expand and evolve the knowledge in this area as well as that the production capability already exists. However the customers can experience change resistance regarding this product. The operable window might be considered as a hygiene factor mentioned in the Kano Model explained in section 2.2. It can hence be a challenge to merge a luxury brand with fixed windows.

5.2 Methodology

The use of Teamcenter Visual Mockup in combination with the knowledge gained from the staff at Volvo Car Corporation provided good and quick insight to the components and parts included in the rear doors and their surroundings. After the software was comprehended there were never any problems with examining any part or component in detail.

The survey provided a satisfying amount of answers in a relatively short time. It also provided several ideas that were used in the concept generation and evaluation phase of the project. A drawback with the use of surveys is that the answers provided by the survey sample might not be carefully thought through. For example, a number of survey participants answered "Yes" on the question "Do you think it is necessary to be able to open the rear door windows?" while they at the same time answered "I never open the rear door window" to the question "What makes you open the rear door window". The result of the survey can hence be somewhat contradicting. Other drawbacks using a survey is that it does not show what you did not know that you did not know as well as that it is not certain that all questions are fully understood by the respondents.

The focus group workshops supplied a large amount of ideas that were more developed and thought through than the survey. The ideas most frequently mentioned are actually included in one of the concepts (Charging or docking of laptops, phones and tablets). The focus group approach provides more qualitative ideas than the survey since the participants are allowed to explain their ideas in detail and also interact with other participants to develop them further. Drawbacks with focus group workshops is that it is more complicated to apply in relation to a survey since a lot of work has to be done to make sure that the workshops have enough participants that are available at the same time. Another drawback is that dominant participants can take up a majority of the airtime which might bring that opinions from less dominant participants get left out of the discussion. Influential and dominant workshop participants can also cause conformity and group-think within the discussions. It is then up to the moderator of the focus group to emphasize diversity of opinions and evenly distributed airtime between the participants.

The competitive benchmarking provided some ideas to the concept generation phase but most of all it showed that implementation of fixed glass within cars with four or more doors barely exist on the market. Competitive benchmarking does however only reveal what already has been launched on the market and it is hence unknown whether other car brands are also researching possibilities with rear door window fixation.

The secondary research study of the work performed by the market intelligence department provided a lot of information regarding customer demographics and target consumer segments. This revealed who is likely to ride in the backseat of the different Volvo car models as well as who is likely to purchase the car. On the other hand the reports that were studied were mostly from between 2008 and 2010 and there is a risk that the information is no longer as accurate as it was back then.

The matrices used for concept generation and evaluation served as an effective method and made the task of evaluating the concepts an easy and structured way for choosing the final concepts. If information was not sufficient the matrices implied that more data was necessary to achieve an equitable comparison. One drawback could be that the criteria used for evaluation and the weighting of these are not aligned with what the average customer perceives as most important. Since the choice of criteria and their weighting was done in accordance to strategic attribute performance of Volvo Car Corporation they were nonetheless assumed to represent customer preferences at least to some extent.

5.3 Final concepts

The multifunctional armrest concept has potential to substantially differentiate Volvo Car Corporation from their competitors. Perhaps especially in China where it is not uncommon that the owner of the car rides in the back seat while a chauffeur drives the car. Since the models presented in section 4.5 are only visualizations of the functionality within the door panels some aspects of the concept have to be further developed before implementation can be considered. The design of the multifunctional armrest has not fully considered ergonomic requirements posed

on the panel. It is not certain that the passenger will be able to reach the features included in the armrest in an adequate way. The docking station for tablets and laptops in the model might also be too small to fit laptops of any size. It is neither certain that the space between the armrest and the docking compartment is large enough for the passenger to be able to slide down any device into the compartment. If a docking mechanism is to be integrated within the docking compartment a lot of difficulties will arise regarding how the interface shall be designed to fit portable devices of different brands, shapes and docking possibilities. To be able to connect the devices to the infotainment system of the car, appropriate software need to be developed that spans eventual differences in operative systems of the portable devices.

The multiple storage compartments concept is not connected with an equal amount of apparent problems. There are however some aspects that also has to be considered in order to move on with the design. The ergonomic aspects have neither in this case, been fully taken into consideration when designing the concept. Reachability has to be examined to guarantee the functionality of the panel concept. Security is another cause for further development. Items stored in a large open compartment can probably be easily seen from a person standing outside the car. If objects such as wallets, computers or other valuable items are stored in the compartments and seen from the outside, there is a greater probability of break-ins

Some positive and negative aspects regarding the two final concepts are listed below.

Multifunctional armrest

+ Adds a premium feel to the car
+ Several functions are integrated into the armrest which was earlier only used for shutting the door and resting your arm
+ Opens up possibilities for a variety of passenger activities
+ A differentiating factor from other premium brands
+ Surprising and delighting product characteristic

- Complex with electricity
- Possibly expensive to manufacture
- Only useful when back seat passengers are guaranteed to be present

Multiple storage compartments

+ Should guaranteed be cheaper than operable window configuration
+ Will most likely reduce the weight of the complete rear door
+ High storage capability
+ Possible to customize the storage compartment
+ Could be used by non-back seat passengers to store items in the car

- Does maybe not add a premium feel unless additional features are added
- Not as many surprising and delighting product characteristics as the multifunctional armrest concept

There is also more general work to be done in order to fully construct the concepts. Determine what material to be used, how to manufacture the panel concepts, make cost estimations and so on. The project scope was however to design concepts that would present the functionality of the concepts to provide Volvo with hard examples of how to utilize the space created by window fixation and it was therefore known from the beginning of the project that development work would remain to be done even after project conclusion.

5.4 Window operability

Not much emphasis has been put on the window configuration in this project since it was outside the scope. Deeper investigation of different window configurations can lead to some opportunities. Instead of introducing an immature market to a fixed window too quickly, implementing a tilting or rotating window could ease and soften up the customers. It might be a way to enter the market and to make the idea of fixed windows pass over the hump of change resistance. On the other hand, if the tilting mechanism is driven mechanically instead of electrically it would feel as if the car is non-premium which would not be aligned with Volvo strategy. A window that could be moved horizontally could be another option that can be looked upon.

The window could also have certain functions. Instead of putting a sun visor in the door panel, the window could be made out of photochromic glass which serves as a sun shade with automatic or manual activation. General Motors has been developing a touch screen window that could be used in different applications such as interacting with the window by drawing pictures on it or using it as a multimedia system where the passenger can share music.

6. Conclusions

The objective of the project was to design two door panel concepts of different price classes that could justify the fixation of the rear door windows. The concepts were to fit the same interface making it possible to attach any of the two concepts to the same car door. The key results from the project will be listed below and each result will also be described thoroughly

- **Design of two door panel concepts**
  Two different panels with intention to outweigh the customer satisfaction related to being able to open the rear door window have been designed. These concepts can clearly be identified to fit different price ranges as well as being modular since they both have the same interface toward the interior panel carrier which in turn is attached to the exterior panel of the rear door.

- **Driving factors for window fixation**
  Several internal advantages for Volvo Car Corporation were identified throughout the project. These advantages or driving factors can be useful in order to persuade responsible decision makers and to get organizational consent regarding implementation of fixed rear door windows. The driving factors can be found in section 4.1.

- **Market views on window operability**
  The market research indicated that 80% of the sample wants to be able to open the rear door window. The main reason for opening the window was to get fresh air and sometimes to interact with people outside the car. Satisfying the need for fresh air could be done by looking further into the alternative window configurations presented in section 4.2.2.4 or simply by opening the front door window instead. For back seat passengers to be able to interact with outside people it is assumed that the car needs to be stationary. In that case the rear door could be opened to allow verbal communication. If there is a need for passengers to communicate while the vehicle is in motion another solution could be to once again look further into the alternative window configurations.

- **Concepts aligned with Volvo strategy**
  The evaluation criteria used in the screening and scoring matrices described in section 3.4 made sure that the final concepts, besides from satisfying the customers would also go along well with Volvo Cars Corporation's strategic choices for the future. The concepts that were the strongest regarding the strategic differentiation attributes were the ones that scored the highest in the matrices and were hence further developed as the final concepts.

- **Marketing possibilities**
  The only car available on the market with rear doors and fixed windows is the Citroën DS4 and no rear door panels with functionality comparable to the concepts developed in this project exist either. There should therefore be a possibility to attain a competitive advantage through differentiation from the competing brands. The possibility to be first on the market with the features related to the fixed windows should also be advantageous.

7. Recommendations

The market for fixed rear door windows is looking promising for the future since it results in many internal advantages for Volvo Car Corporation. There are though, numerous factors to consider when proceeding with the idea of fixed windows. This chapter provides some recommendations for further work

Implementing a fixed rear door window in reality requires more investigation in evaluating customer satisfaction regarding the concepts and including the department of product planning is therefore important. The market could be an obstacle in the sense of changing customer's opinions of the necessity of rolling down the windows. To ascertain that the concepts created in this project provide more customer value than an operable window, physical models of the concepts should be constructed and used in customer satisfaction seminars. Inviting Volvo customers and allowing them to test and try out the concepts and then express their views could be a way to investigate this. If an alternative way to open the window can be presented at the same time, the positive impact on the customers should be greater. Penetrating the market would also require a door panel that is aesthetically appealing for the buyer. It is therefore recommended to put further effort on the design of the final concepts and their physical appearance.

Once it has been established that the customers would prefer fixed rear door windows given what they will get in place of it, the concepts should be designed in detail to correspond to the internal requirements of Volvo Car Corporation. Further development should include manufacturability, safety requirements, quality aspects and ergonomic demands both toward the product user and the assembly personnel. Including attribute responsible staff from the departments concerned in the development should make sure that the internal requirements are met.

Modification of the door structure surrounding the interior panel should also be considered. In this project the exterior panel, for example, has been regarded as a fixed input to which the new door panel concepts must fit. The possibility to make alterations to the exterior panel and other surrounding parts based on the fixation of the windows could facilitate more advantageous designs of the door panel concepts and perhaps also for the surrounding parts in question.

Examining the sales figures of Citroën DS4 over its existence is recommended to reveal the exact demographics of customers purchasing cars with fixed rear door windows. If the users are identified, the door panel concepts could be even more adjusted to fit the targeted consumer segment.

Lastly, it is recommended that extensive testing of physical models of the concepts should be done to reveal eventual lacks in quality and robustness in the design. Test methods to assure that the concepts fulfill all the requirements should be developed and carried out as a last step before production can commence.

However, these recommendations for further development are all based on the fact that the concepts created in place of window operability are more appreciated than the possibility to roll down the window between the interior- and the exterior panel of the rear door.

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Appendix A: Requirement Specification

1 Attribute Requirements

1.1 Chest surface

An energy absorbing profile of minimum thickness 35mm and crush strength of 0.14 MPa shall be fitted in the chest surface

Incompressible objects are not allowed in this area

Trims surfaces shall not exceed 45° relative to a vertical plane

Maximum vertical variation shall be less than 5mm per 60mm horizontal distance

1.2 Armrest

Highest acceptable level of upper surface is 170mm above SRP

Armrest height shall be minimum 50mm

1.3 Closing Handle

The middle point of the closing handle shall be between 255-290mm in front of SRP

2 Safety Requirements

2.1 Crash Safety Requirements

2.1.1 General

No sub-units of the door module or the rear door interior panel may come loose during the crash sequence

2.1.2 Cable requirements

Cables shall have a minimum length for optimal routing +30mm

2.1.3 Interior fittings

Interior fittings may not expose sharp edges causing risk for injury after or during impact

Interior parts shall not deform in way that causes damage to surrounding safety systems and thus increasing the risk of injury

2.2 Fire Safety Requirements

2.2.1 Interior trim material

All interior trim material shall fulfill legal requirements in FMVSS 302, achieved by testing according to VCS 5031.19 and with a maximum burning velocity of 80mm/min

2.2.2 Electrical Components

No drops of burning material must occur in the case of fire

Electrical cables must not melt together due to short-circuiting.

Electrical system must be packed to prevent mechanical wear that could cause short-circuits.

Electricity that can be harmful for rear seat passenger shall not be conducted through the door structure

3 Security Requirements

3.1 Door panel storage

Storage spaces shall be designed in such a way that items stored are not visible when standing outside the vehicle

4 Endurance requirements

4.1. Door operation

No deterioration in door module and interior panel function during service life

No squeaks of rattling may arise from opening or closing the door during service life

No fatigue cracks may appear that have an effect on any part functions

Service life for rear doors refers to 50. 000 cycles from fully opened to closed position

Door must handle being closed with a speed of 4 m/s without damage or plastic deformation

Interior grab handle shall withstand a force of 500N without any permanent deformation

No cracks in door module shall appear with a force of 500N

The handle shall also withstand a force of 700N without any separation

4.2. Solidity

No squeaking or rattling noises shall be emitted from the door module or the interior panel during any driving conditions

No failures critical to safety are allowed

5 Design for Recycling

Hazardous materials and substances shall be avoided

Drainage and removal of environmentally hazardous materials shall be facilitated

Components shall be designed to facilitate material recycling

6 Weight Requirements

Components added to the door module or the interior panel shall not exceed 2250 g/car

7 Manufacturing Requirements

The door module and interior panel shall be designed to be assembled by one person

Components have to be designed so that automized assembly is possible.

Eliminate assembly errors caused by lost production and lacking quality. Parts must be designed where possibilities for exchange of parts are eliminated.

No sharp edges which can cause personal injury shall be present

Designed components shall be assembled using current process facilities and process sequence

Parts variation shall be clearly detected after assembly

A minimum of component connections shall be used

There must be enough space for the operator to carry out each assembly operation

Part numbers should be visible during assemblies and repairs

Parts must be designed to be stiff enough to resist forces applied in assembling processes

8 Maintenance Requirements

Requirements shall be fulfilled in case of part reinstallation

Assembling and disassembling of parts shall be possible without risk of damaging surrounding parts

Each component shall be individually replaceable with mountings designed for repeated removal and reinstallation

There shall be no need to replace or repair electrical components during service life of the vehicle.

Interior door panel shall be easy to clean from a customer perspective

Cleaning with water shall not leave any visible marks or color change

9 Packing Requirements

Moving parts shall generally be surrounded by a space of 10mm and static parts 5mm

10 Cost

The design of each part shall be designed to minimize their cost

11 Material

Avoid tape for attaching loose parts

Scratch resistant material shall be used to minimize risk of ruined material in assembly

Shall provide formability and design freedom by avoiding surfaces exposed to view after paint/trim and when closures are opened on inner panels

Toxic material shall not be used

Recyclable material shall be used to the greatest extent possible

12 Aesthetics

Interior panel design must be appealing

Features and functions of the interior door panel must be perceived as exclusive

Appendix B: Function Category Matrix

Door opener	Automatic	Manual		
Ventilation	Micro pores	Vent	Dryer	
Lighting	Light emitting diodes	Spotlight	Mood lights	
Handle	Traditional S80	New design		
Carry items	Folding Table	Sliding door	Venetian blind	Use armrest
Stowage	Warm/Cold/Ventilated	Closable Fixed/Customizable	Open Fixed/Customizable	
Infotainment	Screen	Sound	Control Panel	
Charge or Dock	Plug in with chord	Induction plate or Wireless docking	Plug-in integrated interface	
Beverage container	Cup holder Warm/cold	Bottle holder Warm/cold	Beverage supplier	
Manage waste	Compressing box Removable	Cleaning device	Removable container	
Comfort	Support Arm	Support feet/legs	Support Head/Neck	

Appendix C: Morphologic Matrix

Area	Function category 1	Function category 2	Function category 3	Function category 4	Function category 5	Function category 6	Function category 7	Function category 8	Function category 9	Function category 10	Function category 11
A	Door Opener	Ventilation	Lighting	Handle	Carry Items	Stowage	Infotainment	Charge or Dock	Beverage container	Manage waste	Comfort
B	Door Opener	Ventilation	Lighting	Handle	Carry Items	Stowage	Infotainment	Charge or Dock	Beverage container	Manage Waste	Comfort
C	Door Opener	Ventilation	Lighting	Handle	Stowage	Infotainment	Charge or Dock	Beverage container	Manage Waste	Comfort	
D	Door Opener	Ventilation	Lighting	Handle	Carry Items	Stowage	Infotainment	Charge or Dock	Beverage container	Manage waste	Comfort
E	Door Opener	Ventilation	Lighting	Handle	Carry Items	Stowage	Infotainment	Charge or Dock	Beverage container	Manage Waste	Comfort
F	Door Opener	Ventilation	Lighting	Handle	Carry Items	Stowage	Infotainment	Charge or Dock	Beverage container	Manage Waste	Comfort
G	Ventilation	Lighting	Stowage	Charge or Dock	Manage Waste						
H	Ventilation	Lighting	Stowage	Charge or Dock	Manage Waste	Comfort					

Appendix D: Elimination Matrix

Concept	Realizable	Safe	Economically feasible	Criteria Fulfillment: (+) Yes (-) No (?) More Info Needed Decision: (+) Keep (-) Remove (?) More Info Needed	
				Comment	**Decision**
1. "Reader"	+	-		Neck-support	-
2. "Tea/Coffee"	+	-		Boiling water	-
3. "Media 1"	+	+	+		+
4. "Media 2"	+	+	+		+
5. "Media 3"	+	+	+		+
6. "Ventilation"	-			Low airflow	-
7. "Stowage 1"	+	+	+		+
8. "Stowage 2"	+	+	+		+
9. "Children 1"	+	+	+		+
10. "Children 2 "	+	+	+		+
11. "Children 3"	+	+	+		+
12. "Empty"	+	+	+		+

Appendix E: Pugh Matrix

Pugh Matrix 1 General Comparison	**Criteria acronyms**	IC = Infotainment & Connectivity
	W = Weight	PQ = Perceived Quality
	PV = Passenger Value	DLU = Daily Life Usage
	DV = Driver Value	SO = Solidity

Concepts / **Criteria**	**Moving glass**	**Media 1**	**Media 2**	**Media 3**	**Stow 1**	**Stow 2**	**Child 1**	**Child 2**	**Child 3**	**Empty**
W	**Reference**	+	+	+	+	+	0	0	0	+
PV		+	+	+	+	+	+	+	+	-
DV		+	+	+	+	+	0	0	0	-
IC		+	+	+	0	0	0	0	+	0
PQ		+	+	+	0	0	+	+	+	-
DLU		0	0	0	+	+	+	+	+	0
SO		-	-	-	+	+	0	0	0	+
Sum +	0	5	5	5	5	5	3	3	4	2
Sum 0	0	1	1	1	2	2	4	4	3	2
Sum -	0	1	1	1	0	0	0	0	0	3
Net Value	0	4	4	4	5	5	3	3	4	-1
Ranking	**4**	**2**	**2**	**2**	**1**	**1**	**3**	**3**	**2**	**5**

Pugh Matrix 2 – Backseat carrying children

Concepts / Criteria	Child1	Child2	Child3	Stow1	Stow2
W	-	-	Reference	+	+
PV	0	0		-	-
DV	0	0		+	+
IC	-	-		-	-
PQ	0	0		-	-
DLU	0	+		+	+
SO	-	-		+	0
Sum +	0	1	0	4	3
Sum 0	4	3	0	0	3
Sum -	3	3	0	3	1
Net Value	-3	-2	0	1	0
Ranking	**4**	**3**	**2**	**1**	**2**

Pugh Matrix 3 – Backseat carrying adults or no one

Concepts / Criteria	Media1	Media2	Media3	Stow1	Stow2	Empty
W	Reference	0	-	+	+	+
PV		-	-	-	-	-
DV		0	0	0	0	+
IC		-	0	-	-	-
PQ		-	+	-	-	-
DLU		0	-	+	+	-
SO		+	-	+	0	+
Sum +	0	1	1	3	2	3
Sum 0	0	3	3	1	2	0
Sum -	0	3	3	3	3	4
Net Value	0	-2	-2	0	-1	-1
Ranking	**1**	**3**	**3**	**1**	**2**	**2**

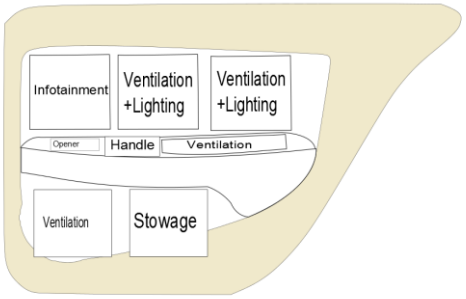
Appendix F: Kesselring Matrix

Kesselring Matrix

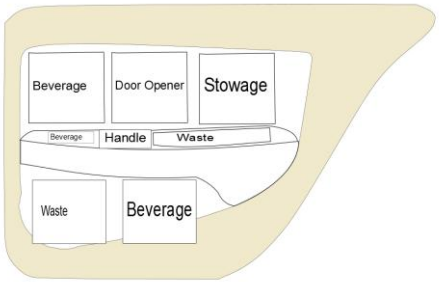
Concepts / Criteria		Ideal		Media1		Child3		Stow1	
	Weight	Rating	Score	Rating	Score	Rating	Score	Rating	Score
W	5	5	25	3	15	3	15	4	20
PV	3	5	15	5	15	4	12	3	9
DV	2	5	10	3	6	3	6	4	8
IC	4	5	20	5	20	4	16	1	4
PQ	3	5	15	4	12	3	9	2	6
DLU	3	5	15	3	9	3	9	5	15
SO	2	5	10	2	4	2	4	4	8
Net Value		110		81		71		70	
Net/Max value		1,00		0,74		0.65		0,64	
Ranking				**1**		**3**		**2**	

Appendix G: Schematic sketches

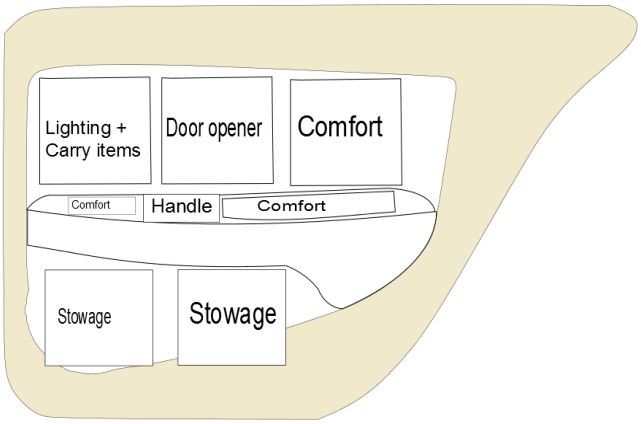
Final concepts highlighted in green



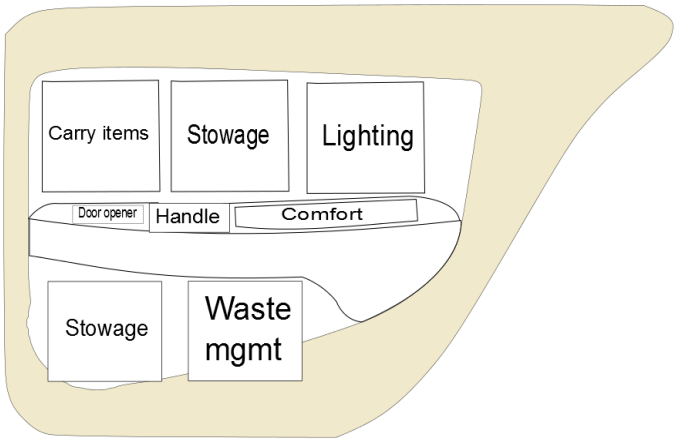
Concept 1 – Ventilation



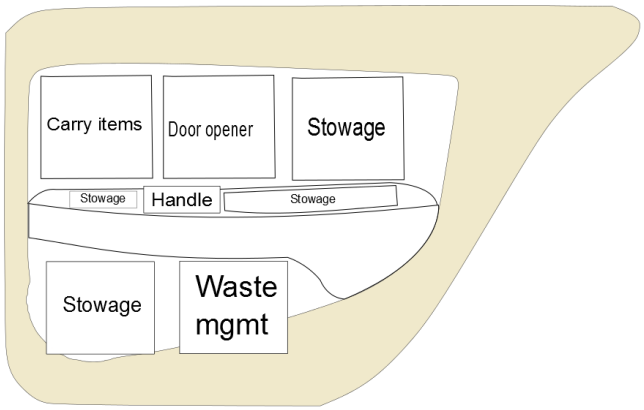
Concept 2 – Tea/Coffee drinker



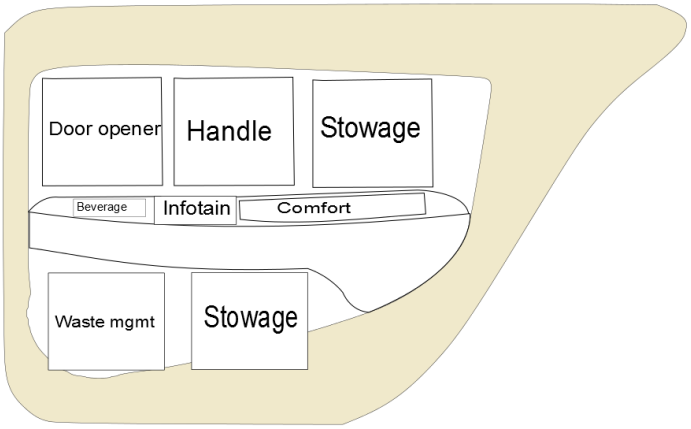
Concept 3 – Reader



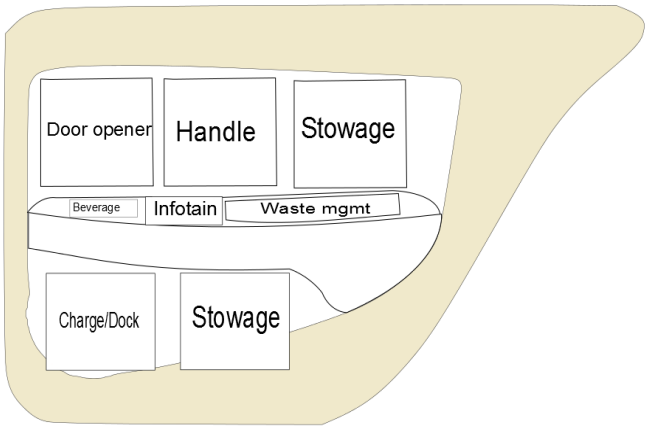
Concept 4 – Child #1



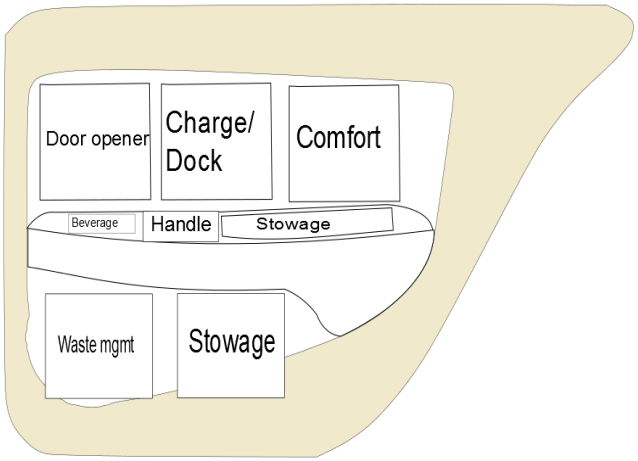
Concept 5 – Child #2



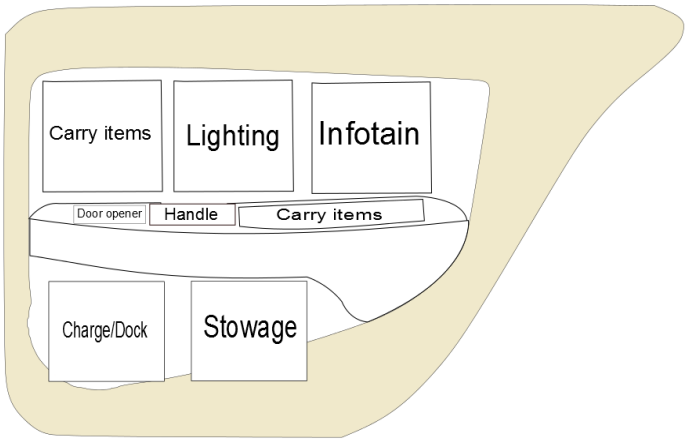
Concept 6 – Child #3



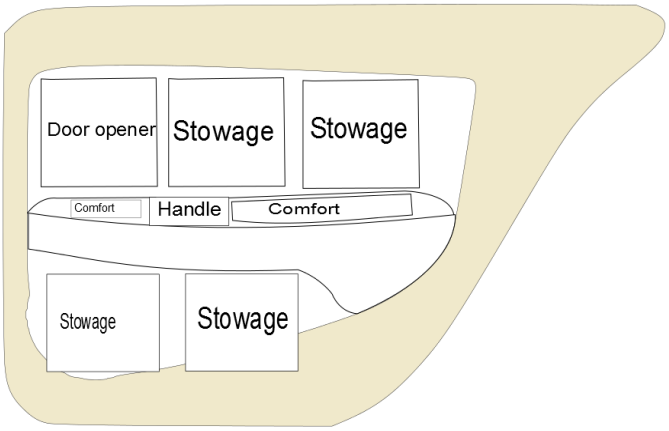
Concept 7 – Media #1



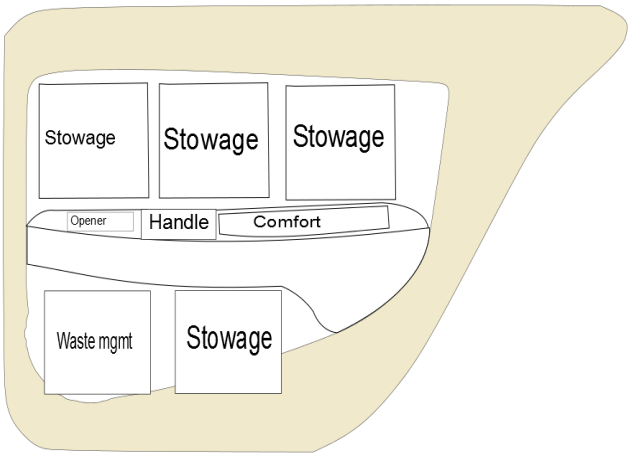
Concept 8 – Media #2



Concept 9 – Media #3



Concept 10 –Stowage #1



Concept 11 – Stowage #2

Concept 12 consited of an empty panel to maximize cost an weigth reduction

Appendix H: Survey

1. How old are you?
2. What do you use your car for, drive to work, training etc.?
3. What car(s) do you drive?

Window functionality

What makes you open the rear door windows?

- Fresh air
- Garbage disposal
- Interaction with people outside
- Clarification of view
- Escape
- Other_____
- I never do

How large part of the rear door window has to be openable?

- All the way down
- Half the way
- Just a little bit
- Nothing

Do you think it is necessary to be able to open the rear door windows?

- Yes
- No

If yes, are there any other functions that might be more useful?

- Yes (like what?)
- No

Questions to driver

How much time do you spend driving cars?

- Zero to half an hour a day
- Half an hour to two hours a day
- More than two hours a day

Do you usually have passengers in the car?

- Yes, front seat only
- Yes, back seat only
- Yes, both
- No

If yes, who usually rides as a back seat passenger?

- Spouse
- Children
- Friends
- Pets
- Elders
- Colleagues
- Car owner

If yes, rate the importance of the back seat passengers´ comfort

- 1 to 5

If yes, what are the passengers usually doing while riding in the car.

- Reading
- Sleeping
- Eating
- Working
- Watching movies
- Playing games
- Listening to music
- Other things _____

If no, do you put the backseat to any other use?

- Yes (what?)
- No

Questions to the passengers

How much time do you spend riding as a passenger?

- Zero to half an hour a day
- Half an hour to two hours a day
- More than two hours a day

How do you spend your time?

- Reading
- Sleeping

- Eating
- Working
- Watching movies
- Playing games
- Listening to music
- Other things _____

How would you like to spend your time?

- _____

What personal belongings do you usually put in the car?

- Clothes
- Wallet
- Computer
- Phone
- Toys
- Video games
- Books & magazines
- Jewelry
- Food/snacks/hot and cold drinks

Is there anything unpleasant, disturbing, annoying or uncomfortable that you usually experience while riding in the back seat?

- _____

General question

If you could add any function, gadget, device or feature anywhere in the car where you spend the most time, what would it be? (Unrealistic ideas are acceptable)

Appendix I: Compiled list of ideas from the workshops and survey

• Modem	• Flashlight
• Pillow / Anything that helps sleep	• Cleaning Equipment
• Footrest	• Central Vacuum Cleaner
• Beer machine	• USB
• Coffee Maker	• Hot / Cold Storage
• Refrigerator	• Climate Control
• Sunscreen/Sunvisor	• Lighters
• Newspaper Holder	• Sockets
• Armrests	• Integrated docking station
• Laptop / Tablet-storage / docking	• Reading lamps
• Various charging stations	• Audio Control
• Trash can	• Motion sickness cure
• Aux Output	• Air Fresh Rare
• Hair dryer	• Automatic door openers
• Toilet	• Cleaning Robot
• Storage in all its forms	• Door Protection tight parking
• Mirror	• ”Reusable shopping bags
• Safety net for bags	• Odor resulting clear tray
• Automatic umbrella	• Electric seat memory
• Retractable table	• Bluetooth integrated keyboard
• Massage	• Cigarr holder