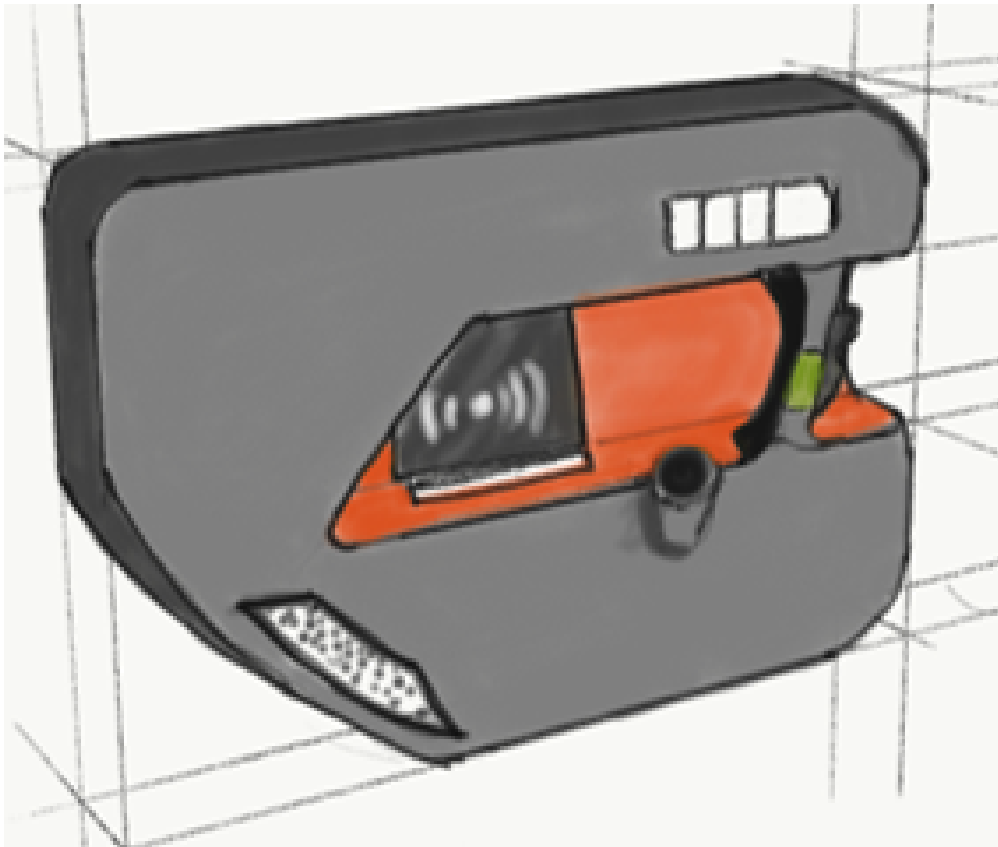




**CHALMERS**  
UNIVERSITY OF TECHNOLOGY

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## **INTERIOR DOOR PANELS FOR FUTURE DRIVERLESS TAXI WITH IMPROVED INGRESS AND EGRESS**

Master's thesis in Product Development

Karthik Lakshmikanthan  
Suhas Sathyanarayana

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Department of Industrial and Materials Science  
CHALMERS UNIVERSITY OF TECHNOLOGY  
Gothenburg, Sweden 2019



MASTER'S THESIS 2019

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Gothenburg, Sweden 2019

Interior Door Panel for Future Driverless Taxi with Improved Ingress and Egress  
In cooperation with Volvo Car Corporation

© Karthik Lakshmikanthan

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Cover: A Digital drawing of the concept Powermat, drawn using Adobe Sketch.

Typeset in L<sup>A</sup>T<sub>E</sub>X

Printed by Chalmers Reproservice

Gothenburg, Sweden 2019

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## Abstract

This report presents a master thesis project pursued at Volvo Car Corporations' door panels department, from January 2019 to October 2019. The thesis is about investigating the market requirements, company expectations about the aesthetic and functional elements of autonomous vehicles and development of a new concept door panel for a future autonomous vehicle.

The autonomous vehicle project from Volvo Cars is intended for the taxi segment and is developed in collaboration with its clients in U.S.A. Due to this, the client's requirements are also taken into consideration while designing the door panel. Being a mass commute vehicle, the interior layout of the vehicle is planned in such a way that it can accommodate the passengers without affecting their safety and privacy.

The most commonly included components in conventional door panels are waist rail, arm rest, speaker, cup holder, lock/ unlock button and door handle. These components are packed together on the door panel by considering packaging, safety and ergonomic guidelines. For an autonomous vehicle in taxi segment, the driver seat is unnecessary and being a taxi, the boot space is rendered moot. Volvo Cars took this opportunity by changing the interior layout and the seats in the car to accommodate more passengers.

The need to come up with a new concept for a door panel is derived based on three main reasons. Firstly, few components in the door panel that enable manual operation of door functions were eliminated for the autonomous car project. Secondly, the need to accommodate more passengers and automate the door functions requires a reduced door panel width. Finally, to accommodate the difference in attitude of customers towards a taxi car compared to a personally owned car and the expectations the future generation has from an autonomous vehicle.

The product development process for the new door panel concept started with an extensive market and customer research, both internally and outside Volvo Cars. The process consisted of idea generation based on market research, ergonomic and safety considerations, followed by various stringent filtering process to find the right concepts for the door panel. Finally the concepts was realised in 3D, by modelling it in Alias and then building the mechanical design in Catia V5. Volvo Cars' design and manufacturing guidelines were considered throughout the detailed design phase to realise the concept. During the course of this thesis, the autonomous vehicle project was put on hold until December 2019. Hence this report and the final door panel concepts developed through the thesis serve as the end product according to the available inputs and market data. But when the autonomous vehicle project is resumed again in Volvo Cars, the outcome of this thesis will serve as a base tool to understand the requirements for the components and help the Research & Development team in making better judgements while developing the actual door panel for the project.

Keywords: autonomous car, door panel, taxi, interior, ergonomics, safety, Catia, Alias, Volvo Cars



# Acknowledgement

The thesis project was carried out in collaboration with Volvo Car Corporation, within the Door Panels team. All the project activities were carried out in Volvo Cars' facility under the guidance of Mr. Peter Möller and Mr. Johan Heinmert. The project was supervised from Chalmers by Dr. Göran Gustafsson.

We sincerely thank Mr. Johan Heinmert for providing the opportunity to pursue a Master's thesis in the Door Panels department and the necessary facilities to carry out the thesis work. We would like to thank our supervisor from Chalmers' Dr. Göran Gustafsson and our supervisor from Volvo Cars' Mr. Peter Möller for their continuous guidance and support during the project.

We extend our heartfelt gratitude to the entire Door panels team, for providing the technical guidance whenever we needed it and for actively participating in our thesis activities. We also thank the members from safety, ergonomics, styling and materials team for providing the necessary inputs during each phase of the thesis project.

We express our appreciation and thanks to the participants from all over the world for sharing their views and inputs regarding autonomous vehicles, in the surveys we circulated online. Finally, we would like to thank all the professors and support staff from Chalmers, for imparting in us, the knowledge that was necessary to carry out the thesis project successfully.

**Gothenburg, October 2019**

*Karthik Lakshmikanthan*  
*Suhas Sathyanarayana*



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# 1

## Introduction

Volvo Car Corporation, usually called Volvo Cars is a global luxury car brand, headquartered in Gothenburg, Sweden. Founded in 1927 as a subsidiary of SKF, the company was sold to Ford Motor company in 1999 and in 2010, Geely Holding Group bought the majority shares in the company. Known for having safety and luxury as prime factors, the company has dealers and suppliers globally. Volvo Cars' (VCC) major markets are China, USA, Sweden and other countries in Europe.

### 1.1 Background

The rise of autonomous driving has seemingly opened up a brigade of questions and doubts as to how the future of transportation might look like. Many of the expert market research firms such as KPMG & ReThinkX believe that, there will be a massive drop of nearly 50% in car sales by 2030 due to the ubiquity of autonomous transport services. Autonomous taxi service pushes us to look at conventional concept of car ownership in a completely different perspective.

Volvo Cars plans to tap the potential of this new market trend by introducing themselves in the autonomous taxi sector.

### 1.2 Purpose

The needs and expectations of passengers travelling in a taxi differs from what they expect from their personally owned cars. Specific to this thesis, the newly emerging autonomous vehicle concepts and introduction of new technologies have also paved a way to look at designing a car differently, especially the interiors. With the elimination of conventional powertrains through electric vehicles and redundancy of steering wheel to some level due to autonomous driving, the overhaul of car interiors becomes imperative. The occupants of the car will be able to do many more things than just travel. Hence there is a need to study how the interior components in an autonomous vehicle should be designed to cater to the needs of future customers. The thesis mainly looks into the door panel out of all the other interior components. It focuses on design changes based on the introduction of autonomous drive systems (ADS), how customer can interact with the door, safety & ergonomic considerations and styling.

### 1.3 Goals and Objectives

The main goal of the project is to understand and redefine the principles behind the design of interior door panel components in conventional cars, based on future trends in autonomous vehicles. The objective of this project is to investigate, design and develop

a concept door panel that can form the basis for further detailed study and development in future autonomous vehicles by Volvo Cars.

### **1.4 Scope and Limitations**

The scope of this project work includes literature review, investigation of customer needs, detailed benchmarking of door panel components in existing autonomous and driverless vehicles, material for the panels according to VCC standards and concept design in CAD software.

The project does not include analysis of the design in CAE software, physical testing of prototype, material testing, supplier interaction and production trial, due to lack of available information and time constraints of the thesis.

# 2

## Methods and Strategies Employed

The chapter aims to introduce its readers to the methodologies used in the different phases of the project. Thereby, helping to understand how certain stages of the project have been conducted and potentially why some decisions were made and lastly, why certain results were obtained.

### 2.1 Market Analysis

A complete assessment of a given market both quantitatively and qualitatively to understand its nature. Market Analysis takes into account various factors such as market need, volume, value, competition and regulations. These tools allows a product development organization to assess viability of a new market or to help thrive in an existing market [1].

#### 2.1.1 PEST Analysis

PEST is a tool that is used by organizations before starting new projects. It provides a birds eye view of the environment in which the product will be released. PEST is a mnemonic that stands for Political, Economical, Socio-Cultural and Technological factors [2]. The PEST analysis was conducted by considering the new technology ADS as the subject and how it can be viewed and received by political, socio-cultural, economical and technological aspects in the US market.

#### 2.1.2 SWOT Analysis

SWOT is another tool used to analyze the internal and external factors that can affect an organization when taking on a new project. It helps understand the company's current position and its ability to pursue new development projects. SWOT is a mnemonic that stands for Strength, Weakness, Opportunity and Threats, where the first two factors focus on the internal ability of the company and the last two factors focus the external environment and how it might affect the company [3].

The SWOT analysis was conducted by considering Volvo Cars as a company that intends to release a new autonomous taxi in the US market. Volvo's internal strengths & weaknesses and external opportunities & threats posed to the company were evaluated based on above-mentioned considerations.

#### 2.1.3 Competitor Bench-marking

A tool used to compare and measure an organization's product, process or practice against other successful competitors. It can be regarded as a continuous process that helps to identify one's own shortcomings, hindrances and inefficiencies. The tool in of

itself does not lead to any improvements but allows the organization to be aware and provides an opportunity to leverage the knowledge gained through the process [4]. The bench-marking process involved sorting relevant competitor door panels using A2MAC1 website and evaluating Volvo's current door panel in terms of material selection, production methods, assembly, weight, mount points and user features.

### 2.1.4 Technology Road-mapping

Technology Road-mapping is a technique widely used in the industries for strategic planning. It helps to establish a relationship between developing markets and technologies, over time. Thus, helping the industries' short term and long term goals through appropriate strategies and providing a method to navigate through turbulent or disruptive times. Technology Road-mapping is usually a graphical representation [5].

### 2.1.5 Surveys

Surveys are a structured data collection methodology used to collect quantitative data for achieving a required goal. In this project we specifically talk only about online surveys, which are easy to circulate to a large and diverse audience in a limited time frame. The survey questions usually consists of demographic questions to understand its audience, later questions regarding a specific topic to understand the general public's views, likes, dislikes, opinions etc.

The survey sent out for this thesis was intended to understand the customer's attitude towards the present taxis and how it can be towards autonomous taxis. The survey was mainly intended for the US market.

### 2.1.6 Interviews

Interviews are a qualitative research methodology used to question a small group of respondents about relevant topics to understand their perspective on the topic or situation. This project consisted only semi-structured interviews, where the framework of relevant topics are fixed and the questions posed to the respondent are mostly improvised during the interview. This helps to delve deep into a topic and make the interview more like a discussion where the respondent can freely express their ideas and views on a topic or a situation [6].

The interviewees were the team members of the door panel department. The interview resulted in understanding their attitude towards an autonomous taxi, its pro and cons, how the technology can specifically impact the design of a door panel. The interviews also aimed to collect data in regards to general design processes, factors and criteria affecting design.

## 2.2 Concept Generation and Evaluation

### 2.2.1 Requirements Specification

The customer needs compiled through the surveys and interviews are usually expressed in the "language of customer". Meaning that these expressions provide a subjective view of the customer issues, which are helpful for developing a product. But these expressions do not provide a clear instruction to design and engineering a product.

Hence, the customer expressions are converted into clear, concise statements that provide info on "What" a product has to do, while not instructing on "how" to achieve. The complete requirement specification addresses all the aspects and subsystems of the defined problem; it is consistent, structured and non-redundant [8].

### **2.2.2 Function-Means Tree**

Function means tree is method of modelling a product through systematic decomposition of its functions. It is represented in a hierarchical format, where functions and means are placed on different levels and are connected according to their casual relations. Usually, each layer is formatted in such a way that the function block is followed by the means block. The top most function is also know as the purpose function. It is also important to note that the means of achieving a function are very generic at this stage to avoid missing out better solutions [7]. Function means tree is used in the thesis to provide structure and clarity on how various functions and sub-functions of a door panel can be met using different means and methods generated in the brainstorming phase.

### **2.2.3 Brainstorming**

Brainstorming is a creative technique usually done in groups to produce ideas to solve a given problem. Here, we use the function means tree as a base to produce ideas for different components of a door panel. The sessions were made sure to be conducted without any criticizing and not limited to technological or logical constraints [9].

### **2.2.4 Morphological Matrix**

Morphological matrix can be a powerful tool to collect, categorize and combine ideas of various functions and sub-functions for a given product. The ideas developed during the brainstorming phase are now categorized and put into the matrix. Further, process also helps to identify the most synergistic combinations among the various ideas to create products [10].

### **2.2.5 Elimination Matrix**

Elimination matrix provides a structured and rational way to eliminate concepts and retain the ones that are worthy. The matrix is usually used in the early stages of a concept evaluation phase. Each concept under consideration is either give a 'pass' or 'Do not pass' status based on how well the concepts satisfy the criteria. Since the level of detail at this stage is low, the criteria used to eliminate these concepts are defined broadly [11].

### **2.2.6 Mood Board**

Mood Boards are templates that helps a designer to follow the right theme while designing a component. A Mood Board is a collection of pictures or a combination of pictures and words, which depicts the feeling, that the component being designed needs to convey to its users. After elimination matrix, the concepts passing it needs to be developed into detailed sketches to be scrutinized in further screening processes. A Mood Board helps in creating detailed sketches with the right design language.

### 2.2.7 Pugh Matrix

Pugh Matrix is concept screening matrix, which can be used to evaluate the concepts against each other by keeping one of them as a datum or reference. The concepts screened at this stage of the product development process are usually more developed and involve more information than the concepts going through the elimination matrix. Here, the various concepts are compared against each other with respect to a list of criteria defined by the developer. For each criterion, the concepts are assigned any of the three symbols '+', '-', 'S' [11]. These symbols represent the following:

- + (plus): Represents that the concept is better than or easier to fulfill, with respect to the datum for the particular criterion
- - (minus): Represents that the concept is worse than or difficult to fulfill, with respect to the datum for the particular criterion
- S (same): Represents that the concept is neither better nor worse, with respect to the datum for the particular criterion

Summation of each concept's 'plus', 'minus' and 'same' scores against the criteria helps one to easily discard concepts that are not relatively better to other concepts. Further, each criterion can be given weights according to their importance, using a simple weight matrix. This increases the resolution of the outcome.

### 2.2.8 Kesselring Matrix

Kesselring Matrix is another concept evaluation method used to get quantifiable data to understand how the remaining concepts are ranked. Since, by this stage in the product development process the remaining concepts would already satisfy the important customer requirements and desires; the method not only helps the developer understand how well the concepts fulfill these requirements and desires in comparison to others but to what degree these are fulfilled [11].

For the matrix, initially the criteria are listed (preferably quantifiable criteria are selected) and weighed to understand their importance. The weights are derived by using a weight matrix where the criteria is compared against each other to see if they are less, equal or more important than the other.

Later the concepts are evaluated against each criterion, usually with a scale of 1-5; which depicts how well each criterion is fulfilled by a concept under study (1 being the lowest and 5 being the highest possible score). Once the concepts are scored, they are now multiplied by the respective criterion weight to give a final value. Finally, all the concepts' final values are compiled in the Kesselring matrix and compared against an ideal concept. The ideal concept is given the highest possible score. This helps to understand the strengths and weaknesses of each concept and how well it fulfills each criterion.

# 3

## Market Analysis

Market analysis is an important process for development of a successful product. This chapter provides a detailed description of various steps taken in order to gather and analyze data, which acts as one of the inputs for concept generation phase.

### 3.1 SWOT Analysis

#### 3.1.1 Strengths

Volvo being a well renowned and trusted brand, with its hallmark as SAFETY, acts as one of its crucial strengths in pursuing an autonomous vehicle project. This is complimented by its consistently high Euro NCAP safety ratings [12]. Volvo's considerably large global presence in over 100 countries, it's decades of knowledge and assets for a successful development puts them in front lines of the race to achieve autonomous products. Adequate R&D facilities and manufacturing capabilities in Europe, Asia and America helps them to develop products at a much faster, cost effective and regional specific way[13]. Volvo has already started testing level 4 autonomous vehicles and its collaborations with cooperation such as ZENUITY propels them further in comparisons to its competitors.

#### 3.1.2 Weaknesses

One of the more outstanding issue for Volvo cars would be its market share and presence when compared to its competitors. It being relatively less might not provide the needed exposure for a product. Volvo is considered to have a higher price range for its product in comparison to its competitors [14]. Although this can be viewed as a contextual weakness, since Volvo's products come with a higher standard of quality, it ultimately affects when the end customer solely decides from an economic standpoint. The recent autonomous taxi car involving a Volvo car might spill bad reputation on the company, even though it is not the company's fault.

#### 3.1.3 Opportunities

The Autonomous culture will cater for a whole new era of innovation in terms of vehicle design, especially the interior design. The companies will now have the opportunity to completely overhaul the interior design, since the fundamental principle of driving will redefined. Ridesharing and Ridehailing services are becoming more popular and turning into a new market segment [15]. The concept of car ownership is now being broken down by these services. Partnering with Ridesharing comapanies to enter this new market segment will help Volvo to get a head start.

### 3.1.4 Threats

In this project, Volvo is only looking after the automotive (Hardware) part and not the autonomous (Software) part might hinder the growth. They need to depend on the client for better software and uphold the reputation. Thus limiting the growth and exposure of Volvo's own autonomous software. Resistance will be offered by people who prefer manual drivers against autonomous vehicles. Volvo's premium reputation can be lowered due to its appearance as a taxi through the eyes of a consumer. [16]

## 3.2 PEST Analysis

### 3.2.1 Political Factors

As the development of ADS increase immensely over the last years, the political outlook on this regard seems to be growing proportionally. The number of legislation's introduced and passed by various states in the US are increasing, currently standing tall with more than 33 states introducing legislation's in regards to autonomous drive systems.

The National Highway and Transport Safety Administration (NHTSA) released new federal guidelines for ADS, named as "A Vision for Safety 2.0". The guidance is meant for both the state and the industry, and mainly focuses on automation levels of 3-4 in accordance to SAE international standards. It states that the concerned parties of development need not wait, to test or deploy their ADS, restructures few elements regarding the self-safety assessment and updates federal guideline to align with the upcoming developments and terms.

A featured highlight took place in 2016, when the US Transport Secretary released a new policy that updates NHTSA's 2013 policy on autonomous vehicles. The new policy is structured to push and encourage the development and release of technologies that has the potential to save lives in relation to operation of fully autonomous vehicles. [17]

### 3.2.2 Economical Factors

The rapid advent of the technology has left many in curious state, probing them to analysis the potential growth of the sector for the future. Several estimates from renowned organizations such as Intel Corporations and Strategy Analytics stated a dollar amount of 7 trillion being reached by 2050, with the assumption that 'Level 5' automated vehicles will be fully functioning on a day to day basis. Similarly, the Boston Consulting Group estimates that the global market for partial and fully autonomous vehicles will reach 42 billion dollars and reaching up to 77 billion by 2035 [18].

Apart from the above estimates, the academic institute of Clements and Kockelman provide an even more interesting study [Figure 3.1] about the economic effects of fully autonomous vehicles measured in terms of net economic benefits attained to the society. The study shows a noticeable change in the dollar amount and credible increase in the per capita income of various industries/sectors. The ones with most change being in Automotive, freight transportation, digital media, software and positive decrease in sectors such as insurance, traffic police and personal transportation [18].

Introduction of autonomous vehicles potentially decreases the number of road accidents caused. From an economic perspective, the decrease in road accidents reduces the road congestion by 25%. This directly relates to increase in roadway capacity and approximately save 488 billion dollars through reductions of injuries and deaths caused in road accidents. Another 448 Billion dollars of increased productivity amount is estimated as now the driver can spend his travel time in productive activities. Currently, it is estimated that Americans spend around 2.7 billion man hours driving to and from work. [18]

Industry	Size of Industry (\$ billions)	Dollar Change in Industry (\$ billions)	Percent Change in Industry (%)	\$/Capita (\$)
Insurance	180	-108	-60%	339
Freight Transportation	604	+100	+17%	313
Land Development	931	+45	+5%	142
Automotive	570	+42	+7%	132
Personal Transportation	86	-27	-31%	83
Electronics & Software	203	+26	+13%	83
Auto Repair	58	-15	-26%	47
Digital Media	42	+14	+33%	44
Oil & Gas	284	+14	+5%	44
Medical	1067	-12	-1%	36
Construction & Infrastruc	169	-8	-4%	24
Traffic Police	10	-5	-50%	16
Legal Profession	277	-3	-1%	10
<b>Industry-specific Total</b>	<b>4480</b>	<b>418</b>	<b>9%</b>	<b>1312</b>
<b>Economy-wide Total</b>		<b>Dollar Change in Industry (\$ billions)</b>	<b>\$/Capita (\$)</b>	
Productivity		448	1404	
Collisions (*)		488	1530	
<b>Economy-wide Total</b>		<b>936</b>	<b>2934</b>	
<b>Collision Value Overlap (*)</b>		<b>-138</b>	<b>-432</b>	
<b>Overall Total</b>		<b>1217</b>	<b>3814</b>	

**Figure 3.1:** Summary of economic effects [18]

It's likely that the trucking and freight companies will be the first ones to adopt the autonomous feature into their organization. America, where trucking is huge, will be early to adopt the technology to reduce transportation costs and increase efficiency.

### 3.2.3 Social Factors

Studies indicate that 90% of all the car accidents occurred are due to human error. The year 2015 saw 35,092 deaths in road accidents in US. The causes varied from inattention, speeding to intoxication and drowsiness. Thus, the realization of ADS will causes the road accidents to plummet at drastic rate. Its acts as catalysis and eliminates the related medical, repair and policing services. Safety of human lives will acts as a major stimulant for people to lean towards autonomous driving. Apart from this, ADS opens

up previously shut off opportunities to people with disabilities, elderly people etc. to have access to a transport system at their call [19].

The way people look at transportation can change with the advent of ADS. With the increase in concepts of ride-sharing / hailing, the idea of car ownership might drop dramatically. This necessarily is not a bad thing to happen, as people limited to access a car for reasons such as lack of driving license, disabilities, old age, cost to learn driving or the cost of the car itself can now use car at their expense and time [20].

The myriad of information suggests that realization of fully autonomous cars will immensely change societal aspects of how one looks at transportation. Some changes might look like cut throat events, as there might no more be jobs related to driving. How would they cope with the situation ? Where is the line, we draw on how much AI replaces human tasks and jobs ? What would the primary role of AI and how big of a role should it be? These questions still remain unanswered and can be known only with time.[20].

#### 3.2.4 Technological Factors

As stated in previous topics, the introduction of ADS technology has huge advantages. Safety on human life being the primary one, as ADS has the potential to eliminate road accidents all together. Alongside, it will increase the mobility by allowing people to mobilize without the knowledge or the ability to drive. Traffic congestion will be drastically reduced due to the orderly, synchronous driving of the vehicles with respect to each other. Even if congestion are caused, the productivity level of the occupants will not decrease since they can engage in other activities than driving [19]. The technology also makes us look at the land use differently. One survey conducted in 41 major metropolitan cities has shown that around 31% of its area is used up for parking spaces. This might not be the case after ADS come into effect, since the cars can simply drop off its occupant and drive off to a remote location to park itself. Similarly, people will also be more welcoming to the idea of long distance travel and be willing to settle far from the work hubs reducing congestion in cities [20].

With increased awareness of sustainability and adoption of alternative power source such as electric drive, it is more likely the fully autonomous cars will be powered electrically. This, coupled with AI's ability to drive more efficiently by accelerating and braking optimally will definitely reduce the energy consumption and pollution comparatively.

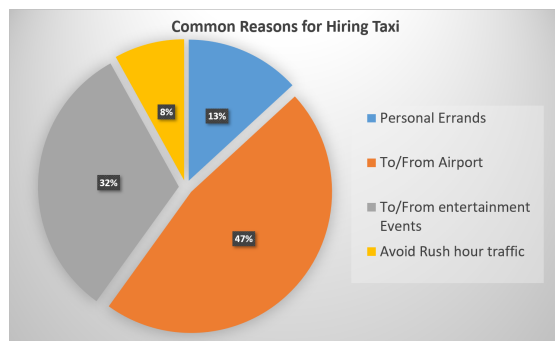
### 3.3 Survey Analysis

The Survey questionnaire was created in a holistic view. The questions formulated focused on understanding the overall needs, desires, fears and dislikes of an user entering an autonomous taxi, rather than focusing on just the door panel itself. Limiting the survey participant to just door panels would reduce the range of opinions due to their lack of knowledge of a door panel and it's uses. The questionnaire contained a majority of MCQ's and a few subjective questions to capture their thoughts in a raw format.

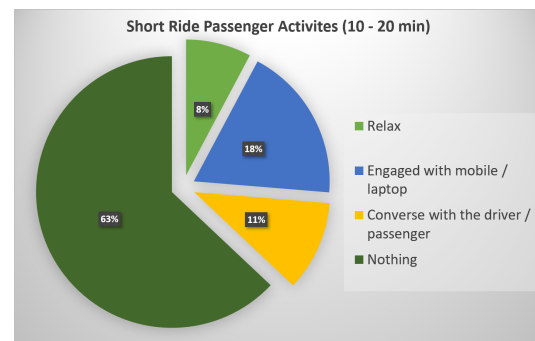
The survey was circulated throughout Volvo Cars Corporation. In order to diversify the demographics, the survey was also posted in several groups on Linked In, Facebook,

Reddit and Automotive forums. A total of 579 responses were recorded. A majority of the responses to our survey was generated in Europe and within Volvo. The participants pool consisted of mainly people between 25-44 years followed by 45-64 years, 18-24 years and lastly above 64 years. 87% of the participants are employed and 98% can drive a car. The demographic questions were asked to understand the biases the answer can have based on a person's lifestyle. For example, a person in the tropic countries can have a completely different lifestyle than the person in cold countries. A coat hanger or a place for an umbrella seems important for a person in the cold country where as it can be redundant for a person in tropic country. Thus it is important to understand the demographics and design the product around it.

The results also conveyed that people use taxis largely to travel to/from entertainment events followed by to/from Airport and railway or port. Some of the other reasons to hire a taxi were to travel to work, personal errands, to avoid rush hour traffic and lastly, long distance travel. In order to understand the users behaviour inside the taxi, the participants were asked what they would do in a taxi ride that lasted for 10-20 minutes? Surprisingly, 61% of the participants answered "Nothing" or wrote "Nothing" as a part of their answer. The other common responses were " Engaged in Smartphone" and "Relax/Sleep".

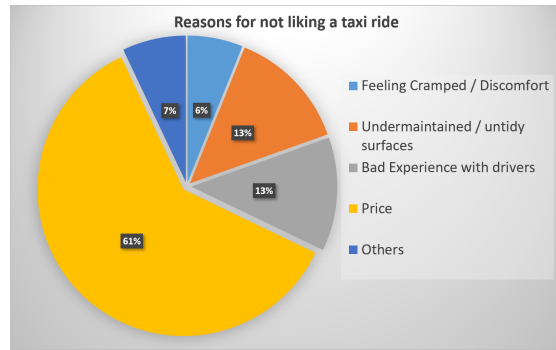
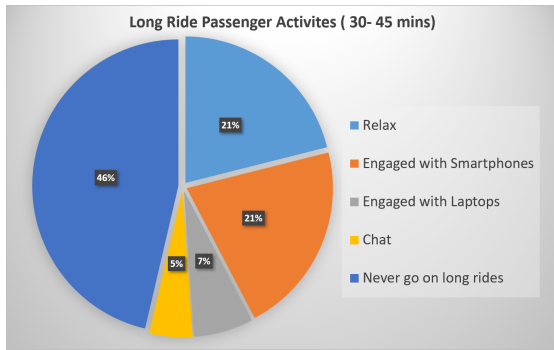


**Figure 3.2:** Reason for hiring taxi



**Figure 3.3:** Activities in a short ride time

Similarly question was proposed for long distant travels that took 30-45 minutes. Here, the most common answers were "Sleep/Relax" or "On mobile calls/Internet", these answers were followed by other answers such as "Working on a laptop/Answering Emails" and "Reading a book". Question about why people dislike taxi ride was asked to reverse engineer the answers to provide a satisfactory solution. The participant's answers suggested that the taxi rides were disliked mainly to due its "price" trailed by answers such as " Bad experience with drivers", "Under-maintained/Dirty surfaces" and finally " Feeling Cramped / Discomfort".



**Figure 3.4:** Activities in a long ride time **Figure 3.5:** Reasons to not hire a taxi

The next couple of questions were subjective and focused on two aspects. One, the main concerns people have using an autonomous taxi and the other, focused on the features that users would like to have in a future autonomous taxi. The participant statements for these questions were concise into need statements. The main concerns were found to be about being trapped inside the vehicle, the lack of control and the lack of trust. The responses for the latter question had a wide variety of answers. The users wanted many things from massage seats to an espresso machine in the vehicle. At the core of these answers, it was found that the users are primarily seeking comfort and to gain more control of the environment (Climate, Stereo and Navigation control).



**Figure 3.6:** Concers of Autonomous Taxi **Figure 3.7:** Features in Autonomous Taxi

The complete collection of the survey response can be accessed through the link [21].

### 3.4 Interviews

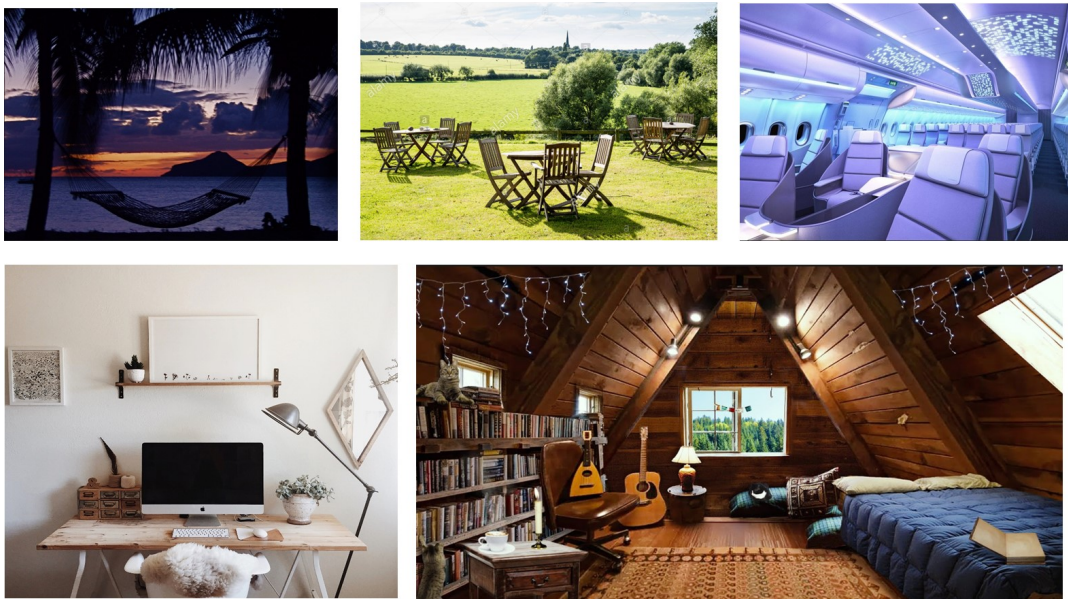
The survey helped in understanding people’s perception toward autonomous vehicles and their expectation when they travel in an autonomous taxi. But more clarity is needed as to how the interior space of an autonomous taxi is planned in Volvo cars, the dominant parameters that control the aesthetics of the interior panels, the kind of ambience that people at Volvo like to have in their cars and what the company’s design language conveys to its employees and the market. This information will help in calibrating the market findings against the company’s direction towards autonomous taxi.

This was achieved by conducting face to face interviews with eleven engineers [A.2] from Volvo cars’ interior design department. 70% of the engineers had a positive attitude towards travelling in an autonomous taxi and the remaining interviewees were sceptical

about it and wanted to wait until the system matures to a level of avoiding accidents [A.3].

When the interviewees are seated in the rear seat of a Volvo car, they expect the interior of the car to provide a comfortable feeling, be spacious, clean and should blend well with the rest of the car. Campfire seating, storage space, coffee cup holder, increased leg space, mobile charging ports, trash bins and a table to place laptop are some of the improvements / changes that the engineers would like to have in Volvo's future autonomous vehicles.

To understand the desired ambience that they would like to have inside the car during travel, we provided five different pictures [Figure 3.8] and asked them to choose the top two ambience that will suit their mindset. The pictures with a bright workplace atmosphere and a green pleasant atmosphere were chosen by most of them as the desired ambience inside the car when they travel. Amidst all the different parameters that support the design of interior components, the interviewees chose lighting, smell, texture and sound (noise level) to be the dominant parameters, that mainly impact the ambience inside the car.



**Figure 3.8:** Different types of ambience desired inside the car

90% of the interviewees have a Volvo Car for personal use and they mentioned safety and appearance to be the main reason to buy a Volvo car. Further they added that Volvo's design language must convey Scandinavian design, safety, comfort and luxury to its customers.

### 3.5 Customer and User Needs

As we had a total of 579 survey responses and each participant's response could be translated into 5 - 7 different needs and desires, it was imperative for us to crunch

the data into a more process-able size. For this purpose we adopted KJ analysis, where the abstract data was grouped into broadly classified topics. These topics had no other significance than sorting the raw data, as more appropriate classification of the need statements is done during the creation of requirement specification. Similar customer opinions were clubbed under the appropriate groups. Many of the redundant and non-achieve able statements were eliminated. (For example: A survey participant asking for a coffee machine or salon inside the autonomous cars were directly taken out of scope.) Once the data size was reduced, the customer needs and desires still in a abstract form were interpreted [Table 3.1].

<u>Comfort</u>	<u>Safety</u>	<u>Control</u>
Browse on smartphone	Accident Needless overtaking	No way to control
Listen to a song, sleep	Road rage	Not reaching the destination.
Usually nothing	No option to force stop	Reliability
Talk to the driver	Malware attacks	No Emergency medical help
Relax	Getting hacked	Can't trust the car
<u>Cost</u>	<u>Productivity</u>	
Expensive, time consuming	Entertainment system	
Price	Interaction Voice System, massage, AIAS	
Costly	Phone charging dock, a good sound system	
How expensive will it be	Interactive display in window panes	

**Table 3.1:** A snippet of the KJ analysis

The complete KJ analysis can be seen in Appendix [A.1 & A.2]

In order to interpret all the data compiled during the above steps into need statements, the following steps were taken:

- All the customer statements were expressed in terms of what the product has to do.
- In order to avoid loss of data the customer statements were interpreted at the same level i.e the need statement were not our interpretation of what the customer was trying to say.
- The need statements mostly try express the attribute of the product and avoids negation.

Apart from the interpreted customer need statements, certain requirements were also posed by the clients, who wanted their product to meet a set of standards. Finally, client requirements were added to the list of customer needs list, which gave us a total of 32 different need statements.

## 3.6 Benchmarking

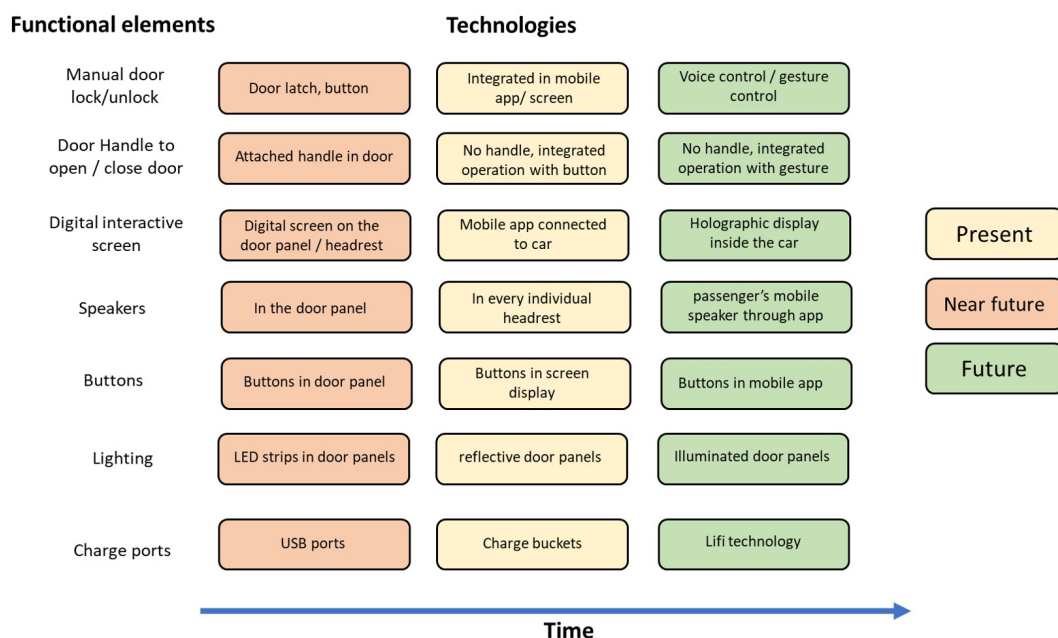
Though extensive study is being conducted to understand the different attributes and functionalities that go into developing a new door panel for Volvo's autonomous taxi, the type of door and door panel was already defined by the company and it's clients.

Benchmarking was carried out to compare different interior door panel components of existing competitors in terms of functionality, shape and dimension. Benchmarking was done using the data available from A2mac1's website. Since the benchmarking was done for a specific type of door panel, only 10 car models data was available to benchmark. The benchmarking was carried out using "Auto reverse" platform in the website. The "Auto-Reverse" platform provides information by stripping down the required component from a production car.

In initial stage, the door panels were benchmarked for total trim weight, total dimension (minimum possible rectangle to cover the trim) and different components present in the door panel like armrest, speaker, door handle, window adjustment switch, cup holder, door lock/ unlock switch etc. Most of the door panels had armrest, door handle, speaker and cup holder. Hence, in the next stage, a much-detailed benchmarking was carried out to understand the shape and placement of speakers, cup holder and the door handle. The complete benchmarking data is compiled and presented in Appendix [A.4].

### 3.7 Technology Roadmapping

In technology road mapping all the necessary functionalities in a door panel were mapped with respect to how each of them will evolve technologically over time [Figure 3.9]. This helps in understanding where we are, what can we aspire to achieve in the near future with the available technologies and what could be possible later in the future with technologies under development.



**Figure 3.9:** Technology roadmap

Functionalities like manual door lock / unlock, door handle, digital interactive screen, speakers, buttons, lighting and charge ports were mapped technologically over three different time periods. Functionalities like panel carrier and waist rail are ignored as

they are standard components and don't change. Few functionalities like storage, cup holder, and arm rest were not considered as they are out of scope.

### 3.8 Requirement Specification

Requirement specification was established in order to ease the further development process. The Requirement Specification list consists of all the complied need statements in terms of what the product has to do. Each statements were then grouped into one of the 7 below mentioned categories. The categories were establish based on what a particular group of statements are trying to achieve.

- |                      |                      |
|----------------------|----------------------|
| 1. User Comfort      | 5. Sustainability    |
| 2. User Safety       | 6. Panel Reliability |
| 3. User Productivity | 7. Cost Reduction    |
| 4. Cleanliness       |                      |

The need statements were also identified as either a requirement or a desire. Lastly, justifications for each statement and verification of how statement can be achieved were stated. As the no. of statements to be satisfied were considerably high, the need statements were put into a weight matrix to understand their relative importance. The output of the said matrix is shown the table [3.2], where as the complete matrix is shown in Appendix [A.6] The requirement specification list can be seen in figure [3.10].

<u>Sl. no</u>	<u>CUSTOMER NEEDS</u>	<u>Weight</u>
1	The panel accommodates take-off, pull over and support buttons.	<b>8.941</b>
2	The panel should last for 3-4 years.	<b>8.471</b>
3	The panel is dust resistant	<b>7.294</b>
4	The panel is made of Odourless materials	<b>7.294</b>
5	The panel avoids the user from forgetting small items.	<b>7.294</b>
6	The panel maintenance is low cost	<b>6.824</b>
7	The panel provides context based illumination.	<b>5.412</b>
8	The panel's upholstery should be exchangeable.	<b>4.706</b>
9	The panel accomodates sound system	<b>4.471</b>
10	The panel aids in reducing motion sickness	<b>4.235</b>
11	The panel accomodates interface to navigate the vehicle	<b>4.235</b>
12	The panel provides user to have visual interface.	<b>4.235</b>
13	The panel provides a way to charge electronics	<b>4.235</b>
14	The panel enbales the cabin to be bright / luminous	<b>4</b>
15	The panel feels spacious	<b>3.529</b>
16	The panel should be ECO designed.	<b>3.529</b>
17	The panel accommodates a lighting system	<b>3.294</b>
18	The panel allows ambient temperature adjustments.	<b>3.294</b>
19	The panel aids the user to work	<b>2.824</b>
20	The panel provides storage	<b>1.412</b>
21	The panel provides user with audio interface	<b>0.471</b>
22	The panel design blends with the interior	<b>Mandatory</b>
23	The panel is easy to clean	<b>Mandatory</b>

<b>Sl. no</b>	<b>CUSTOMER NEEDS</b>	<b>Weight</b>
24	The panel is easy to maintain'	<b>Mandatory</b>
25	The panel allows user to stop the car incase of emergency	<b>Mandatory</b>
26	The panel accommodates interface to handle the door manually	<b>Mandatory</b>
27	The panel provides space for trash	<b>Mandatory</b>
28	The panel is durable	<b>Mandatory</b>
29	The panel is robust	<b>Mandatory</b>
30	The Panel should not have PP surfaces.	<b>Mandatory</b>
31	The panel should not have PU spray.	<b>Mandatory</b>
32	The panel has minimum no. of speakers.	<b>Mandatory</b>

**Table 3.2:** Need statement Weights

Figure 3.10: Requirement Specification

Sl. No.	Statements	Requirement / Desire	Category	Justification	Verification
1	The panel accommodates a lighting system	Desire	USER COMFORT	Enhance user comfort.	Engineering Assessment , Testing
2	The panel accommodates sound system	Desire	USER COMFORT	VCC / client requirements	Engineering Assessment
3	The panel design blends with the interior	Requirement	USER COMFORT	VCC requirements	Engineering Assessment
4	The panel enables the cabin to be bright / luminous	Desire	USER COMFORT	Enhance user mood.	Engineering Assessment , Testing
5	The panel feels spacious	Desire	USER COMFORT	VCC / client requirements	Engineering Assessment
6	The panel aids in reducing motion sickness	Desire	USER COMFORT	enhance riding comfort.	Engineering Assessment , Testing
7	The panel is easy to clean	Requirement	CLEANLINESS	VCC / client requirements	Engineering Assessment , Testing
8	The panel is easy to maintain	Requirement	CLEANLINESS	VCC / client requirements	Engineering Assessment , Testing
9	The panel is dust resistant	Requirement	CLEANLINESS	less maintenance	Engineering Assessment , Material Testing
10	The panel is made of Odourless materials	Requirement	CLEANLINESS	enhance riding comfort.	Engineering Assessment , Material Testing
11	The panel accommodates interface to navigate the vehicle	Desire	USER SAFETY	to provide a sense of control to the user.	Engineering Assessment
12	The panel provides user with audio interface	Requirement	USER SAFETY	client requirements	Engineering Assessment
13	The panel allows ambient temperature adjustments.	Requirement	USER SAFETY	client requirements	Engineering Assessment , Testing
14	The panel allows user to stop the car in case of emergency	Requirement	USER SAFETY	safety requirements	Engineering Assessment , Testing
15	The panel accommodates interface to handle the door manually	Requirement	USER SAFETY	safety requirements	Engineering Assessment , Testing
16	The panel provides user to have visual interface.	Requirement	USER SAFETY	VCC / client requirements	Engineering Assessment , Testing
17	The panel provides space for trash	Desire	CLEANLINESS	VCC / client requirements	Engineering Assessment , Testing
18	The panel provides a way to charge electronics	Desire	USER PRODUCTIVITY	VCC / client requirements	Engineering Assessment , Testing
19	The panel aids the user to work	Desire	USER PRODUCTIVITY	Enhance user productivity.	Engineering Assessment , Testing
20	The panel provides storage	Desire	USER PRODUCTIVITY	Enhance user productivity.	Engineering Assessment , Testing
21	The panel is durable	Requirement	PANEL RELIABILITY	VCC / client requirements	Engineering Assessment , Testing
22	The panel is robust	Requirement	PANEL RELIABILITY	VCC / client requirements	Engineering Assessment , Testing
23	The panel maintenance is low cost	Requirement	COST REDUCTION	VCC / client requirements	Engineering Assessment , Testing
24	The panel avoids the user from forgetting small items	Requirement	USER PRODUCTIVITY	VCC / client requirements	Engineering Assessment , Testing
25	The panel should last for 3-4 years.	Requirement	PANEL RELIABILITY	VCC / client requirements	Engineering Assessment , Testing
26	The panel accommodates take-off, pull over and support buttons.	Requirement	USER SAFETY	VCC / client requirements	Engineering Assessment , Testing
27	The panel should be ECO designed.	Requirement	SUSTAINABILITY	VCC / client requirements	Engineering Assessment , Testing
28	The panel's upholstery should be exchangeable	Requirement	PANEL RELIABILITY	VCC / client requirements	Engineering Assessment , Testing
29	The Panel does not contain PP surfaces	Requirement	SUSTAINABILITY	VCC / client requirements	Engineering Assessment , Testing
30	The panel does not contain PU spray	Requirement	SUSTAINABILITY	VCC / client requirements	Engineering Assessment , Testing
31	The panel provides context based illumination	Requirement	USER SAFETY	VCC / client requirements	Engineering Assessment , Testing
32	The panel has minimum no. of speakers	Requirement	COST REDUCTION	VCC / client requirements	Engineering Assessment

# 4

## Idea Generation

The chapter provides a detailed explanation of the various steps and methods used to gather information and generate ideas during each steps.

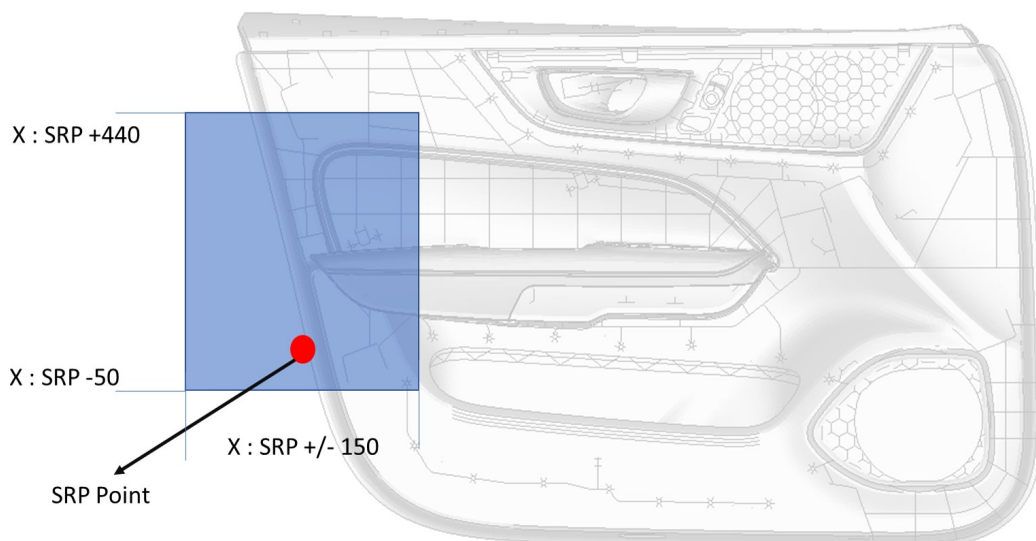
### 4.1 Inputs

The section explains different information gathered from different departments such as guidelines and criteria that help generate reasonable ideas.

#### 4.1.1 Safety Inputs

Since the door panel is designed for autonomous vehicle, safety takes utmost priority in developing the components. Usually, every door panel designed will be analysed in CAE softwares for several crash and safety criteria to make sure the customers are safe during an unprecedented event. But since CAE analysis is out of scope for the thesis, the project team joined hands with the safety team at Volvo Cars to establish new safety requirements for the autonomous taxi, that will be helpful in planning the door panel components.

The autonomous taxi comprises of campfire seating, where the middle row and the last row passengers will face each other during the travel. Also the rear row seats are pushed more towards the rear side of the car as there is not boot space available in the model. This further increases the distance between the SRP (seating reference) point and the door panels in vehicle X- direction.

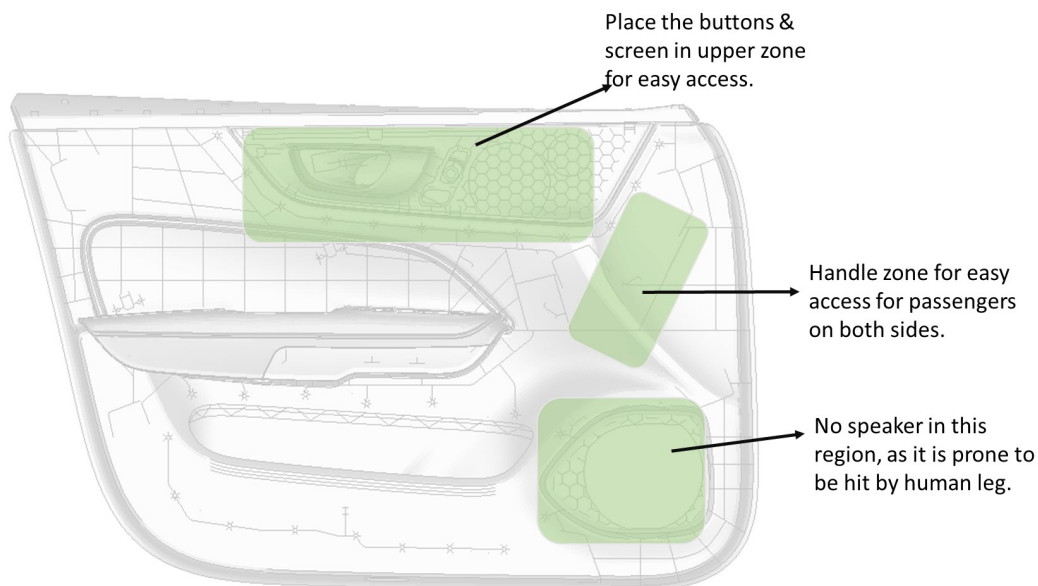


**Figure 4.1:** Safety zone in door panel

Due to these changes, the safety requirements for passenger side airbag zone, for regular cars has been modified and adapted according to the positioning of seats in autonomous taxi. The main requirement is that, in the airbag inflation zone, there should not be any bumps / intrusions in order to facilitate the inflation. This is mandatory because, failure of side air bag might cause severe rib injuries to occupants. This area should not have any hard object/ materials like metal. and no components that can break of injure the passenger. The Figure [4.1] shows the safety zone in blue colour, reference to the SRP of the taxi. This zone must not have any sudden bumps and must be as flat as possible.

### 4.1.2 Ergonomic Inputs

Ergonomic considerations for any product to be successful in the market. Components that are voluntarily accessed by the customers need to be designed and positioned in the system, such that the the user is able to access it with minimal physical actions. Also, components that are prone to be involuntarily in contact with the users must either be designed such that it doesn't harm the user, or it needs to be placed in a location to avoid damages to both the parties.



**Figure 4.2:** Ergonomic considerations in positioning door panel components

For the system under consideration [Figure 4.2] the digital screen and buttons are placed in the top most zone, which can be accessed by passengers sitting on both the rows. The door handle is designed to operate vertically, so that the passengers don't require to rotate their elbow to access it. Also the location is chosen such that it can be accessed by passengers in both the rows. The speaker zone is restricted such that it is not easily damaged by the passengers.

### 4.1.3 Market Inputs

Market inputs comprise all the information collected during the market analysis [3]. There are five major market inputs needed in order to proceed with the concept generation. First, the PEST [3.2] analysis provided information about the regulations and factors in the society, that impact autonomous vehicles. Second, the information from SWOT [3.1] analysis provides insight about the market potential for Volvo Cars as a brand and the products from the brand.

Third and most important information needed from the market was the needs and desires of potential customers about the interior of autonomous vehicles. This was collected through Online survey analysis [3.3] and interviews [3.4]. The needs were then translated into customer requirement statements, that were weighed against each other [Table 3.2] to choose the most important expectations to satisfy. Later the dominant requirements were grouped under seven common functions that the door panel could provide, which will form the basis for concept generation in the upcoming chapters.

Fourth, the data collected from bench-marking [3.6] helped to an extent in understanding the competitor products. Though the data available was old, it gave an idea about the different functions provided in other company products and how they are packaged together. Finally, information from technology road-mapping [3.7] supported in understanding the maturity of technology concerned with each function in a door panel over a period of time and helped in setting the technical target to achieve through the new door panel concept.

## 4.2 Functional Decomposition

In functional decomposition, the system is analyzed in terms of its purpose. It involved identification of the functions of a system to be designed, improved or analysed starting from the main function [28]

There are several methods to carry out functional decomposition; the two widely used methods are process-flow model and function-means tree. For this thesis, the function means tree was suitable as the components in the door panel can be associated with respective functions in the next step.

The functions that go into the diagram are identified from market and customer needs study conducted in previous chapter. Starting from the main function, to design a door panel for future, the means to achieve them is listed below each function in the tree [Figure 4.3]. The blue box represents the ways in which the function can be achieved and the yellow box represents functions.

For the project, seven main functions were identified and various means to achieve it were listed in the tree. One important thing to note is that each function can be achieved by any one of the means listed below it and the main function can be satisfied by achieving one or more of the sub functions. It is not necessary to satisfy all the sub functions to achieve the main function.

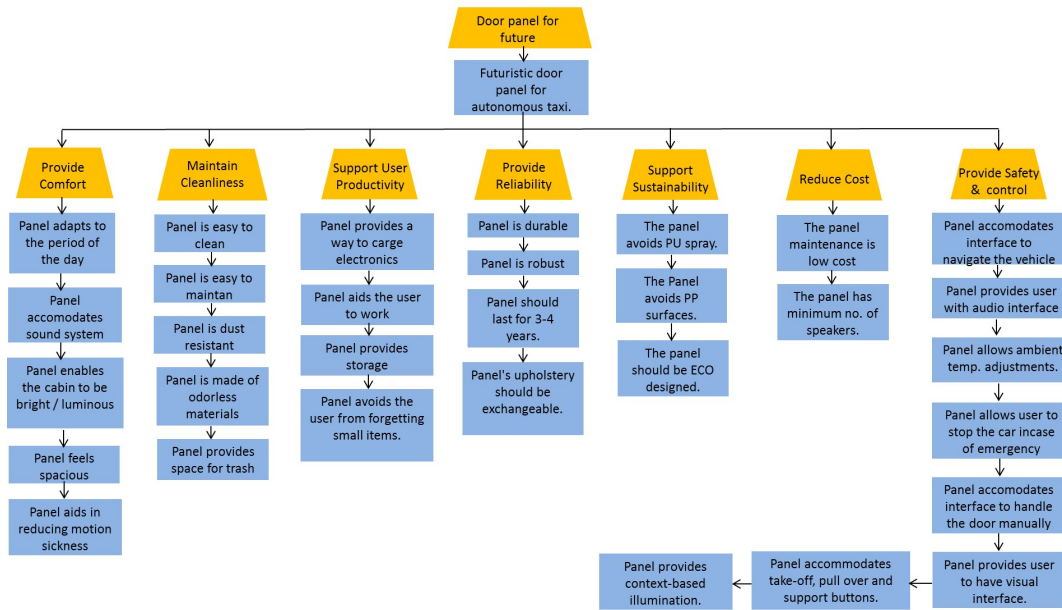


Figure 4.3: Function - means tree

At the end of functional decomposition, there were seven different sub-functions for the main function and 31 different means in total, to achieve the sub-functions.

### 4.3 Connecting Functions to the Functional areas in door panels

In this project, the end product that needs to be developed i.e. door panel and the sub components that it can contain are already defined. Now that various functions that are expected out of future door panel and respective means to achieve them are identified [Figure 4.3], the next step is to connect the functions with respective components / functional areas in a door panel.

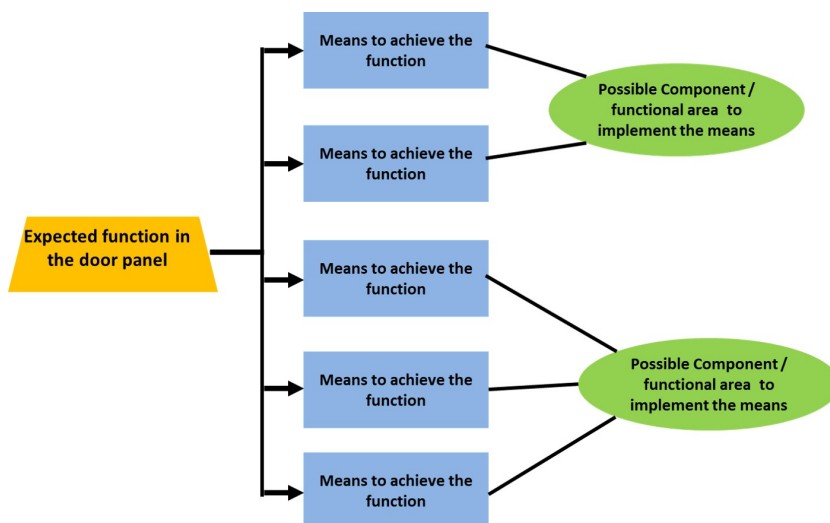


Figure 4.4: Connecting functions to respective functional areas in door panel

First, the possible components that the door panel can accommodate were listed. This

list is created from bench-marking data, inputs from the company and door team members at Volvo Cars. Then each of the 31 different means to achieve the sub functions [Figure 4.3] were matched with respective components, based on the possibility of implementation, the flexibility in the component design and Volvo Cars' design guidelines.

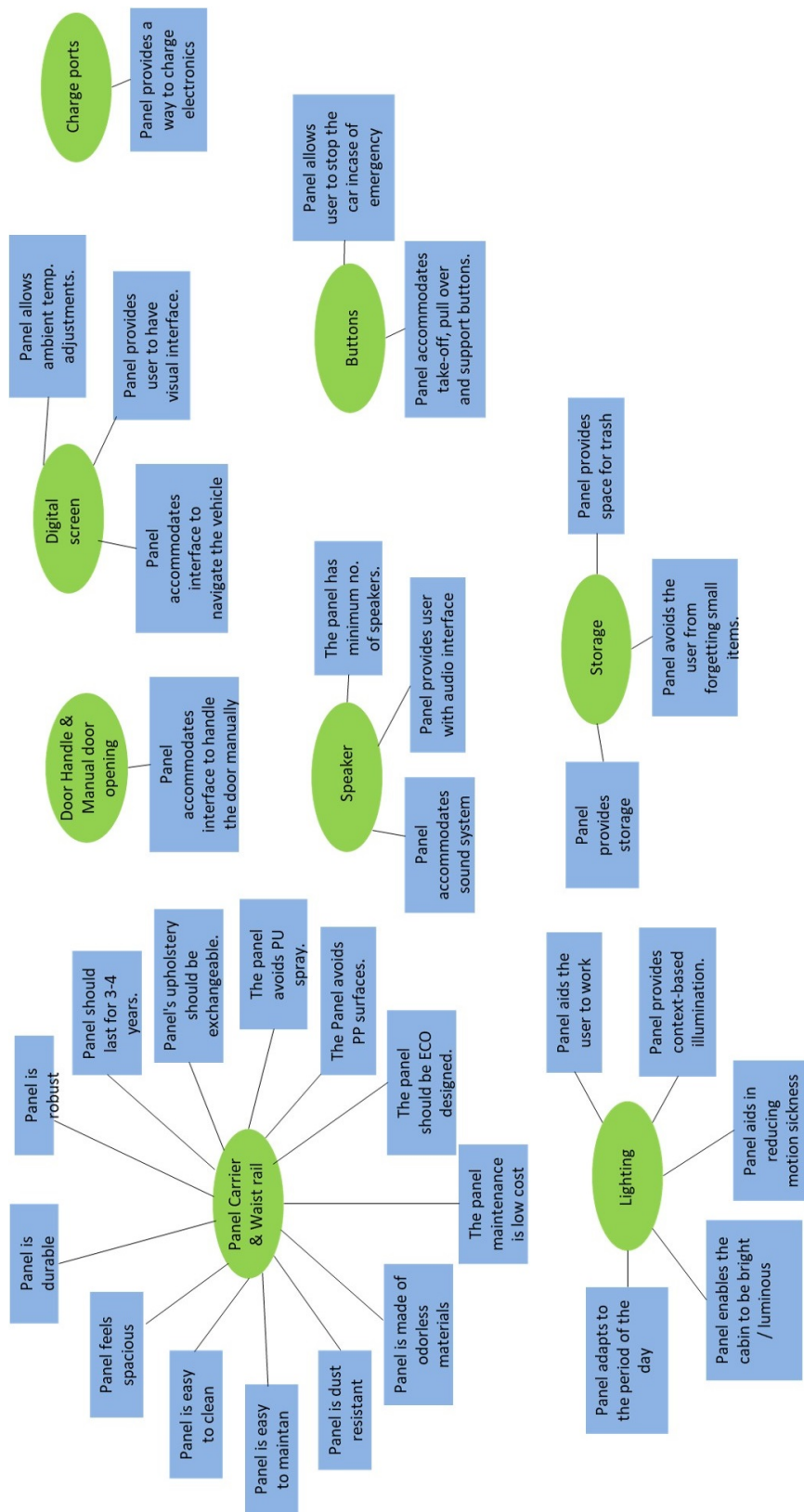


Figure 4.5: Matching various means to functional areas / components in door panel

## 4.4 Brainstorming

Brainstorming is a key technique to generate ideas and provide these ideas a physical form in terms of concepts. There were 2 main brainstorming phases in the project. The first phase involved generating various ideas for the different functional areas in the door panel based on the means to satisfy. The generated ideas were then fed to the morphological matrix. The second phase of brainstorming was mainly focused on generating concepts, where door panel as a whole including all the sub functions were generated. For this phase, mood boards were used to guide the concept generation. The contents of the mood boards and its inspiration are explained in 5.3. These brainstorming session ended with few important conclusions in terms of the feel, look of the door panel along with other technical points. Notes from the brainstorming session are stated below:

- Scandinavian design to retain Volvo's Brand image. Meaning minimalist approach, clean and clear lines, simple yet functional.
- Lighting combinations should not contain many colours and overwhelm the user.
- Visual Interface should not lead to customer straining his/her neck. i.e User need not interact with the interface more than 15 seconds at any point of time.
- The door handle must be easily accessible by both users seated across each other.
- The buttons should be easily accessible and understood intuitively.
- The charge stations must always be placed at a higher level than the cup holders to avoid spillage.

The results from the brainstorming sessions are shown in 4.5 & 5.4

## 4.5 Morphological Matrix

The morphological matrix was used to catalogue the results of the first brainstorming phase [Section 4.4], where various ideas for each functional area was generated. In order to help us visualize the product better and ease the further development activities, the morphological matrix was in-terms of functional areas.

The functional areas represented a category under which a sub function from functional decomposition, could be satisfied. For example, The functional decomposition consists of a sub-function "Provide Safety and Control" [Figure 4.3 ]. One of the means to satisfy this sub function is "Button for Door opening/closing" which provides the user with a sense of safety and control. The particular idea was later put under the functional area "Manual Door Opening" in the morphological matrix [Figure 4.6].

A total of 10 different functional areas are listed in the morphological matrix, shown in the figure 4.5

#### 4. Idea Generation

Morphological Matix - Door Panel						
Ideas =>	1	2	3	4	5	6
Functional Areas						
Panel Carrier	Standard Component					
Manual Door opening	Button for door opening	Integrated in app	Conventional door handle	Voice control to manually over ride	Conventional latch mechanism	Icon in available display screen
Door Handle	Spring activated handle	Conventional door handle	Pop out handles	Projection in the trim	Gripping Surface	Hollow Projection in trim
Digital Screen	Sealed ( blends with panel seamlessly)	Pop out ( by customer)	Attached ( serice)	Sealed ( blends with panel seamlessly)	Integrated in mobile app	Glass projection
Speaker	Central Speaker	Head rest speaker	Door panel speaker			
Buttons	Roof	Screen Button	Door Panel	In Mobile App		
Lighting	Strips of LED for door panel	Reflective Door Panels	Illuminated Door Panels			
Storage	Feature not included					
Charge Ports	Charge Buckets	USB ports	LI-FI			
Waist Rail	Standard Component					

**Figure 4.6:** Morphological Matrix

Functional areas such as waist rail did not involve a lot of brainstorming, as it is a standard part of door panel that is present due to manufacturing constraint. Another such area was storage. Avoiding storage was one the primary requirements from the client end, due to the fact that it is a taxi and there is a high chance of passengers forgetting their belonging in the taxi. This also acts as a gateway for unclean environment inside the taxi.

# 5

## Concept Generation and Evaluation

The process of arriving at a solution from ideas developed for its various functions, is achieved by filtering the pool of ideas using stringent process filters. This chapter describes various steps in filtering, combining and evaluating various ideas to solve the problem.

### 5.1 Idea Elimination Matrix

The first step in the process funnel is the Idea Elimination Matrix. Section 4.5 describes the morphological matrix that contains several brainstormed ideas for each function in the door panel. One idea from each function needs to be selected and combined together to form a concept door panel. But there are several ideas for each function and by combining the ideas, we can arrive at 23328 different possible combinations for door panel.







Elimination matrix											
Elimination criteria: ● Pass concept ● Eliminate concept (?) Search for more inform (!) Check requirement spe		Solves main problem	Fulfills all requirements	Feasibility	Reasonable cost	Safe (Human/Societal)	Fits Volvo's portfolio	Enough information	Concept	Comment	Decision
		1	2	3	4	5	6	7			
Button for Door Opening		●	●	●	●	●	●	●	Feasible, intuitive , easy to operate.	Passed	
Integrated in App		●	●						Possible but firewall issues, user mobile charge is depleted to 0, easy to misuse. Out of scope	Eliminated	
Conventional Door Opening		●	●	●	●	●	●	●	Need to confirm if its a regulation or not.	Decision Pending	
voice control to manually over ride		●	●						Not suited for public transport: AI requires lot of training , people with speech impairment, different accents , different voices overlapping	Eliminated	
Gesture control		●	●	●	●				Users required to be trained to show the gestures. Misinterpretation of Gestures by AI .	Eliminated	
Icon available on display screen		●	●	●	●	●	●	●		Passed	

Figure 5.1: Idea elimination matrix for type of door opening function

Evaluating each concept out of this huge number of concepts is a tedious and time consuming process. Hence a preliminary Idea elimination matrix was created in which,

## 5. Concept Generation and Evaluation

the poor and unattainable ideas out of all the brainstormed ideas for each function is filtered out. The picture 5.1 shows the idea elimination matrix for type of door opening function. Each idea is evaluated against various elimination criteria specific to the function that is mandatory to be fulfilled. The elimination criteria are, namely, solves the main problem, fulfills all requirements, feasibility, reasonable cost, safe (human / societal), fits Volvo's portfolio and availability of enough information. Ideas that fail to satisfy any of these mandatory requirements are eliminated directly. The idea elimination matrix was done for all the functions and is given in Appendix B.1.

Ideas =>	1	2	3	4	5	6
<b>Functional Areas</b>						
<b>Panel Carrier</b>	<b>Standard Component</b>					
<b>Manual Door opening</b>	Button for door opening	Integrated in app	Conventional door handle	Voice control to manually over ride	Conventional latch mechanism	Icon in available display screen
<b>Door Handle</b>	Spring activated handle	Conventional door handle	Pop out handles	Projection in the trim	Gripping Surface	Hollow Projection in trim
<b>Digital Screen</b>	Sealed ( blends with panel seamlessly)	Pop out ( by customer)	Attached ( serice)	Sealed ( blends with panel seamlessly)	Integrated in mobile app	Glass projection
<b>Speaker</b>	Central Speaker	Head rest speaker	Door panel speaker			
<b>Buttons</b>	Roof	Screen Button	Door Panel	In Mobile App		
<b>Lighting</b>	Strips of LED for door panel	Reflective Door Panels	Illuminated Door Panels			
<b>Storage</b>	<b>Feature not included</b>					
<b>Charge Ports</b>	Charge Buckets	USB ports	Li-Fi			
<b>Waist Rail</b>	<b>Standard Component</b>					

**Figure 5.2:** Idea elimination matrix for results

The results are represented in Figure [5.2] where all the red colored ideas were eliminated. After discarding the less potential ideas of all the seven functions, the number of possible combinations to solve the problem reduced to 8. From the figure it be seen only three functions namely, Manual Door Opening, Door Handle and Buttons have 2 different possible ideas which sums up to 8 combinations (  $2 * 2 * 2$  ).

## 5.2 Concept Elimination Matrix

The next step in Concept generation is to evaluate eight concepts that were possible by combining the remaining ideas from the results of idea elimination matrix. This is done with the help of another elimination matrix. Since each concept is a combination of different ideas, it was hard to visualize the concept while evaluating them in the elimination matrix.

To easily visualize the concepts, an individual icon is drawn for each and every idea in the matrix [Figure 5.3]. Then depending on the combination, the icons are put together in a layout in the shape of a door panel and then the complete picture is fed into matrix [Figure 5.4] in order to easily visualize them. A total of 8 different combinations were generated from the remaining ideas.

After all the concept layouts were fed into the matrix, the elimination was carried out [Figure 5.4]. The criteria that the concepts must satisfy are broadly defined as the information available at the stage is relatively low. The concepts that fail to pass through all the elimination criteria are eliminated.

At the end of the concept elimination matrix, two concepts passed through all the selection criteria [Figure 5.4].

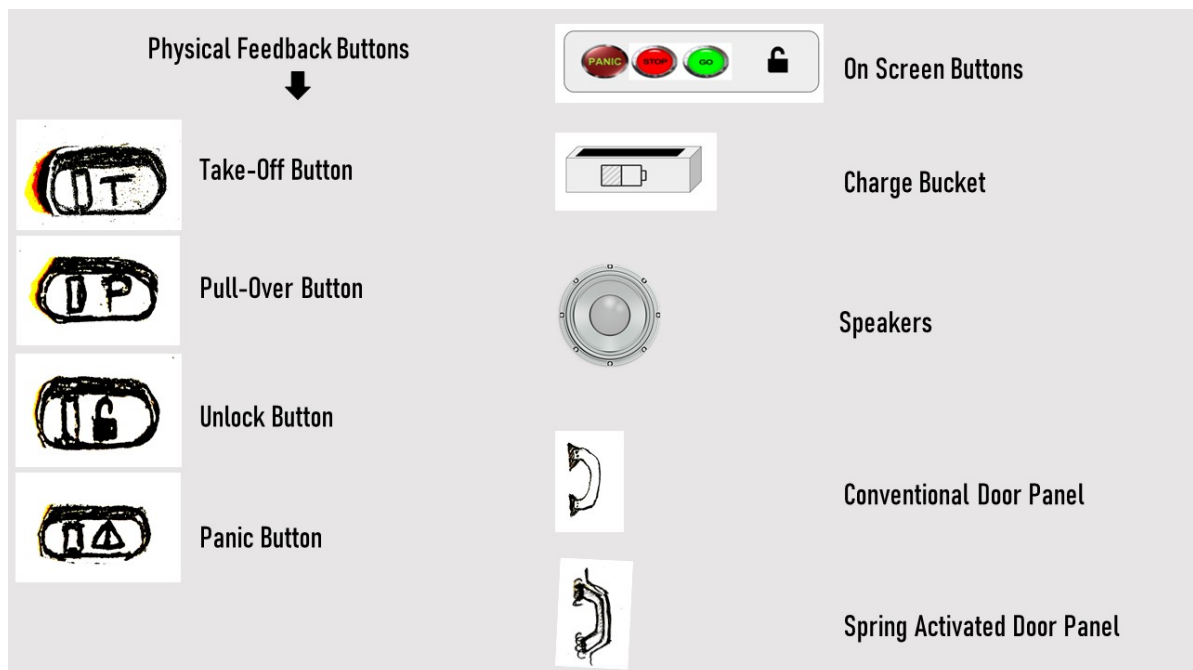


Figure 5.3: Icons Representation

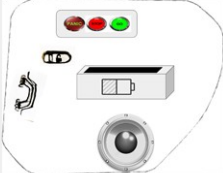
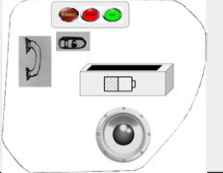
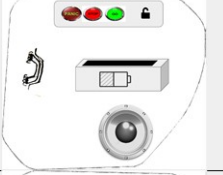
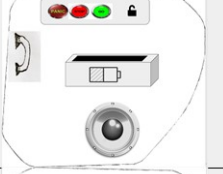
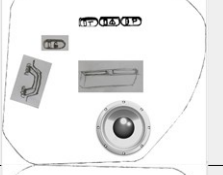
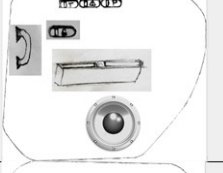
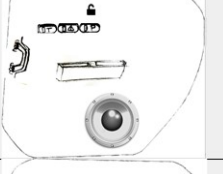

Elimination matrix											
Concept		Elimination criteria:									Decision
		1	2	3	4	5	6	8	9		
		Solves the main Problem	Fulfills all Requirements	Feasibility	Reasonable Cost	Safety	Regulations	Fits Volvo's portfolio	Enough Information		
Idea 1		●	●	●	●	●	●	●	●	Eliminated	
Idea 2		●	●	●	●	●	●	●	●	Passed	
Idea 3		●	●	●	●	●	●	●	●	Eliminated	
Idea 4		●	●	●	●	●	●	●	●	Eliminated	
Idea 5		●	●	●	●	●	●	●	●	Eliminated	
Idea 6		●	●	●	●	●	●	●	●	Passed	
Idea 7		●	●	●	●	●	●	●	●	Eliminated	
Idea 8		●	●	●	●	●	●	●	●	Eliminated	

Figure 5.4: Concept elimination matrix

### 5.3 Mood Board

Mood board was primarily used to provide a framework for styling, colour combination and design language. For the project, the qualities that go into the mood board were derived from market survey, interviews with door team engineers and the meeting with styling team at Volvo Cars. From the mood board [Figure 5.5], the chair and cutlery pictures depict Scandinavian design, which is all about being minimalistic yet luxurious. The cockpit area pictures depicts futuristic design.

The two most preferred pictures to depict the interior of a car during the interviews, were the work environment setup and pleasant green scenery. Hence these two pictures were included in the mood board to depict the right theme during the design. Finally Volvo cars has always stood out in the market for safety. Hence the picture of holding hands is included to convey the feeling of safety.



Figure 5.5: Mood Board

### 5.4 Concept Drawings

Once all the generated ideas were compiled, it was time to create conceptual drawings of the entire product with all the sub-functions included. Mood board [Figure 5.5] acted as our preliminary guidance, whereas various inspirations were drawn from existing door panel concepts on the internet. The aim was to make the concepts look futuristic, aesthetically pleasing and minimalist.

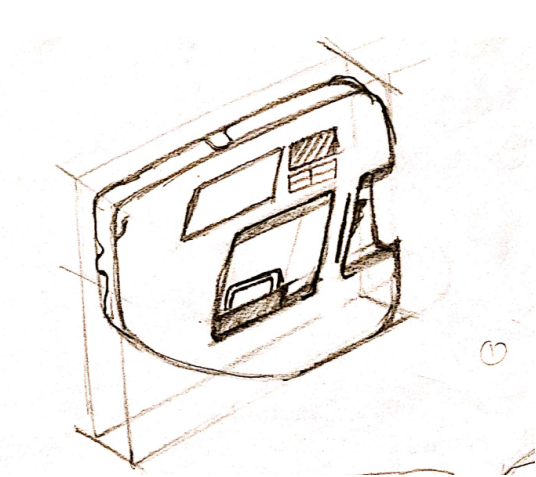
An outline of the door panel region was extracted from the Volvo Design team's concept. A total of 16 concepts, were sketched on paper as a rough estimate of what the door panel would look like, based on the 2 concepts that resulted from concept elimination matrix 5.4. Later, the team internally evaluated and decided to take 8 concepts to be further developed. These 8 concepts were digitally drawn in 3D perspective view using 'Adobe Sketch' and were given unique names for easy identification. Main reason for further developing the hand written 2D drawing to digital 3D drawings was to send

these concepts in the form of survey to get feedback. It was important that the viewers of the survey were able to easily understand the drawings and draw their conclusions. The survey results can be seen in section 5.5.1

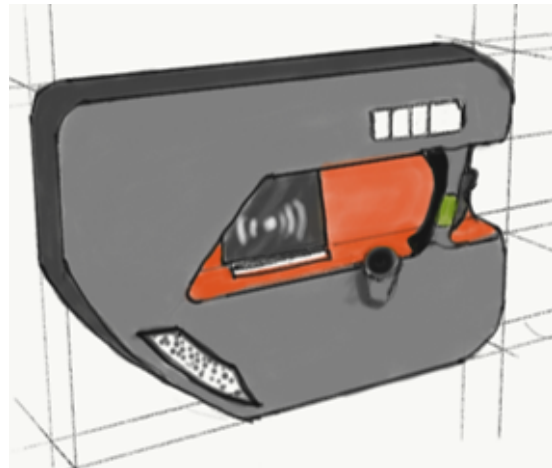
The name of the 8 concepts were as follows:

1. The Beak
2. Basic
3. Powermat
4. Float Handle
5. Mirage
6. Inspiration
7. The Block
8. 2030

The figures 5.6 & 5.7 shows the evolution of the concept 'Powermat' from hand drawn sketch to digital drawing; complete set of 2D and 3D drawings and their description are shown in the Appendix [B.2.1 & B.3].



**Figure 5.6:** Concept Sketch : Powermat



**Figure 5.7:** Concept Digital Drawing : Powermat

## 5.5 Concept Screening

The 8 concepts which were developed in to digital sketches were now fed into the Pugh Matrix for further evaluation. Criteria for the Pugh matrix were derived from various cross-departmental meeting and discussions conducted through the course of the thesis. These were categorized and weighted using a weight matrix. Weights of each criterion helped us evaluate the final results with better clarity and made sure the most important criteria took priority. The criteria were mainly split into 8 different categories as follows:

1. Safety
2. Ergonomics
3. Intuitive Design
4. Visual Appeal
5. Cleanliness
6. Packaging
7. Modularity
8. Cost

Two Pugh iterations were conducted to avoid biases over any one concept. During the first iteration, 'The Block' was used as reference and the other 7 concepts were relatively scored. Whereas in the second iteration, '2030' was used as a reference. The results from these iterations were evaluated along with the concept survey results, to discard the least potential concepts.

It can be seen from figures 5.8 & 5.9, concepts 'The Beak', 'Basic', 'The block', '2030' and 'Float Handle' yielded lowest results based on the criteria used to evaluate them.









		Pugh Concept Selection								
Criteria		concept	7	2	3	4	5	6	1	8
		Weight (1-5)								
			The block	Basic	Powermat	Float handle	Mirage	Inspiration	The beak	2030
Safety	Air bag inflation zone is properly designed	4		0	0	-	0	0	-	-
	Passenger is not hurt due to loose components in a crash	5		+	+	0	0	0	+	0
	appropriate position of emergency stop button (not prone to misuse)	4		-	-	0	0	0	-	0
Ergonomics	Easy to reach the Door Handle	4		0	0	-	0	-	0	-
	Easy to access the charge port	3		0	0	-	0	0	-	-
	Easy to see the display	3		0	0	0	0	0	0	0
	Easy access of Buttons	3		+	0	+	+	0	0	+
Intuitive Design	Buttons are intuitive to operate	4		-	-	+	-	0	-	-
	Door handle Opening (mechanism) is Intuitive	4		0	0	-	0	-	0	-
Visual Appeal	Minimalistic	3		0	0	-	0	0	+	+
	Scandinavian Design	4		0	0	0	0	0	0	0
	Blend with interior	5		0	0	-	+	+	-	-
Packaging	possibility to fit the components into the design space	5		-	0	-	0	0	0	0
	easy integration of components	4		-	0	-	0	-	0	+
Cleanliness	Easy to clean	4		0	-	+	0	-	0	+
	Less no. of split lines	4		-	-	-	0	+	0	+
Modularity	Easy to replace the old / broken components	4		-	-	0	0	0	-	+
	easy to remove for maintenance	4		-	-	0	0	0	-	+
Cost	Low cost	3		+	+	-	-	-	+	+
Result	Number of "+"			2	1	2	2	1	2	2
	Number of "0"			8	9	4	9	9	5	4
	Number of "-"			2	2	6	1	2	5	6
	Total with weights			-18	-16	-28	1	-10	-17	5
	Total without weights			0	-1	-4	1	-1	-3	-4
	Rank			VI	IV	VII	II	III	V	I

Figure 5.8: Pugh Matrix Iteration 1

## 5. Concept Generation and Evaluation









Criteria		Pugh Concept Selection								Reference
		concept	7	2	3	4	5	6	1	
		Weight (1-5)								
Safety	Air bag inflation zone is properly designed	4	+	+	-	-	+	+	+	
	Passenger is not hurt due to loose components in a crash	5	+	0	+	0	0	0	+	
	appropriate position of emergency stop button (not prone to misuse)	4	-	0	-	0	0	-	-	
Ergonomics	Easy to reach the Door Handle	4	+	0	+	-	+	+	+	
	Easy to access the charge port	3	+	+	0	+	+	+	+	
	Easy to see the display	3	0	0	0	0	0	0	0	
	Easy access of Buttons	3	+	+	+	+	0	+	+	
Intuitive Design	Buttons are intuitive to operate	4	+	+	+	+	0	+	+	
	Door handle Opening (mechanism) is Intuitive	4	+	0	+	+	+	+	+	
Visual Appeal	Minimalistic	3	0	+	0	-	0	-	-	
	Scandinavian Design	4	0	0	-	-	0	-	-	
	Blend with interior	5	0	0	-	-	0	0	0	
Packaging	possibility to fit the components into the design space	5	-	-	0	0	0	0	-	
	easy integration of components	4	-	-	0	0	0	0	-	
Cleanliness	Easy to clean	4	-	-	0	+	0	0	-	
	Less no. of split lines	4	-	-	0	0	0	0	-	
Modularity	Easy to replace the old / broken components	4	-	-	+	-	0	0	-	
	easy to remove for maintenance	4	-	-	+	-	0	0	-	
Cost	Low cost	3	0	-	0	-	-	-	0	
Result	Number of "+"		7	5	7	5	4	6	7	
	Number of "0"		5	7	8	6	14	9	3	
	Number of "-"		7	7	4	8	1	4	9	
	Total with weights		-2	-11	11	-13	12	8	-9	
	Total without weights		0	-2	3	-3	3	2	-2	
Rank			IV	VI	II	VII	I	III	V	

Figure 5.9: Pugh Matrix Iteration 2

### 5.5.1 Concept Survey

A concept feedback survey was sent out within Volvo Cars while the Pugh Matrix was under process. It was important to understand how the concepts were received by customers. Although the employees of Volvo Cars do not make the whole customer base, due to time constraints this seemed to be the best viable option.

The survey consisted, finalised 8 concepts. Each concepts were to be rated by the participant on 4 different aspects respectively from a scale of 1 to 10 ( 1 being the lowest rating and 10 being the highest). A comment section was provided to add comments or feedback for each concept. The 4 aspects being:

1. Aesthetic Appearance
2. Utility / Functionality
3. Volvo's Design Language
4. Futuristic

A quantitative analysis of the survey answers was conducted and all the comments and feedback were compiled. The results indicated concepts 'The Beak', 'Basic', 'The block', '2030' and 'Float Handle' to be the least liked concepts. Also, the Pugh matrix results also had these same concepts yield the lowest result. Thus, it was decided to move forward to next phase by discarding them. Only the comments of the selected concepts were taken into account and the rest of the concepts were discarded. The results and a

brief summary of the comments / feedback from the survey are listed and shown in the figure 5.10 below:

RANK (Parameter)	The beak	Basic	Powermat	Float Handle	Mirage	Inspiration	The Block	2030
Aesthetic appearance	246	308	367	331	355	385	328	366
Utility / functionality	291	371	368	379	376	386	362	319
Volvo design language	251	292	328	311	317	347	325	354
Futuristic	252	284	327	290	316	322	303	304
Total	1040	1255	1390	1311	1364	1440	1318	1343
RANK (Overall)	VIII	VII	II	VI	III	I	V	IV

**Figure 5.10:** Feedback Survey

- POWERMAT

- Provision of a cup holder might lead to people forgetting , thus making the next passenger’s experience bad.
- There needs to be a reminder to not forget the cups and mobile.
- Would rather prefer cable charging so it can be used simultaneously
- Speaker can be covered by the seats or user legs

- INSPIRATION

- Having screen on door panel is not ergonomic
- System to indicate forgotten mobile in the car
- User friendly buttons
- Strap for coffee cup is a bad idea
- Good to have lock / unlock buttons separate from the rest
- Prefer physical buttons for pullover and emergency

- MIRAGE

- Buttons need to be intuitive
- Screen options need to be easy to handle for first time volvo users
- A display for all the buttons and not both
- Need mechanical door opening to feel safe
- Wire charging instead of inductive – to use / charge at the same time

## 5.6 Concept Scoring

The results of Pugh Matrix and feedback survey left the team with 3 potential concepts for further evaluation. These 3 potential concepts were developed further to better evaluate and eliminate the less competitive ones with the help of Kesselring Matrix.

A weight matrix was introduced to recognize the importance of each criteria. The matrix evaluation took into account knowledge gained through surveys, interviews and teams

## 5. Concept Generation and Evaluation

engineering assessment for deciding the weights of each criterion. The criteria were more specific compared to previous evaluation stages. For example, instead of the criterion 'Safety', the criterion was stated as 'Air bag Inflation Zone'. The table below represent the weights of each criterion. The complete matrix can be seen in the figure 5.12

Later the final 3 concepts were internally assessed by the team against all the criteria as seen in figures [ B.20, B.21, B.22 ], the resulted were averaged out and fed into the Kesslering matrix. The results from the matrix showed that POWERMAT and INSPIRATION secured the first two positions with a very little gap between the scores.

Kessrling Matrix									
Criteria	Weight	Ideal concept		Powermat		Mirage		Inspiration	
		v	t	v	t	v	t	v	t
Air bag inflation zone is properly designed	3	5	15	5	15	5	15	4	12
appropriate position of emergency stop button (not prone to misuse)	4	5	20	4	16	5	20	5	20
Ergonomics	5	5	25	4	20	3	15	4	20
Intuitive Design	3	5	15	5	15	3	9	4	12
Blends with the interior	2	5	10	4	8	4	8	4	8
Easy intergation of the components	1	5	5	3	3	4	4	3	3
Easy to Clean	3	5	15	5	15	4	12	4	12
Easy to replace old/broken components	1	5	5	3	3	4	4	3	3
Low Cost	1	5	5	4	4	3	3	3	3
Manufacturability	4	5	20	4	16	3	12	5	20
V = sum v		50		41		38		39	
V / Vmax		100%		82%		76%		78%	
T = sum t		135		115		102		113	
T / Tmax		100%		85%		76%		84%	
Rank				I		III		II	

Figure 5.11: Kessrling Matrix

Criteria	0 = Less important 0.5 = Same importance 1 = More important										Σ	Σ rel	Weight
	Air bag inflation zone is properly designed	Appropriate position of emergency stop button (not prone to misuse)	Ergonomics	Intuitive Design	Blends with the interior	Easy intergation of the components	Easy to Clean	Easy to replace old/broken components	Low Cost	Manufacturability			
Air bag inflation zone is properly designed		0.5	1	1	0.5	0	0	0	0	0.5	3.5	0.0795	3
Appropriate position of emergency stop button (not prone to misuse)	0.5		0.5	0.5	0	0	0	0	0	0.5	2	0.0455	4
Ergonomics	0	0.5		0.5	0	0	0	0	0	0.5	1.5	0.0341	5
Intuitive Design	0	0.5	0.5		0.5	0.5	0.5	0.5	0.5	1	4.5	0.1023	3
Blends with the interior	0.5	1	1	0.5		0	0.5	0.5	0	1	5	0.1136	2
Easy intergation of the components	1	1	1	0.5	1		1	0.5	0.5	1	7.5	0.1705	1
Easy to Clean	1	1	1	0.5	0.5	0		0	0	0.5	4.5	0.1023	3
Easy to replace old/broken components	1	1	1	0.5	0.5	0.5	1		0	1	6.5	0.1477	1
Low Cost	1	1	1	0.5	0	0.5	1	1		1	7	0.1591	1
Manufacturability	0.5	0.5	0.5	0	0	0	0.5	0	0		2	0.0455	4

Figure 5.12: Kessrling Weight Matrix

# 6

## Detailed Design

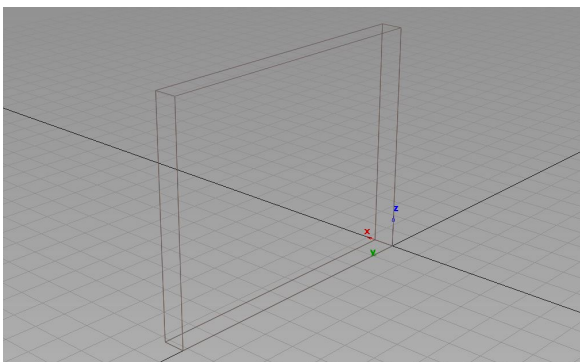
### 6.1 A-surfacing

The completion of the concept evaluation phase left us with 2 potential concepts for development namely, POWERMAT & INSPIRATION. In order to develop these 2D hand drawn sketches to a 3D model, Autodesk Alias was used. Autodesk Alias is a widely used computer aided industrial design software predominantly used for in many automotive and product design industries. It is well known for generation of Class A surfacing. Class-A (or 'Strak') is a term used specifically in automotive design. It describes the final production surface data for the aesthetic parts of the car. [26]

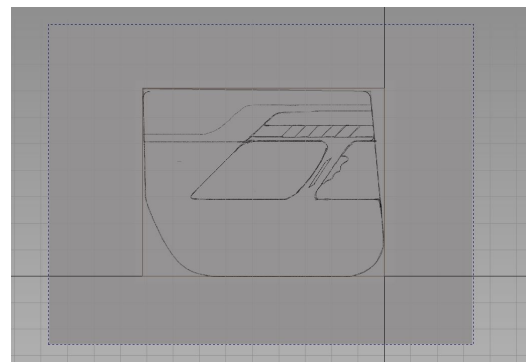
Autodesk Alias is also used in Volvo Cars for conceptual modelling and later used as a base for mechanical development or commonly know as 'B' surfacing. But the primary use of Alias is to develop high quality 'A' surfaces which makes a huge impact on how the visible parts of an automobile are seen under various lighting conditions. The thesis followed a similar process.

#### 6.1.1 Development

In order to start with the surface modelling , it was imperative to first get a solid reference block imitating the volume enveloped by the door panel. The measurements for door panel were derived from previously developed door panels. Once, the volume cube was in place [Figure 6.2], the 2D sketch developed by us was resized proportionally and used as a background reference image [Figure 6.1] to plot the curves. Note: The development process of one of the two models are shown in the further stages, as both of the models undergo a similar process.



**Figure 6.1:** Reference volume cube



**Figure 6.2:** 2D reference image

The curves being plotted were made sure to have minimum number of spans and the degree of curves used was limited to a maximum of 5 deg [Figure 6.4]. This is was done to achieve either G0, G1, G2 or G3 continuity in the surface, which acts as a base criteria for class A surfaces. Curvature Comb tool was regularly used in order to evaluate the

curved plotted and avoid any sudden acceleration, inflection or break-offs. The tool essentially made sure that the curves were taking on a smooth and fluent transition from one curve to another. Another important method implemented was to not break the curves and replicate the reference drawing exactly. Instead the curves were acting as guidelines for the surfaces to intersect and make up the shape of the panel. This method reduces the risk of discontinuity [Figure 6.3].

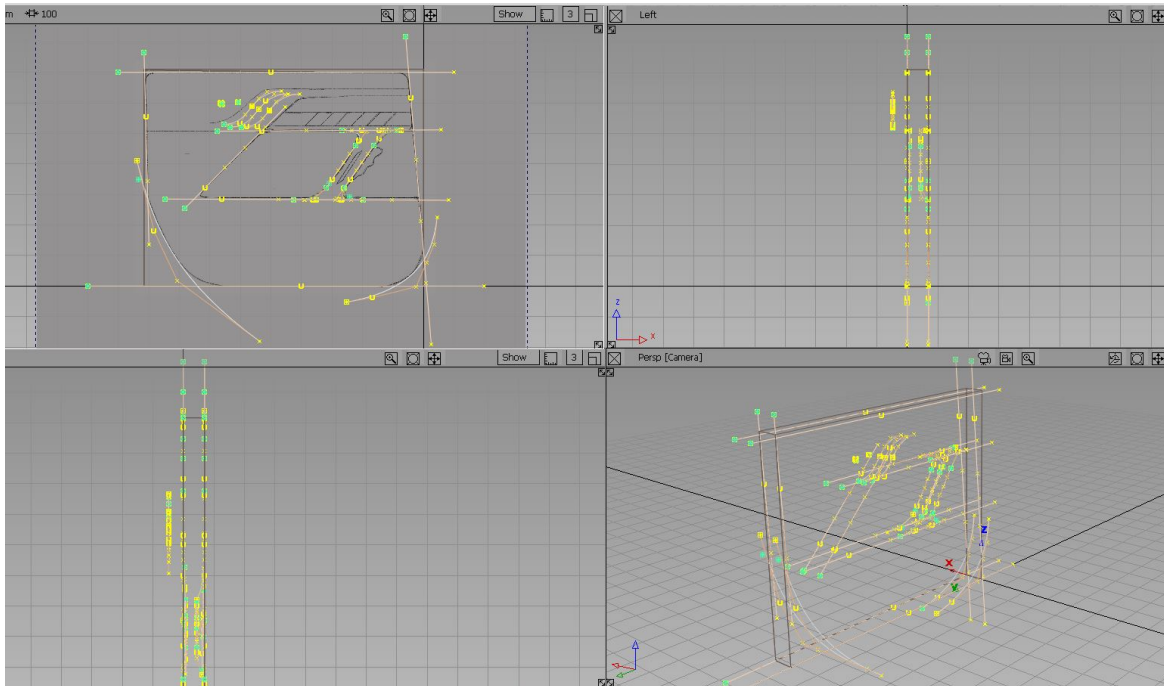


Figure 6.3: Curves plotted

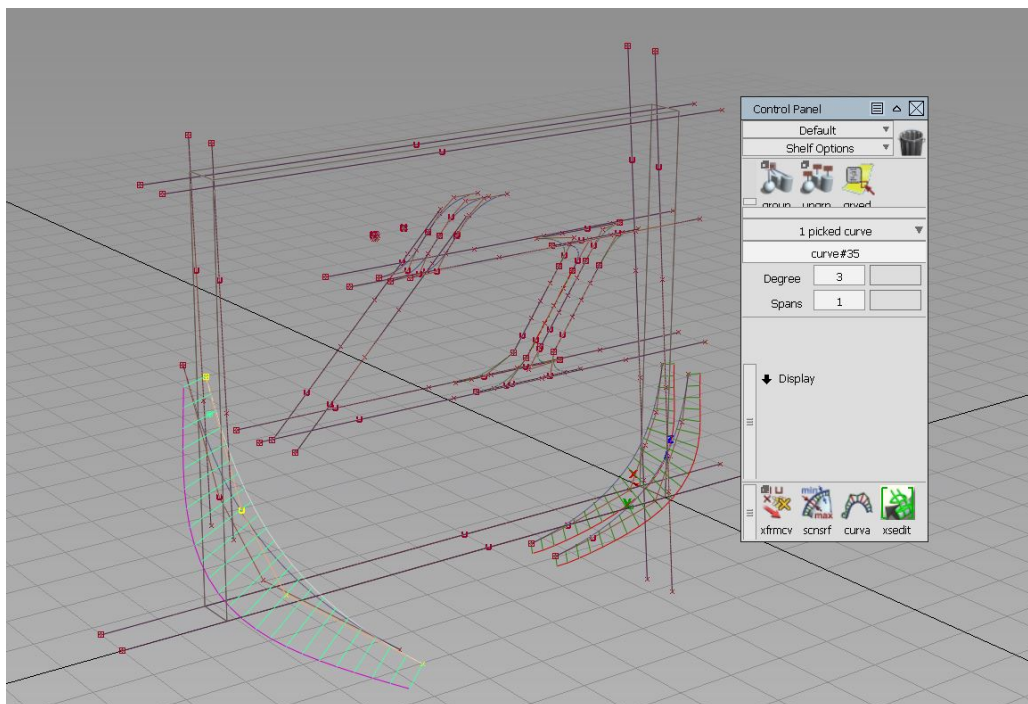
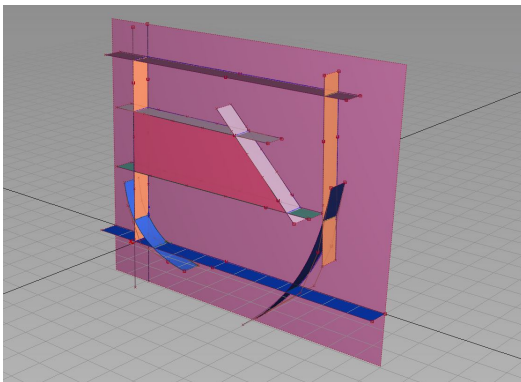
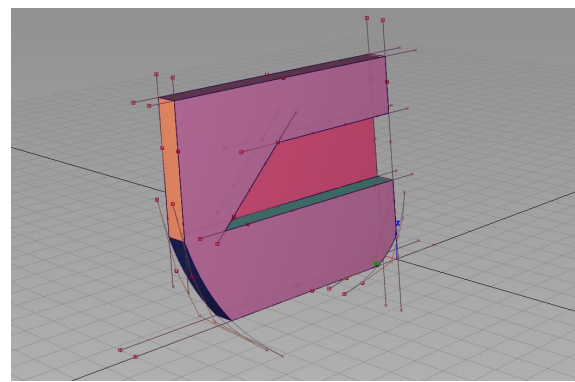


Figure 6.4: Curve degree and span

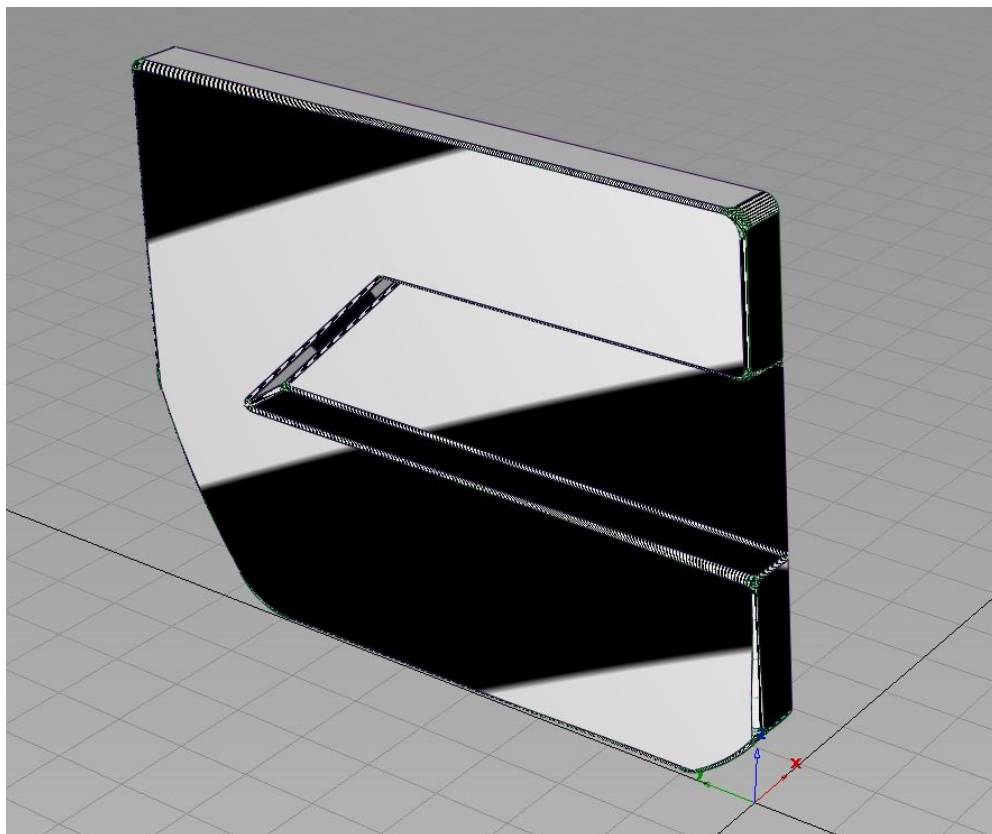
Once all the necessary curves were plotted, surfaces were generated for the panel carrier, which is the base of a door panel [Figure 6.5]. It is on this panel carrier other components are fixed on to. Once all the surfaces were generated, they were trimmed to form the shape of the door panel envisioned [Figure 6.6]. Now, the most critical part, adding fillets and curvature to surfaces, so that there are no visible edges and all the parts of the panel have a smooth transition. Although, the 'round' tool is not a go-to tool for such steps, due to the lack of experience and time constraint, only the 'round' tool was used to create fillets. At this point, it was time to check surface continuity using the 'Horizontal/Vertical (Zebra) diagnostic shader'. The tool helps to find surface flaws by checking if the adjacent surfaces have mismatched tangents. A simple way to visualize it is by checking if the 'zebra' stripes going across the product has any abrupt variations [Figure 6.7].



**Figure 6.5:** Surfaces before trimming

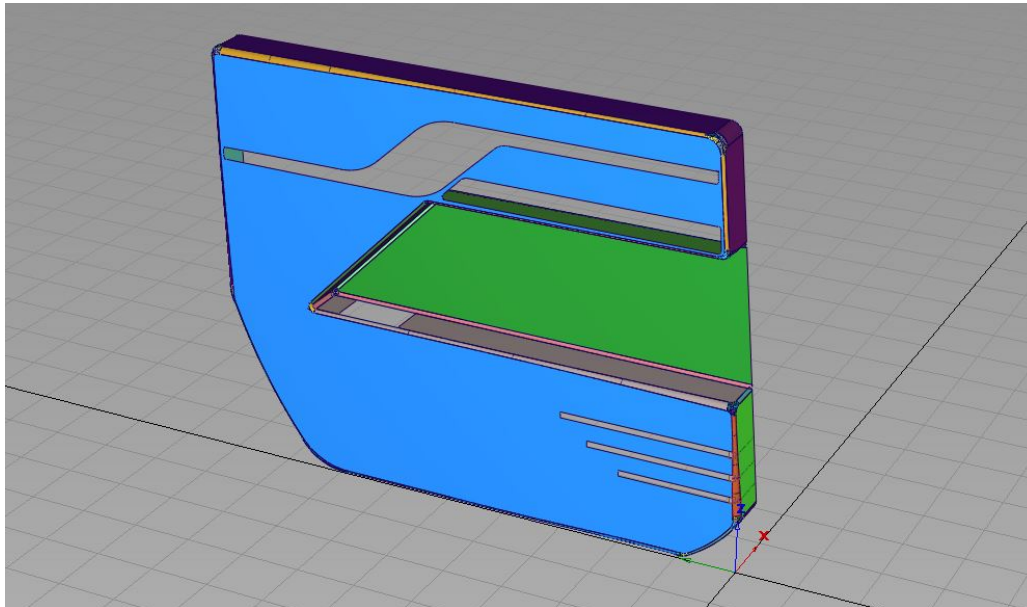


**Figure 6.6:** Surfaces after trimming

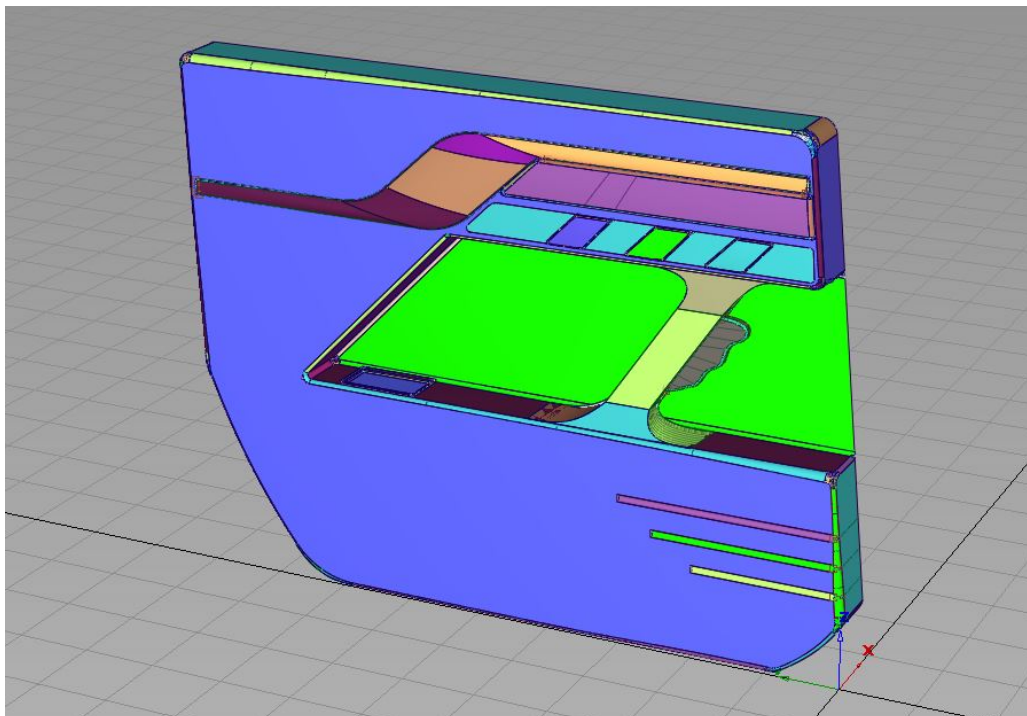


**Figure 6.7:** Zebra Diagnostic shader to check surface flaws

With the base surface ready , the necessary cut-outs for components to be assembled on the door panel such as: Speaker grill, Wood trim, Button panel, Charge bucket, lighting were made [Figure 6.8 ]. Later, each components was developed with the cut-outs as reference and fixed into place[ 6.9 ].

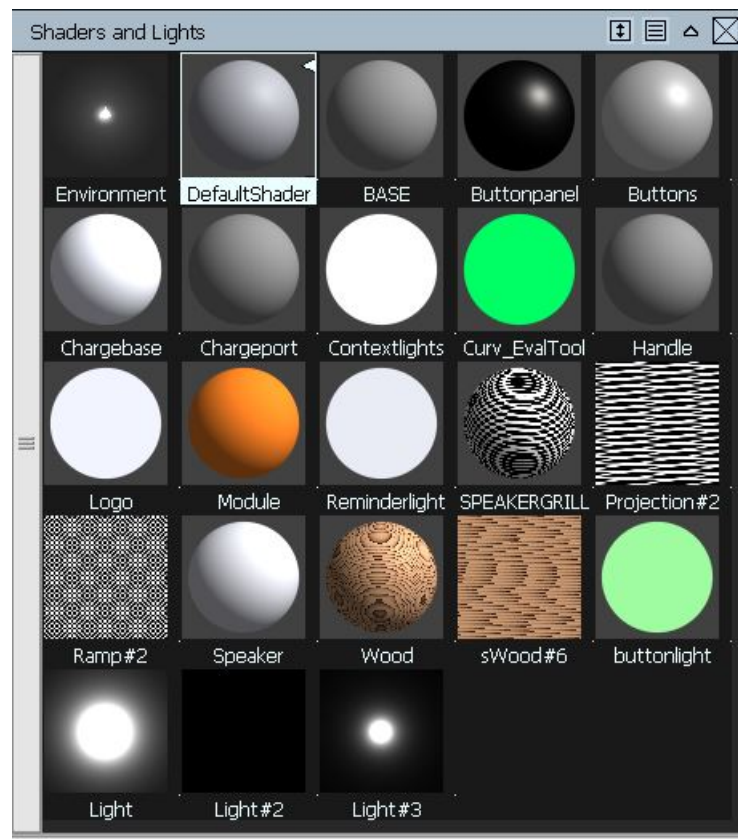


**Figure 6.8:** Cut-outs for component assembly



**Figure 6.9:** Assembly of all the components on the door panel

In order to visualize the door panel as realistically as possible , shaders were developed. A custom shader for each component was developed on a trial and error basis to resemble as close to reality as possible [Figure 6.10 ].



**Figure 6.10:** Shaders

The colour theme picked for the concepts were with two main consideration. Firstly, so that the surface of the door panel can maintain its pleasing appearance after constant use and doesn't highlight scratches or dents. Secondly, to resemble Volvo's product portfolio. The complete rendered picture of the two concepts and their detailed explanation can be seen in the Results Chapter [7]

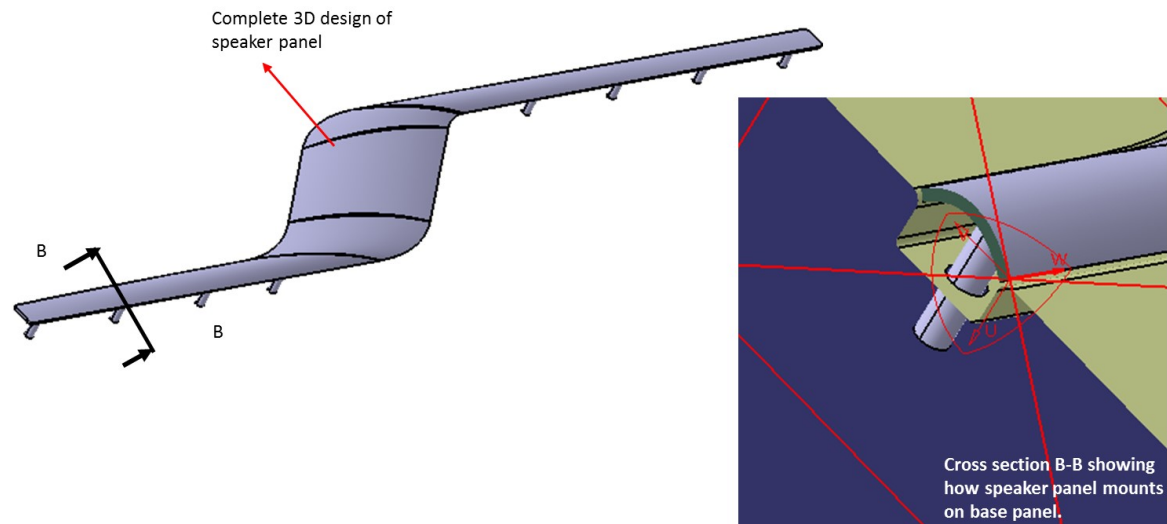
## 6.2 Detailed development

A-surface or the styling surface was created for the concepts INSPIRATION and POWERMAT. Out of these, only POWERMAT is developed into detailed design due to time constraints. Detailed development involves modelling the actual components in 3D using Catia in their actual size. The detailed design development consists of three important stages namely 2D Master section creation, 3D design development with thickness and checking for packaging and manufacturability.

### 6.2.1 Master section creation

Master section creation is the first step in detailed development of any mechanical component. In this step, the cross section (car line or normal to a curve on the component) of the component's styling surface along with the surrounding parts, is taken and copied to sketcher [Figure 6.11]. Thickness is given to the component in 2D and checked if there is any interference with surrounding components.





**Figure 6.12:** 3D design and development of Speaker panel

### 6.2.3 Packaging and manufacturability check

Usually, each component is designed according to packaging and manufacturability guidelines during the 3D detailed development. But after each stage of maturity in design, usually called as project milestones, each component is analyzed for manufacturability, assembly sequence, assembly direction, packaging, and performance (in CAE). But CAE is out of scope for the thesis project.

Since the components in door panel are made of plastic, they were checked for manufacturability constraints according to injection moulding guidelines. The component was checked to prevent negative draft with respect to the unmounting direction. Assembly sequence is picked in such a way that the components are assembled in shortest time possible without any quality issues, whereas assembly direction is picked so that there is not interference with surrounding components and it is ergonomic for the line worker to assemble the component in that direction. Packaging constraints govern the part and assembly tolerances to make sure the components fit with one another.

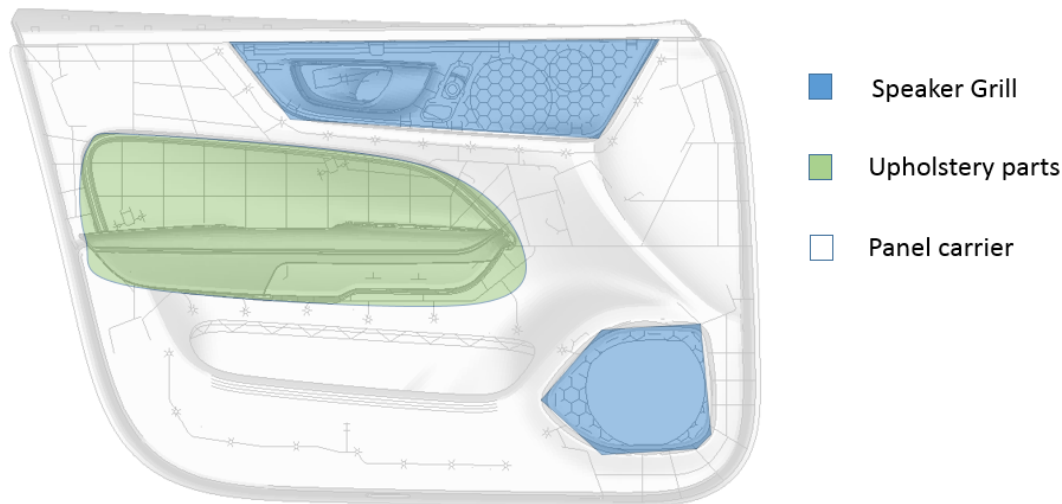
## 6.3 Material Selection

Material selection also plays an important role in the thesis work, as it acts as a medium to propagate company's vision and satisfy some of its client needs. The Scandinavian culture and thereby, Volvo Cars is huge proponents of sustainability, Eco-friendly and renewable products. With concerns about the environment raising more than ever, the clients wanted to showcase sustainability in their products. The relevant requirements and desires are listed below :

- The panel is easy to clean.
- The panel is easy to maintain.
- The panel should last for 3-4 years.
- The panel should be ECO designed.
- The panel's upholstery should be exchangeable.

- The Panel avoids PP surfaces.
- The panel avoids PU spray.

The Door panel can be categorised in distinct parts with respect to the materials attributed (As shown in the figure 6.13 below). Namely,



**Figure 6.13:** Door Panel Nomenclature

1. Panel Carrier : It makes up most of the door panel and houses various components such as handle, open/close latch mechanism, speaker grills etc.
2. Speaker Grill : It is usually made up of stamped aluminium plates, that acts as enclosure to the speaker.
3. Upholstery parts : These are the parts of the door panel that is wrapped in fabric to enhance visual appearance and texture. Its common to see armrests wrapped in textile.
4. Wood trims : These are modular parts that are assembled on a panel carrier either as a sign of luxury or to increase aesthetic appearance.

The above listed requirements and desires were translated into specific material attributes that could potentially satisfy the said requirement. And it was decided that these requirements were to be primarily satisfied by the panel carrier as it made up most of the door panel. Hence, the panel carrier material had to have impact resistance, scratch resistance, good surface finish, good colorability, Eco-friendly, sustainable and most importantly be injection moulding compatible.

When it comes to the subject of Eco-friendly and sustainable materials, the idea could be propagated in two different ways. The material selected either could be made up of recyclable materials which promotes sustainability or could be made up of natural fibers which promotes Eco-friendliness. Both the options had its own set of trade-offs. From the possible potential choices, the recyclable materials had more amounts of PP but were available in visually pleasing inherent colors. Whereas, the more Eco-friendly

materials had significantly less amount of PP but were required to be post processed with PU sprays to attain desired mechanical properties and pleasing appearances.

With the amount of literature review done within the team in a limited time, could not find a potential material choice that is completely made up of natural fiber elements. Although, there are such materials, for instance Faurecia's BioMat, a completely bio based material made up of natural fibers, bio based matrix that is injection moulding compatible. It is not yet ready to be industrialised as there are yet to be solved inherent problems related to its bio-degradation, stability to external environmental factors and process change in injection moulding for better compatibility [23]. Further there are materials with higher percentage of natural fiber content but requires to undergo compression moulding instead of injection moulding. One such example is the UPM Formi by Flex Form Technologies, which is a durable, odorless, non-toxic and uniform-in-quality biocomposite, with up to 50% renewable raw material, that is ideal both for industrial applications. Flex form also offers materials with 50-50 ratio of PP and Natural fiber that is being widely used in the automotive industry, but these materials need to be compression moulded.[24]

The table 6.14 provides a final list of potential material choices for panel carrier:

Material	Properties	Sustainability
Inspire TF1500	High Impact Resistance, Good Scratch Resistance, Pleasing Surface Appearance.	No Recycled Content, No Bio Content
Daplen™ EG265AI	Good Impact Resistance, Good Stiffness, High Scratch Resistance, Low Gloss High Flow, Good Processability,	Recyclable Material
PULSE™ GX70 AB	High Heat Resistance, Low Gloss, Low Odor, Pleasing Surface Appearance, Good Scratch Resistance. Low VOC, High Flow, High Melt, High MFI	No Recycled Content
Borstar® NJ200AI	Good Scratch Resistance, Good Stiffness, Good Surface Finish, Low Density, Good Gloss Low Specific Gravity	Natural Fiber, 20% Filler by Weight Renewable Resource Content, Recyclable Material
Fibremod™ GE277AI	Chemically Coupled, High Flow, Recyclable Material	Glass Fiber, 20% Filler by Weight Recyclable Material
Santoprene™ 8221-75M300	Good UV Resistance, Good Colorability, Pleasing Surface Appearance Good Moldability, High Flow, High Melt, High MFI	Recyclable within the manufacturing stream
Daplen™ WN100AI	Low Gloss, Good Impact Resistance, Good Stiffness, Good Surface Finish, High Scratch Resistance High Purity	Mineral, 10% Filler by Weight Recyclable Material

**Figure 6.14:** Potential Panel Carrier Material Choices

It was decided to move forward with Borstar® NJ200AI Supplied by Borealis AG as the final choice. It is a 20% natural fibre filled polypropylene compound specially developed for the automotive industry. The materials is an amalgamation of all the needs and requirement, which is made of 20% natural fiber renewable resource, recyclable, scratch resistant, durable and has high impact resistance [25].

The speaker grills are decided to be made through aluminium stamping. This has been a very common practice in the automotive industry and the material is recyclable 100%, thus promoting sustainability. Similarly the wood trims components are usually made using wood veneers which are Eco-friendly, renewable and adds a level of luxury to the automotive interior.

Along the same lines to improve sustainability, the upholstery to be used are also carefully picked. One name that stands out in promoting eco-friendliness is Dinamica by Miko. Dinamica is a eco-suede microfiber material that undergoes production very similar to that of recycling paper, where no harmful chemical are used. It is derived

from used polyester fibres (T-shirts, fibres, etc.) and PET (bottles, plastic, etc.) and is design for easy disposal and 100% recyclable. Most of the upcoming EV cars such as Porsche Tycan and Volkswagen ID.3 use the same material.[22]

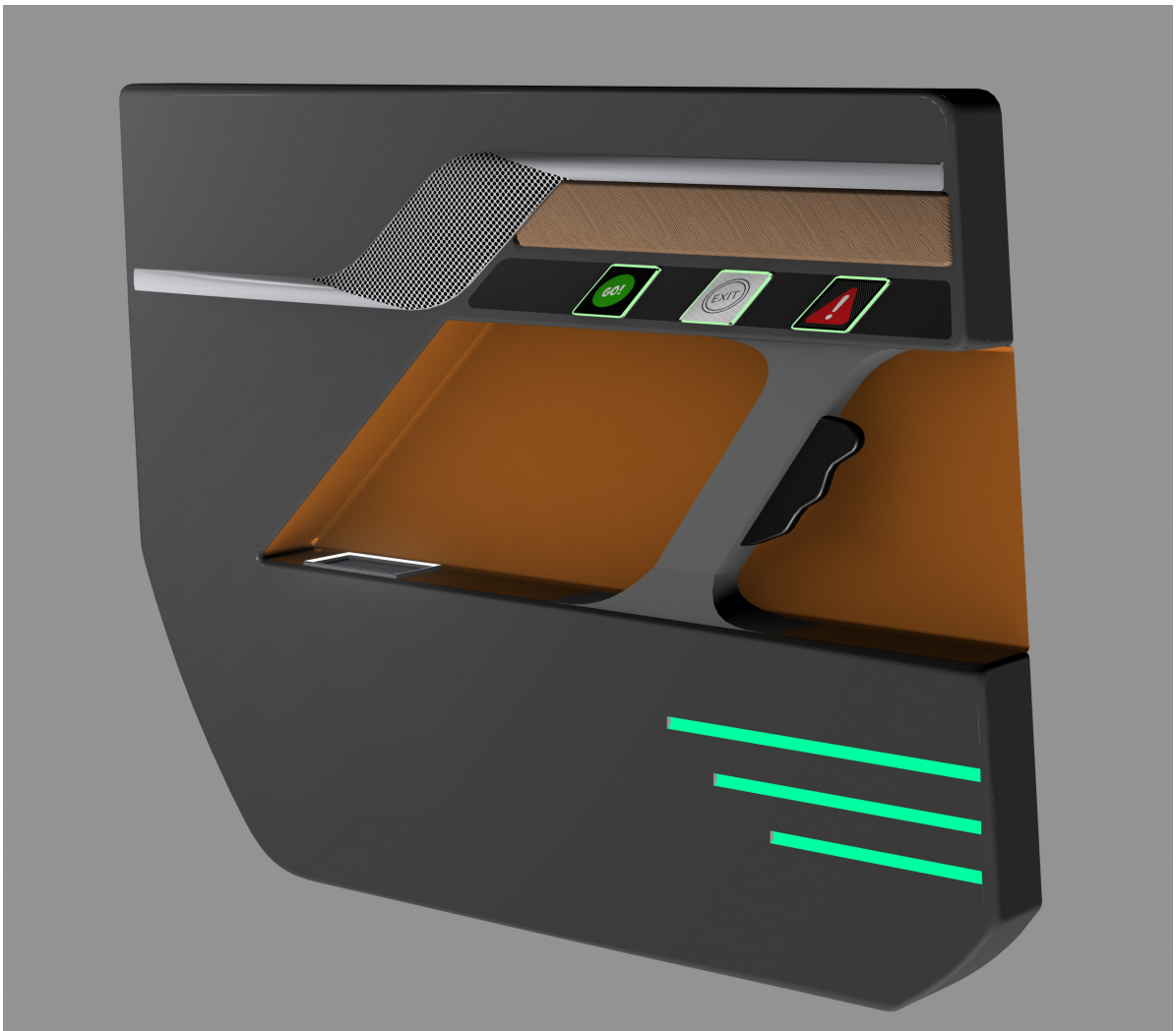
# 7

## Results

The chapter aims to present the final outcome of the thesis work and provide a detailed explanation of the concepts developed.

### 7.1 POWERMAT

The name 'Powermat' was initially given during the concept generation phase. During the early stages of the concept, the idea was to provide wireless charging in form of a mat laid vertically on a door panel, as seen in the figure 7.1. But this was later changed due to safety concerns.



**Figure 7.1:** Concept 1: Powermat

The concept envelopes a switch plate with 3 different button. These buttons are a way

to interact with autonomous taxi, thereby providing its user with a sense of control and safety. Two of the buttons 'Go' & 'Stop' are meant to be used frequently and letting the taxi know that the passengers are seated and ready to travel or to stop the taxi for exiting. The last button is meant for emergency purposes which acts as a panic buzzer to interact with taxi's customer service.

In order to reduce the risk of misuse and accidental activation of 'Go' & 'Stop' command, the voice assistant in the taxi asks for confirmation by reactivating the button. Although the confirmation feature is not applicable for the emergency button. The button peripherals lit up to provide the passengers with feedback of it being activated.

The handle bar is designed to be accessed by people sitting in either side of the campfire seating. It is tilted at an angle for the same purpose and to further the ergonomic ease of use. The handle bar is also coupled with an door opening mechanism. This is provided for using in times of distress or when the automatic door opening fails, thus ensuring a sense of safety and control.

The door panel also provides its user a way to charge their mobile devices via wireless charging technology. 'Charge bucket' is a platform with raised boundaries within which a mobile can be kept to recharge. The raised boundary are given to reduce the risk of mobile falling off while the taxi travels through rough roads / turns. The raised boundary is also equipped with a lighting system, that lights up when the charge bucket is activated, whose main purpose is to remind the user of their devices and reduce the risk of people forgetting.

The contextual lighting provided at the bottom of the door panel is one more way the taxi interacts with its passengers. The name contextual lighting is given as it signals its passengers when the door is being opened / ready to be opened and closed/ ready to be closed. In order to differentiate between opening and closing actions, the light shines green and red respectively.

The speaker grill expands to the entire width of the door panel and warps the wooden trim and switch plate under it. The wooden trim serves as a luxury element in the car and also to bring about an earthy feeling to its users.

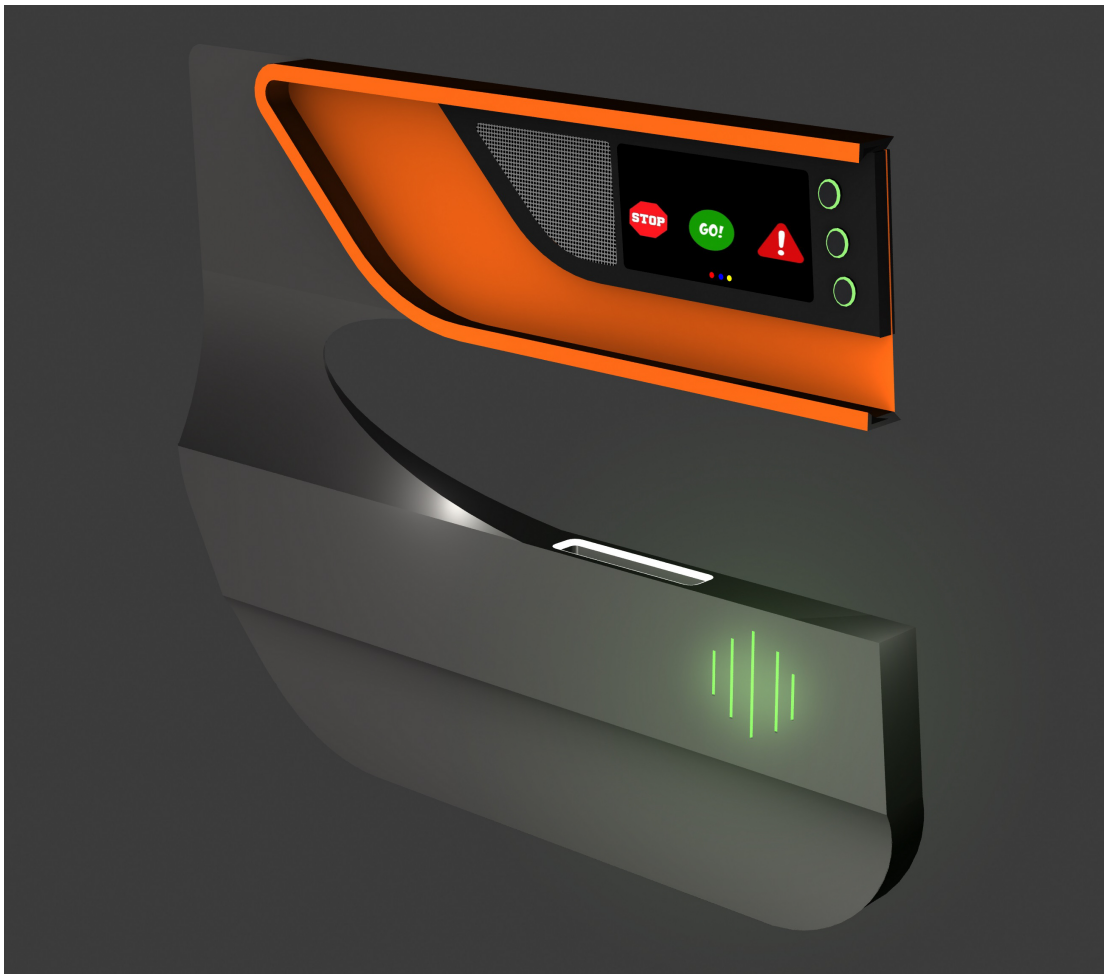
## 7.2 INSPIRATION

The concept is named as 'Inspiration' as the styling is inspired by Volvo Design team's concept. The idea was to make the concept more daring and futuristic.

The concept entails most of its feature on a single pane at the top right corner of the panel carrier. A digital interactive display can have lots of different uses either in terms of enhancing the passenger experience or marketing. The display can be used to show maps, which the passengers can use to alter their destination along the way. It can display the traffic in front, to provide passenger with instructions and information. The clients use the display as a platform to advertise and grow their reach.

The panel carrier also contains 3 buttons, 'Go', 'Stop', 'Emergency' to interact with the

taxi as explained in the previous concept explanation. And lastly the speaker interacts with the passengers to confirm if they intended to active a certain command and few other general information.



**Figure 7.2:** Concept 1: Inspiration

The concept has no handle bar, which takes away the sense of control and safety from its passengers. But the idea is that automatic doors do not need a handle bar. This changes the conventional design constraints and opens a lot of opportunities to use the design space in various ways. In this case, the charge bucket could be placed where the handle would have been. The door panel thickness becomes considerably thin without a handle, thus, contributing weight reduction and less complex manufacturing process.

The charge bucket in this concept is made like a slot, to reduce the thickness of the panel. This design also promotes a safer way to charge the mobile device, as it cannot fall off or fly and injure a passenger if an accident occurs. The peripheral of the charge bucket is provided with light strips to indicate activation and remind the passenger about their mobile devices. Lastly, the contextual lighting is provided at the bottom to indicate whether the door is being opened (Green light signal) or closed (Red light signal)



# 8

## Discussion

The project was initially started with the idea of working alongside with Volvo Cars' employees and develop the door panel according to styling and design inputs from the project stake holders. But the scope and aim of the project work had to be altered along the way due to several unavoidable circumstances. This discussion chapter explains how the project scope changed during its course and the challenges that the team faced at several stages of the project.

### 8.1 How and why the project scope changed?

The final door panel design of this project was intended to be designed and developed based on the styling surface provided by Volvo cars' styling team. But in March 2019, the autonomous taxi project at Volvo cars was put to freeze until December 2019, making all the stake holders in the project to stop their works. Because of this, various activities which were initially not part of the thesis scope had to be done in order to come out with a door panel concept.

The initial plan was to explore deep into the design of plastic components, the factors that influencing the dimensions of each door panel component, how the design principles need to be modified for the autonomous vehicles and develop the mechanical design for the door panel based on styling surface provided by Volvo cars. But due to project freeze, the team was given complete freedom to develop a door panel concept based on their findings from market and customers.

Thus the scope of the project was changed to identifying the customer and market requirements in an autonomous car, developing a concept door panel based on the findings, create their own Styling surface using Alias, and to develop the mechanical design for the same. CAE calculations for the developed design were not carried out due to time constraints and unavailability of information.

### 8.2 Challenges faced during the project

There were two surveys conducted in the project; first survey to gather inputs regarding the customer expectation and attitude towards autonomous vehicles and second one to get feedback about the concept sketches. Though the intended participants for the survey was customers from U.S.A, the survey could not be circulated there due to data restrictions and GDPR rules in the country. Majority of the response for the surveys were from Europe and the participants are employed in Volvo Cars. There is a chance for the participants to have had a bias towards Volvo products and a filtered way of

looking at the cars. Hence there are possibilities of different survey results, if the target participants were accessible.

In benchmarking phase, the unavailability of data from latest models was a setback. The door panel data from very old vehicles were only available in the benchmarking site. If the latest vehicle data was accessible, it would have put the project team at a better place while determining the dimensions of components that go into the final design.

Since the project was frozen at the preliminary stage, there was no prototype available in the right scale to conduct practical ergonomic studies like RIBA and RULA. Also the seating arrangements and positions in the autonomous car is different compared to the regular cars. Thus ergonomic considerations were done only for dimensioning of the components in the door panel and not for positioning the components in the panel.

In the second survey for analysing and choosing the best concept sketches, the feedbacks from the participant concerning all the concepts were considered but only the relevant ones to the winning concepts were applied. Other feedbacks were discarded. If there was another iteration of concept survey conducted after implementing the feedbacks, the results could have been different. But due to time constraints, the second iteration of survey was not carried out.

Finally, the team faced difficulty in the detailed design phase due to lack of experience in creating A-surface and working with plastic part design. The teams at Volvo cars who used to work on this project were not having complete information that was needed during the design phase, as they all stopped working on the project due to design freeze.

# 9

## Recommendation

The thesis work involved looking at the problem in a more holistic view. It aims to provide a strong foundational database upon which future teams can develop further and get it to level of production. The recommendation chapter pinpoints the areas of the thesis which needs to be verified, investigated, improved and developed.

- **Market Survey Analysis:** The survey was mainly aimed to understand the needs and desires of US customers when it comes to autonomous taxis. Due to GDPR issues it was very hard to get responses from the US and the few responses gathered were insufficient to form a conclusion. The conclusions of our survey are mainly based on Swedish citizens and those who work in the automotive industry. We believe this might impact the overall result, since the lifestyle, environmental and economic factors of a person change from region to region. Thereby changing their responses to a particular problem. Thus, it is very important to gather responses from US citizens with various backgrounds and cross-check for deviations from our survey results.
- **Safety and Ergonomic Inputs:** The data gathered for safety are primarily based on previous model cars. Upon which the thesis group together with the safety team came up with assumptions of how the safety zones will be shifted. But it is important to verify the issued safety recommendations with airbag inflation and crash simulations. The ergonomic recommendations are also based off the available data and prototype. The prototype was not an accurate representation of autonomous taxi, hence the placements of handles, switches and digital screens might have to be readjusted in accordance to the actual model car.
- **Concepts Generated:** In the same lines of previous recommendations, the concepts generated were based on our limited knowledge of Volvo's design language. The overall interior aesthetic theme was not considered during the concept generation process, as there was no relevant information being generated at VCC due to the project freeze. Thus, the provided colour theme and styling should be revisited and changed accordingly. Although, the placement of the components were well researched and decided to be optimal.
- **Material Selection :** The materials that have been selected for the panel carrier are based on existing suppliers and production methods commonly used in VCC. It is possible to shift to more Eco-friendly materials with higher percentage of natural fiber content and recyclable rates. But such materials are compression moulded or use special production techniques, thus, further investigation in regards to compatibility and effectiveness of these methods to VCC is needed.



# 10

## Conclusion

The thesis work was intended to develop an interior door panel for future driverless taxi to be deployed in U.S.A. The work included approaching the problem in a holistic way, primarily, to understand the intended user's attitude towards an autonomous taxi. Later to combine this researched data from market analysis with the company's portfolio and client's requirement, together forming a set of requirements and desires. These requirements and desires were translated in the form of functions, components, aesthetics and material characteristics to form a door panel. Safety, ergonomic and manufacturing considerations played an important role in the shaping final result.

Its is important to note that developing products of the future involves undertaking assumptions. During the course of our thesis work, it can be seen that the team had to make decisions based on various assumptions in order to move forward. The market survey participant demographics were vastly different from the intended ones. But it was assumed to be close by comparing our survey to US survey results found on the internet. Similar assumptions were made while developing the product in accordance to the underdeveloped safety and ergonomic considerations.

Another important factor to take into account is our own biases and limitation. Concept generation and evaluation phases involves a fair share of subjectivity. This can be seen during assigning weights to criteria for a concept screening or scoring matrix. Limitations arise when developing styling surfaces due to the lack of experience in the field. These seemingly minute deviations in each phase of the thesis work can compound and its ramifications can only be know once the product reaches its user.

However, it is safe to say that our thesis work provides satisfactory results. It complies with most of the critical company and client requirements, makes sure the users feel safe, comfortable and in control of their environment. Thus, to ensure the success of such a product , it is important to take results of the thesis as a baseline of data points upon which the company can explore.



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# A

## Appendix - Market Analysis

### A.1 Customer Need Statements

Comfort	Safety	Control
I use my mobile, look out, if a person accompanies then talk to them	Accident, Rare incident like- overtaking other vehicle.	getting stuck in a pod, if I want to stop in the middle of my ride, I cannot.
Browse on smartphone	Reaction of other drivers on the road, like road rage could be directed at me	Emergency, quick change of route?
listen to song, sleep(most often if its early)	1. Component malfunction. 2. During passenger Emergency situations if it doesn't have options to force stop it might be end up in a problem	Isolation. Even though there is normally little exchange between driver and passenger, it is nice to have the option
Usually nothing	Lack of driver.	if someone else would get in when the car is stopped for a redlight ect.
Check e-Mail	not reaching the destination. let's say I only have an address in a city I have never been before. the reliability to get me to the right place.	Lack of driver.
Check phone, text friends	Software fails and there have been too many death reports from Tesla to make me feel that any car company is ready.	Emergency, quick change of route?
Talk to the driver	getting stuck in a pod, if I want to stop in the middle of my ride, I cannot.	not reaching the destination. let's say I only have an address in a city I have never been before. the reliability to get me to the right place.
Will check notifications in my phone Or will see roadside shops and etc	Malfunctioning, trapped in the car, under the control of a robot	Wrong way or place.
Looking at my phone	Accident, Rare incident like- overtaking other vehicle.	How I would be able to communicate with the car, for instance if I wanted to change route
Looking at my phone	Actually an autonomous taxi wouldn't scare me at all	If I suddenly need emergent medical help (for example asthma or stroke or heart attack) that I don't have anyone help me. That can kill me.
Look out the window	Reaction of other drivers on the road, like road rage could be directed at me	Thrust the car, that the car will take the correct decisions in strange situations.
relax	Safety	Similar as going by airplane, feeling that I do not have any control over the situation
Check on my mobile phone.	nothing, I think that a driverless car can be more safe then a car with a driver.	Förutom olyckor, inget.
Look at my phone	That all the technique is not updated, not calibrated	It would take a while to get used on having nobody to be ready to assume the steering wheel in case of unexpected events.
nothing, meditate	Software fails and there have been too many death reports from Tesla to make me feel that any car company is ready.	Can be unpleasant and slow
Read mail.	Tekniska problem, stillestånd	That the technology isn't ready for autonomy and manufacturers are rushing with it
Calm down	accident	Someone or something taking control over my ride and I don't have the possibility (no steering wheel/brakes etc.) to stop it.
talk to taxi driver	Non autonomous cars which doesn't communicate with my AD vehicle	If it don't stop if I want to jump off earlier or if it cannot find the right address I want to go to.
Relax	Accident and how to continue the ride	Car to be hacked.
Slappna av, fundera, reflektera	Getting hacked	Electronic malfunction - locked inside, wrong destination, communication with car
Talking to drivers, Reading kindle ebooks or play cellphone.	Being alone in car if something would happened	Car getting hacked and still run in to an accident/off course...
Talk to the driver, there is no opting out. I feel forced to talk with them.	Reliability (=everything work as it should). Motion sickness	feeling of no control. Communication if something happens.
Look out or use iPhone app	Hijacking / Exploiting vulnerabilities of taxi. Lot's of fiction (series movies) on this topic. Also price, looking at the last questions with features and blahblah, all this stuff make AD taxis expensive and therefore on easily available.	Not having control
watching movie	Probably failure due to complexity of AD that make the rides stop	I do not have control. Technique can be manipulated / hacked and has always failures (when I think of my Navigation system... Jesus..) - I do not trust the technique
sit back & follow the traffic	a bug would cause the car to do something irrational and cause an accident	Communication whit the taxi
Phone - texting, talking	Possibility of accident	communication on where to go, if changed route/plans
Surfar i mobilen och pratar med föraren	Malfunctioning on the half way to the destination	Not finding my final destination in time
Relax	strange/unforeseen acceleration and deceleration	not knowing were the taxi will drive me.
Read the mail or talk to the driver	honestly saying, until now havent experienced with an autonomous taxis. With the stereotype belief I too concerned about the behaviour of the vehicle in case of emergency braking and control.	no real control-driver
Sleep	Don't need to be social if I don't want	Car breaking down
look out the window	How reliable is the taxi to drive autonomous	Get stuck in a traffic jam. The taxi will be the only one keeping the speed limit aka. too slow.

Figure A.1: KJ analysis

## A. Appendix - Market Analysis

Productivity	Clean	Cheap
Entertainment system	Under-Maintained	Expensive and time consuming
Interaction Voice System, massage, AIAS	Dirty	Price
Phone charging dock, a good sound system	Smelly	Costly
Interactive display in window panes	Littered	
Option to stretch out	Cleanliness and maintenance	
Display	I'm concerned about the cleaning, how people using the car. Perhaps don't care at all about how the next person experience the ride. For example put shoes in wrong places. Leaving garbage...	
Newspaper or magazines, Touchscreen display.	<b>Comfort</b>	
Speakers, HMI - decide climate in car, footrest, charger space, a small desk to have the computer on.	Looking out on the road (motion sickness)	
Charger and a screen you can stream YouTube or Netflix on.	read in my mobile or call	
Charging, personal music space, virtual window displays so you can pretend your riding somewhere much nicer	Talk to co-passanger or driver	
charging, news	Listen to podcasts	
Infotainment, very comfortable seating, maybe a small fridge	Thinking	
Facility to take outside photos using car cameras	using mobile phone	
Display for mirroring devices.	Enjoy the ride...	
be able to use internet and have a nice cup espresso	Communicating via smartphone	
Wifi	Relax	
Entertainment System (like long-distance-airplanes), great voice control system to communicate perfectly with vehicle,	Talk	
TV	Looking out the window	
Electric outlet	Look at my phone or talking to the taxi driver	
Definitely a screen with some apps, would be great if they connected to some of my accounts for like Netflix and so on, so I could keep watching my preferred shows or subscribed channels. Charger for my phone. Somekind of drink dispenser would be nice!	read messages on phone	
Display, speakers, charger for sure, navigation so I can follow the route (like in airplanes)	talk to driver	
Climate control, Radio, TV, Charge, Cold water.	Talk with taxi driver	
Speakers, display, charger, reading light, comfort seating that you can put in laying position	consume social media via my phone	
USB charger	Chat with driver	
Water bottles, coffee, snacks or fruit, newspaper, space to lean back, table to put laptop on, massage chair, space for at least two persons	Listen to music, Check messages on phone, just relax.	
TV, Wifi	talk to the taxi driver or read emails, read news in the mobile phone.	
Manicure saloon : including UV machine, nail care etc.	Talks to the taxi driver, looking at my phone	
display	Chat with friends in the taxi.	
Disturbance free driving. Sitting in the back seat is usually not the most comfortable space, when sitting in the front seat you can look out on the road and you are also placed in front of the center of mass of the vehicle.	Talk to the driver.	
Charger Screen Climate Your guide	Social meida	
taxi arriving with pre-ordered food, and a seat position favourable for eating then sleeping	Reading news from my mobile	
radio channels to select, speaker volume adjustment, charger phone /computer, comfortable seats, possible to lean back, possible to lay your feets up, TV-screens, kareokee, on-board games, rent a movie, curtains to make it darker, glas roof, emergency phone to taxi-central	Surfar	

Figure A.2: KJ analysis

## A.2 Interview questions

- What is your attitude towards autonomous car? what is your perception about autonomous car?
- If you are seated in today's rear seat of a car, what do you notice the most ? What does it lack ? What do you like to see changed/added/subtracted ?
- What are the main things in a cab that will influence the ambience ?
  - Sound
  - Light
  - Colour
  - Texture
  - Shape and size
- What kind of ambience would you like to have inside a taxi?
- If you spend 1 hr of the travelling, Do you prefer to optimize and be efficient and productive or relax ?
- Why would you choose Volvo over other car manufacturers ?
- What do you think Volvo's design language states ? What is it trying to convey to its customers?

### A.3 Interview responses

S.NO	NAME	Attitude towards AD	Perception about AD	What do you see the most from the rear seat of the car	What would you like to change w.r.t interiors ?	top three qualities that affects ambience	ambience picture preferred	efficient during travelling or to be relaxed ?	why choose volvo over other OEMs ?	what volvo's design language conveys to its customers?
1	Emil	Overall a positive outlook.	Will have a hard time to trust it and need a transitional time to adjust and become comfortable.	seeks for comfort. Checks door panel as he work with it. Does not notice much if he is travelling in a taxi , normally.	Campfire seating . Place to keep a laptop. An option to work if necessary.	Light. Texture . Shape & Form.	Cozy room ( Not too bright). Workplace Scenario.	Would like the opportunity to do both. But would like to relax than work.	Safety.	Leans towards comfort and safety. Not sporty. Not too much lines in the interiors , represent the cozy room.
2	Markus	He would like to try and nothing is holding him back.	Depends on the traffic around.	Usually looks out off the car. comfortable seats. stresses on how much he can look outside the car.	Store the things that carry in your hand (Coffee). more space (leg space) . Storage.	Shapr&form. Light. Sound	Depend on the time and context. Mornings - pleasant & cozy	Productive while going to work and relax while going back home	Safety.	Represent the cozy and pleasant pictures.
3	Pontus	Pretty Positive.	Eliminates human error. Needs a transitional period.	There are no specific things that is being noticed.	Leg space . More comfort	Sound, Smell, Light.	cozy room . Depends on outside weather. Workstation	Would like the opportunity to do both. Would like to relax watch short tv series. or if the hours can be taken into account , he will work.	Not really sure , if he would choose a Volvo if he did not work here.	Scandanavian design. Clean lines , no bright blue colors.
4	madeline	positive	convinient , efficient way of transport	seat comfort, leg space,	more comfort to rear seats, possibility to have face to face talk with co passengers, proper lights to work and read, charging ports for mobile,	light, sound, texture	workspace , pleasant green scene	both depending on where the person is travelling	scandinavian design, safe	comfort, safety and feels luxurious
5	erik	feel unsafe in the beginning, but will try	effective way of ransport, can do many works while travelling0	door panels, leg space	increase leg space , cozy seats, better armrest, foldable table,	sound, light , texture	relaxing environment,	depends on the situation, would like an option of changing ambience	safety,	clean lines, simple,
6	jonas	cant accept immedietly, but will try for sure	uses taxi very less, takes time to trust	door panel, roominess, luggage space, view through window/fr	roominess,	colour, smell, shape & form	need adaptable environment, changeable,	some entertainment but enjoy the ride	safety,	simple, more connection to natural materials
7	Ida	Positive.	Its a good thing if all th other cars are autonomous.	Space and vision outside . Mostly in the front.	Trash bag.Comfy seat.	Smell, Color ( lighter) , light.	workspace, (it is clean , and it knows what to do)	Relax and enjoy (has car sick).	safety	safe and comfortable.
8	Victor	Positive	Only thing holding back would other manua, drivers.	Leg space , storage.	Table to work at. easy ports to charge.	Light , Smell , texture.	workspace.	Relax.	Not really sure , if he would choose. volvo has mostly been a family friendly and safe car.	good feeling , nordic minimalistic design.
9	Hans	a little skeptical	will try once he trust the technology after several people have tried it out.	Leg space, head room , windows.	comfortable seating position , rest your head.	no Smell,no Sound,. Light colour texture	Pleasant , hammock.	Relax	Trust and Confidence.	Contrary , shophisticated.
10	Max	open but not trust worthy	Skeptical	Cleanliness(Smell) , seat feeling , check the driver.		sMELL, TEXTURE AND LIGHT	aeroplane . workspace	relax and enjoy music/movie	safety, scandinavian design	nature oriented, eco friendly
11	Gunnemar	Positive		cant see the front.	better ingress, comfort seats and adjust the seat heights.		Pleasant	Relax	safety & reliable	simplicity clean and intuitive .

Figure A.3: Interview Response

## A.4 Benchmarking data











Model	SPEAKER	DOOR HANDLE	ARM REST	WINDOW ADJUSTMENT SWITCH	CUP HOLDER	DOOR LOCK / UNLOCK SWITCH	SOUND PROOFING MATERIAL	TOTAL TRIM WEIGHT (INCL FASTENERS) KG	TRIM DIMENSIONS ( W*B*D)	PICTURE
Model 1	2	YES	NO	YES	YES	YES	YES	1,959	835*745*160	
Model 2	1	YES INTEGRATED WITH DOOR METAL	YES	YES	YES	YES INTEGRATED WITH HANDLE	NO	1,856	938*696*114	
Model 3	1	YES	YES	YES	YES	YES	YES	2,539	905*745*110	
Model 4	NO	YES	YES	YES	YES	YES	NO	2,707	890*735*165	
Model 5	1	YES	YES	YES	YES	YES	2	2,402	894*408*92	
Model 6	1	YES	YES	YES	YES	YES	1	2,904	872*750*152	
Model 7	NO	YES	NO	YES	NO	YES INTEGRATED WITH HANDLE	NO	1,555	962*733*63	
Model 8	NO	YES	YES	YES	YES	YES	NO	3,247	885*648/100	
Model 9	YES	YES	NO	YES	YES	YES	NO	2,513	1020*600*60	
Model 10	YES	NO	YES	YES	YES	YES	NO	2,716	848*720*135	

Figure A.4: Benchmarking data - basic information

A. Appendix - Market Analysis





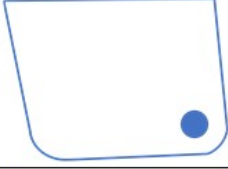


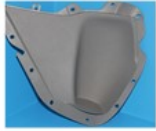























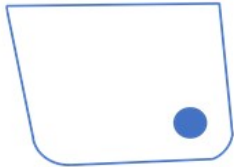



MODEL	SPEAKER	SPEAKER SHAPE AND POSITION	DOOR HANDLE	CUP HOLDER	ACTUAL VIEW
Model 1	2				
Model 2	1				
Model 3	1				
Model 4	NO	NO			
Model 5	1				
Model 6	1				
Model 7	NO	NO		NO	NO
Model 8	NO	NO			
Model 9	YES				
Model 10	YES				

Figure A.5: Benchmarking data - detailed information VI

## A.5 Requirement Specification

CUSTOMER NEEDS	The panel adapts to the period of the day	The panel accommodates sound system	The panel embarks the cabin to be bright / luminous	The panel feels spacious	The panel aids in reducing motion sickness	The panel is dust resistant	The panel is made of Odourless materials	The panel accommodates interface to navigate the vehicle	The panel allows ambient temperature adjustments	The panel provides user to have visual interface	The panel provides space for trash	The panel provides a way to charge electronics	The panel aids the user to work	The panel provides storage	The panel maintenance is low cost	The panel avoids the user from forgetting small items.	The panel should last for 3-4 years	The panel accommodates take-off, pull over and support buttons	The panel should be ECO designed	The panel's upholstery should be exchangeable	The panel provides context based illumination.	Percentage
The panel adapts to the period of the day	x	0.5	1	0.5	0	0	0	0	0.5	0.5	1	0.5	0.5	1	0	0	0	0	0	1	0	3.294
The panel accommodates sound system	0.5	x	0.5	1	0	0	0	0.5	0	1	1	1	1	1	0	0	0	0	0.5	1	0.5	4.471
The panel embarks the cabin to be bright / luminous	0	0.5	x	0.5	0.5	0	0.5	0.5	1	0.5	1	0.5	0.5	1	0.5	0	0	0	0	0.5	0.5	4.000
The panel feels spacious	0.5	0	0.5	x	0.5	0	0.5	0.5	0.5	0	1	0.5	0.5	1	0.5	0	0	0	0.5	0	0.5	3.529
The panel aids in reducing motion sickness	1	1	0.5	0.5	x	0	0	0.5	0.5	0	1	1	0.5	1	0	0.5	0	0	0.5	0	0.5	4.235
The panel is dust resistant	1	1	1	1	1	x	0.5	0.5	0.5	1	1	1	1	1	0.5	0.5	0.5	0	1	0.5	1	7.294
The panel is made of Odourless materials	1	1	0.5	0.5	1	0.5	x	0.5	1	1	1	1	1	1	0.5	1	0.5	0	1	1	0.5	7.294
The panel accommodates interface to navigate the vehicle	1	0.5	0.5	0.5	0.5	0.5	0.5	x	1	0	1	0.5	1	1	0	0	0	0	0.5	0	0	4.235
The panel allows ambient temperature adjustments	0.5	1	0	0.5	0.5	0.5	0	0	x	1	1	0.5	0.5	0.5	0	0	0	0	0	0	0.5	3.294
The panel provides user to have visual interface	0.5	0	0.5	1	1	0	0	1	0	x	1	0.5	1	1	0	0	0	0	0.5	0.5	0.5	4.235
The panel provides space for trash	0	0	0	0	0	0	0	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0.000
The panel provides a way to charge electronics	0.5	0	0.5	0.5	0	1	0.5	0.5	0.5	0.5	1	x	1	1	0.5	0	0	0	0.5	0.5	0	4.235
The panel aids the user to work	0.5	0	0.5	0.5	0.5	0	0	0	0.5	0	1	0	x	1	0	0	0	0	1	0	0.5	2.824
The panel provides storage	0	0	0	0	0	0	0	0	0.5	0	1	0	0	x	0	0	0	0	0.5	1	0	1.412
The panel maintenance is low cost	1	1	0.5	0.5	1	0.5	0.5	1	1	1	1	0.5	1	1	x	0.5	0.5	0	1	0.5	0.5	6.824
The panel avoids the user from forgetting small items.	1	1	1	1	0.5	0.5	0	1	1	1	1	1	1	1	0.5	x	0	0	1	1	1	7.294
The panel should last for 3-4 years	1	1	1	1	1	0.5	0.5	1	1	1	1	1	1	1	0.5	1	x	1	1	0.5	1	8.471
The panel accommodates take-off, pull over and support buttons.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	x	1	1	1	1	8.941
The panel should be ECO designed.	1	0.5	1	0.5	0.5	0	0	0.5	1	0.5	1	0.5	0	0.5	0	0	0	0	x	0	0	3.529
The panel's upholstery should be exchangeable	0	0	0.5	1	1	0.5	0	1	1	0.5	1	0.5	1	0	0.5	0	0.5	0	1	x	0	4.706
The panel provides context based illumination.	1	0.5	0.5	0.5	0.5	0	0.5	1	0.5	0.5	1	1	0.5	1	0.5	0	0	0	1	1	x	5.412

Figure A.6: Weight Matrix for Customer Need Statements



# B

## Appendix - Concept Generation & Evaluation

### B.1 Idea Elimination Matrices





Elimination matrix										
Concept		Elimination criteria:							Comment	Decision
		1	2	3	4	5	6	7		
		Solves main problem	Fulfills all requirements	Feasibility	Reasonable cost	Safe (Human/Societal)	Fits Volvo's portfolio	Enough information		
Spring activated handle		●	●	●	●	●	●	●		Passed
Conventional door handle		●	●	●	●	●	●	●		Passed
Pop out handles		●	●						Requires maintenance, handle needs to be restored in neutral position everytime after use	Eliminated
Projection in the trim		●	●						Trim upholstery might wear, interference with door flange while sliding	Eliminated
Gripping surface		●	●	●					User tends to put force in Y-dir for grip, not ideal when wearing gloves	Eliminated
Hollow projection in trim		●	●						System complexity increases and the technology is still in an infant stage , high cost	Eliminated

Figure B.1: Idea elimination matrix for door handle

## B. Appendix - Concept Generation & Evaluation

Elimination matrix										
Elimination criteria: ● Pass concept ● Eliminate concept (?) Search for more information (!) Check requirement specification										
		Solves main problem	Fulfills all requirements	Feasibility	Reasonable cost	Safe (Human/Societal)	Fits Volvo's portfolio	Enough information		
Concept		1	2	3	4	5	6	7	Comment	Decision
Sealed ( blends with panel seamlessly)		●	●	●					Complex to manufacture, costly to maintain, whole panel carrier needs to be replaced when screen has issues.	Eliminated
Pops out ( by customer)		●	●	●	●				Requires continuous maintenance, more prone to breaking, may interfere with door functionality (if display is restrained)	Eliminated
Attached ( serice)		●	●	●	●	●	●	●		Passed
Sealed ( blends with panel seamlessly)		●	●	●	●				Maintenance cost is high, system complexity increases, not easy to clean , prone to break and interferes with door functionality	Eliminated
Integrated in mobile app		●	●						Out of scope	Eliminated
Glass projection		●	●	●	●				System complexity increases and the technology is still in an infant stage , high cost	Eliminated

Figure B.2: Idea elimination matrix for digital screen

Elimination matrix										
Elimination criteria: ● Pass concept ● Eliminate concept (?) Search for more information (!) Check requirement specification										
		Solves main problem	Fulfills all requirements	Feasibility	Reasonable cost	Safe (Human/Societal)	Fits Volvo's portfolio	Enough information		
Concept		1	2	3	4	5	6	7	Comment	Decision
central speaker		●	●						Out of scope	Eliminated
head rest speaker		●	●						Out of scope	Eliminated
door panel speaker		●	●	●	●	●	●	●		Passed

Figure B.3: Idea elimination matrix for speakers

Elimination matrix									
Elimination criteria: ● Pass concept ● Eliminate concept (?) Search for more inform (!) Check requirement spe									
	Solves main problem	Fulfills all requirements	Feasibility	Reasonable cost	Safe (Human/Societal)	Fits Volvo's portfolio	Enough information		
Concept	1	2	3	4	5	6	7	Comment	Decision
roof	●							Out of scope	Eliminated
screen button	●	●	●	●	●	●	●		Passed
door panel	●	●	●	●	●	●	●		Passed
in mobile app	●							Out of scope	Eliminated

Figure B.4: Idea elimination matrix for buttons

Elimination matrix									
Elimination criteria: ● Pass concept ● Eliminate concept (?) Search for more inform (!) Check requirement spe									
	Solves main problem	Fulfills all requirements	Feasibility	Reasonable cost	Safe (Human/Societal)	Fits Volvo's portfolio	Enough information		
Concept	1	2	3	4	5	6	7	Comment	Decision
strips of LED for door panel	●	●	●	●	●	●	●		Passed
reflective door panels	●	●	●					prone to scratches , high maintenance	Eliminated
illuminated door panels	●	●	●					High maintenance, not durable and not easily replaceable	Eliminated

Figure B.5: Idea elimination matrix for Charge ports

## B.2 Concept Drawings

### B.2.1 Concept Sketches

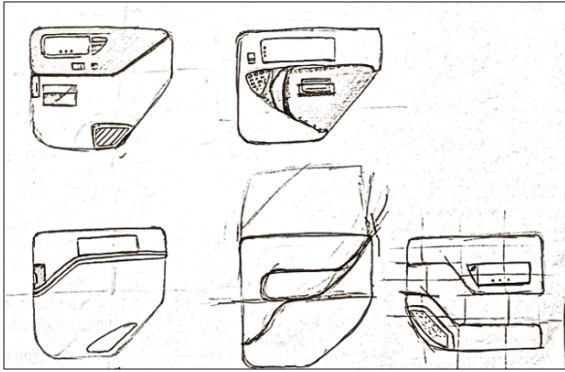


Figure B.6: Concept Sketches 1



Figure B.7: Concept Sketches 2

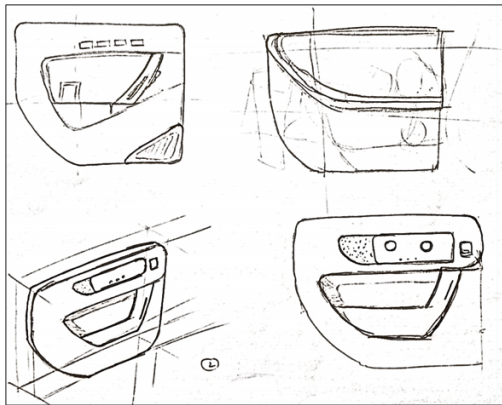


Figure B.8: Concept Sketches 3

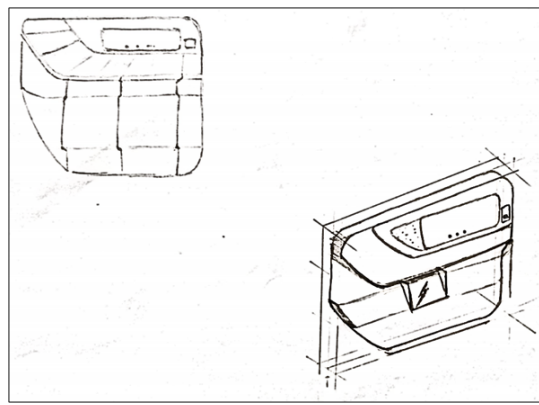


Figure B.9: Concept Sketches 4

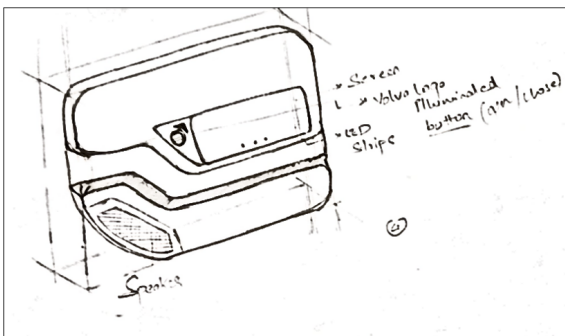


Figure B.10: Concept Sketches 5

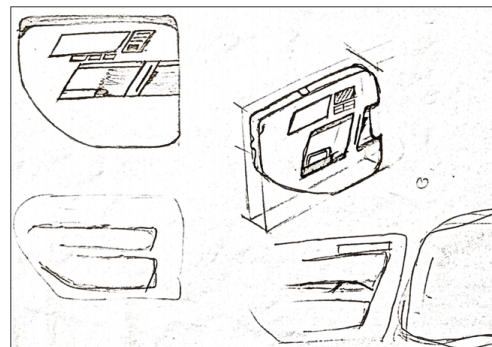
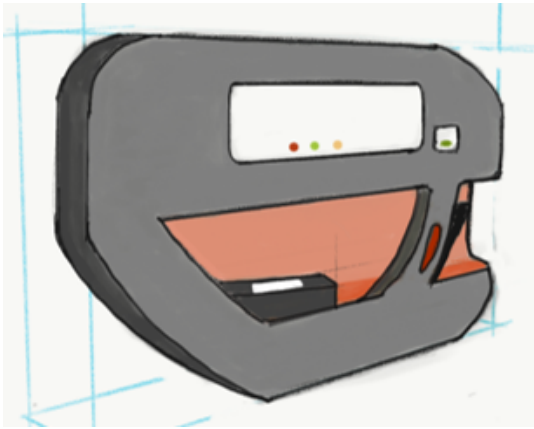


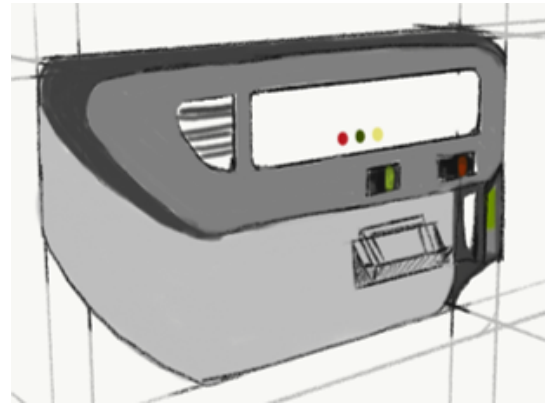
Figure B.11: Concept Sketches 6

### B.3 Digital Concept Sketches



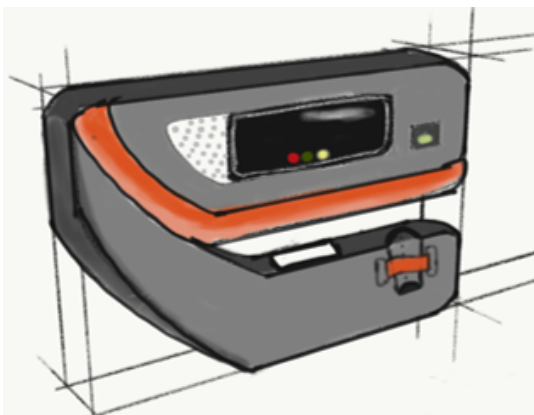
**Figure B.12:** Concept: The Block

Naming the concept 'The block' was mainly because of its simple, fundamental features and lack of modern styling. The concept intended to provide most of its functionality through a interactive screen but the emergency button as a physical feedback button. The contextual lighting is provided on the handle bar.



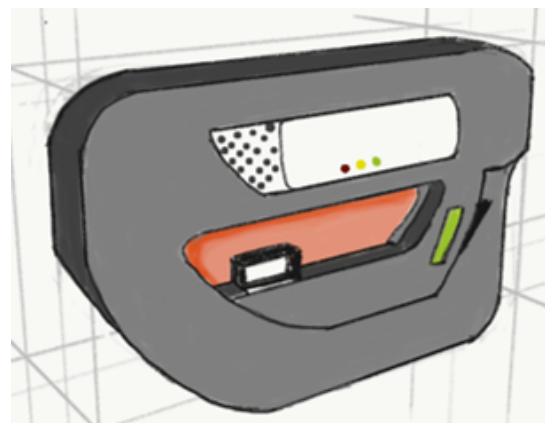
**Figure B.13:** Concept: Float Handle

Float handle got its name mainly because of the fact that the handle seems to float on one end as seen in the picture. The concept aimed to reduced the thickness of a door panel. Two physical feedback buttons were provided, where one was used as an emergency button and the other as a customer service interact button for emergencies.



**Figure B.14:** Concept: Inspiration

The concept 'Inspiration' styling was mainly inspired by Volvo's Design language. As in the concept 'The block', it has one physical button and a interactive display with other functions. The speaker is aligned alongside the display for a clean design. The concept does tend to be daring and futuristic by not having a handle bar.



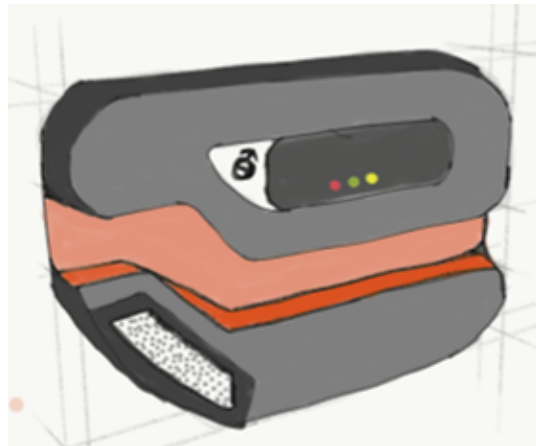
**Figure B.15:** Concept: Mirage

Mirage is an evolution of the concept 'The Block' in terms of styling. The concept was developed to have the complete door panel made of two parts, i.e the door panel and the handle & storage part. Here the emergency button is integrated into the interactive display itself.



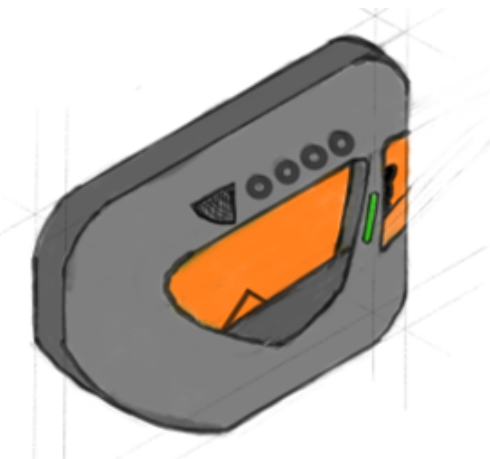
**Figure B.16:** Concept: Powermat

'Powermat' got its name due to the fact that it charges the mobile devices via a wireless mat place vertical on the door panel. A small ridge is provided to place the mobile device for charging. The concept has no interactive displays, in order to reduce cost. Instead the functions such as open/close, start/stop & emergency are activate through physical buttons.



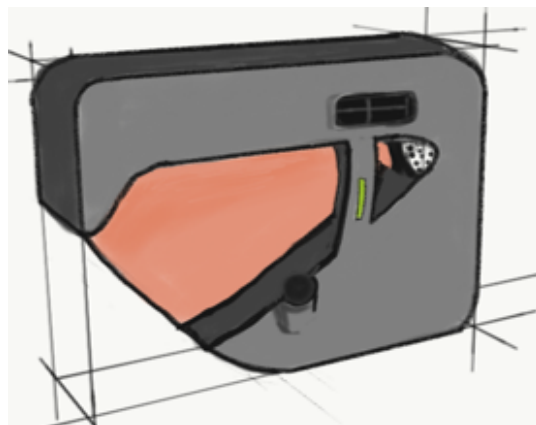
**Figure B.17:** Concept: 2030

The concept '2030' derives its name due to its futuristic features. The styling tend to be minimalist and subtle. The interactive display consists most of the functionalities, where as a button inform of the Volvo logo is used for emergency scenarios.



**Figure B.18:** Concept: The Basic

'The Basic' as the name suggest, is a basic combination of the cost effective ideas developed in previous stages. It consists of buttons to provide functionality to the door instead of a display and speaker effective for voice interaction and audio commands by the taxi.



**Figure B.19:** Concept: The Beak

'The beak' was created with an intention to use less material and volume. The name was derived as its design inspired by a bird's beak. The tip of the beak consists of the speaker and the panel has 4 buttons to provide functionality .

## B.4 Concept Scoring



Figure B.20: Individual Criteria Evaluation for Powermat

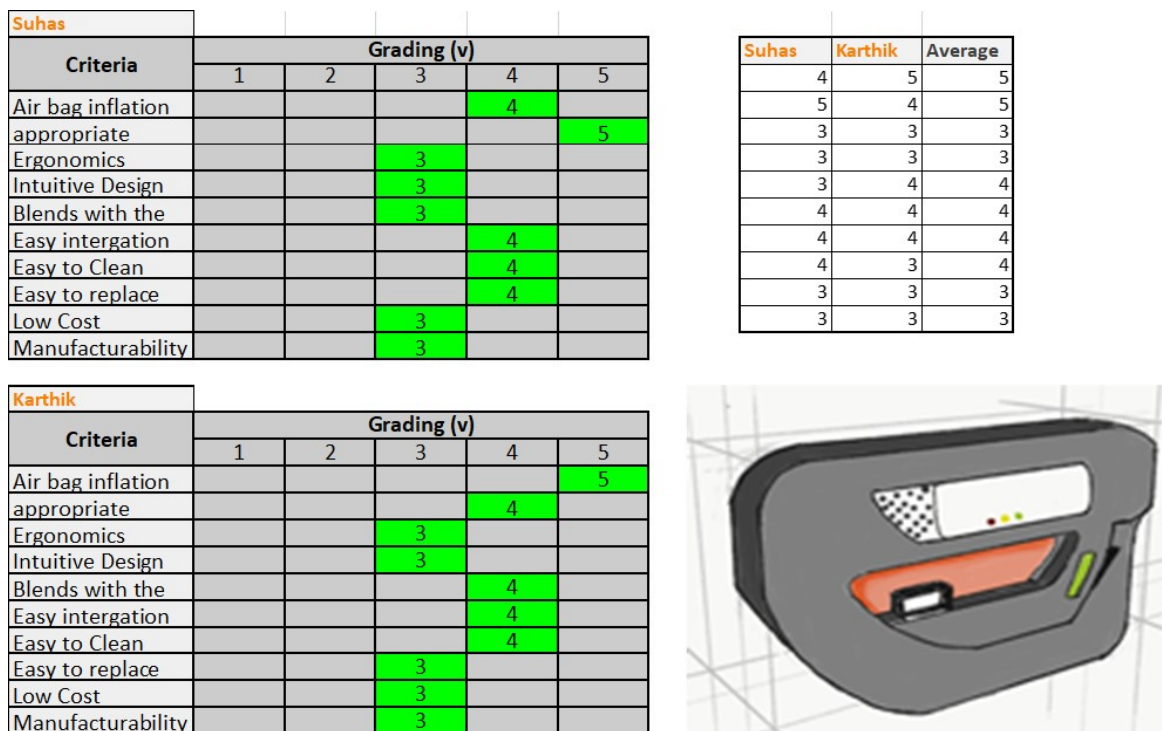


Figure B.21: Individual Criteria Evaluation for Mirage

B. Appendix - Concept Generation & Evaluation

Suhas					
Criteria	Grading (v)				
	1	2	3	4	5
Air bag inflation appropriate			3		5
Ergonomics				4	
Intuitive Design				4	
Blends with the			3		
Easy intergation		2			
Easy to Clean			3		
Easy to replace			3		
Low Cost		2			
Manufacturability				4	

Suhas	Karthik	Average
3	4	4
5	5	5
4	3	4
4	4	4
3	5	4
2	4	3
3	4	4
3	3	3
2	3	3
4	5	5

Karthik					
Criteria	Grading (v)				
	1	2	3	4	5
Air bag inflation appropriate				4	5
Ergonomics			3		
Intuitive Design				4	
Blends with the					5
Easy intergation				4	
Easy to Clean				4	
Easy to replace			3		
Low Cost			3		
Manufacturability					5



Figure B.22: Individual Criteria Evaluation for Inspiration