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Stowage Concepts for a Future Autonomous Car

A detailed engineering study on luggage holder concepts in the cabin area that is safe, convenient to use and sustainable

Master's thesis in Materials Engineering and Product Development

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Department of Industrial and Materials Science
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Gothenburg, Sweden 2019

Master's thesis 2019:NN

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Abstract

Autonomous vehicles are reshaping the way car interiors are designed today. With radical concepts for interiors being launched, the luggage brought into the car by the passenger raises new safety issues. This thesis is an exploration of design concepts for luggage retention solutions that could meet the demands of different usage scenarios of an AD (autonomous drive) car. Based on surveys, interviews, literature review and benchmarking, the team established the requirements from customer, company and market perspectives which was then referred to generate the morphological matrix. Using this, 22 concepts were developed. These concepts were put through rigorous screening and scoring until it was concluded to pursue three concepts for further development. The top two concepts were combined into one solution and pursued as the main product design for detailed engineering study. Another concept was also developed into a solution due to it being a unique and patentable product. The two solutions were drawn using CAD and the choice of material for each component was investigated with emphasis on cost and sustainability. Further, the designs were updated for ease of assembly and the time to assemble the product was estimated. For the final evaluation, working prototypes of the solution were fabricated and installed in the AD test rig.

Acknowledgements

This thesis work was made possible in no small part due to the valuable contribution of several people - at Volvo Cars and elsewhere - with different areas of expertise. It is not possible to sufficiently extend thanks to everyone with the proper adulation they deserve but here we mention the most important ones.

We would like to start by thanking our supervisor at Volvo, *John Eriksson* for his guidance and invaluable support without which we might have floundered along the way. We are grateful to our thesis examiner at Chalmers, *Gauti Asbjörnson* who followed us closely through every step of the project and provided constant feedback that ensured that we gave the best we could. We heartily thank our manager, *Emma Mårtensson* who provided us with the resources and guidance required. We would not have felt as welcomed as we did without her.

We are extremely grateful to the entire team at *Occupant Safety* and the *Concept Center* for sharing their expert knowledge with us. All the people involved in the Autonomous Car project deserve a special mention for sharing valuable information required for executing the thesis and so do the survey respondents who took out some of their time to answer our questions and write detailed comments. We cordially thank *William Hübinette*, a wonderful CAE engineer and a fellow thesis worker without whose constant company and jokes we would've left work much sooner.

We express our gratitude to *Spotify* without which this report would have still been written, but less enthusiastically. We also extend our gratitude to *StackExchange* forums for LaTeX, *LaTeX TableGenerator*, *Mathcha*, and *LaTeX colors* without which this report would not have looked so pretty. The door to *Volvo PVH pantry* was always open and provided us with coffee which was our nectar on long evenings. We would like to thank *God* (or as Anirudha calls it *The Laws of Science that Guides the Universe*) for creating language, civilized society, and vegofärs.

Finally, with equal (if not greater) importance, we extend our thanks to our friends and family. We won't mention you individually because you know who you are (also because one of you mentioned GDPR or something).

Thanks for believing in us!

Anirudha Chandraiah Shivappa *Sangeeth Gandhi*

Gothenburg, July 2019

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Chapter 1

Introduction

This chapter is intended to familiarize the reader with the thesis background, scope and limitations as well as the company- Volvo Car Corporation. The thesis deals with technology and platforms that the company has not yet made public, it is a tricky matter to convey all the useful and relevant information without revealing sensitive data. The writers have taken it upon themselves to ensure the integrity of the document without sacrificing the content matter that is crucial to this thesis.

For the purposes of readability, Volvo Car Corporation will be referred to as *Volvo, Volvo Cars* and *VCC*, while the authors will be referred to as *the team* as suitable throughout the document.

1.1 Thesis Aim

Volvo is entering a new challenge with autonomous cars and needs to prepare for new safety concerns. In order to enhance convenience for customers traveling in an autonomous car, the car cabin should be able to accommodate the luggage brought in by all passengers. The principal aim is to investigate innovative concepts for luggage holders after obtaining an understanding of customer needs and usage behaviour. The design of the luggage holder shall be based on the interior layout that is under development at Volvo at the time of conducting this thesis. The concepts should be extremely simple so that passengers recognize it instantly and are willing to use them. Previously, Volvo has developed many clever storage solutions for the cabin such as the hook for food take-aways, card holder and large door bins as seen in the XC40 model launched in 2017. In this thesis, however, a deep investigation of storage concepts exclusively for the autonomous car shall be conducted. The storage solutions will be developed from a safety perspective so that they can function as restraints and minimize damage to passengers in case of a crash.

1.2 Thesis Delimitations

There was a strong motivation by the team to apply sustainability principles which was also in line with Volvo's vision for having 25% recycled plastics in the interiors by 2025 [1]. CAE testing and safety simulations shall not be conducted on the different concepts. Complex concepts shall not be delivered due to uncertainty with the perception of usability. As the interior layout of the car was not yet fixed, the team focused on investigating concepts that were independent of any features of the car and could be transferable.

After one of the interviews, the team also decided to exclude aesthetics from the scope of the thesis as the design expert suggested to the team that once the concepts are finalized, the design team could be tasked to glamorize the solution.

1.3 Volvo Car Corporation

Volvo Car Corporation is a Swedish premium car manufacturer that has a people-centred approach to its business. Headquartered in Gothenburg, Sweden, Volvo sells in more than 100 countries and has its main production plants in Torslanda (Sweden), Ghent (Belgium), Charleston (USA) and Daqing (China) [2]. The three core values of Volvo- Quality, Environment and Safety were the top focus to the team as well. This along with Volvo's modern Scandinavian design philosophy was absorbed and applied through all stages of the thesis work.

Volvo has always been synonymous with safety. Some of their inventions include the laminated windscreen to protect the driver from breaking glass, introduction of the three-point safety belt that has saved millions of lives since 1959 and the most recent one being the lane keeping assist with automated steering. Volvo's commitment to safety has been in place even before government safety regulations existed. It is now taking this commitment to the next level with the Safety Vision 2020 principle- To ensure that by 2020 no one should be killed or seriously injured in a new Volvo car [2]. This thesis work was carried out at the *Occupant Safety Department* that works with designing safety features for both the passengers and cargo in the interiors of the car. Multiple safety features are present in today´s Volvo cars that are designed to minimize the severity of the injuries caused by an accident. Some of these features are completely designed as safety components and can be easily identified, for example- airbags or seat belts, while others have a multifunctional role and are often not perceived as such, for example- instrument panel or seats. The paradoxical beauty an occupant safety engineer faces in their everyday work, is not only to understand how these safety components work by themselves, but to create a balanced and optimized safety system where they all work together at their best.

Chapter 2

Background

In this section, a list of useful terminology will be described in order to help readers better understand the concepts. The standards of autonomous driving will be explained and some interior concepts of current scenarios as well as future expected scenarios shall be presented.

2.1 List of Terms

ADAS

Advanced Driver Assistance Systems are electronic systems installed in a car to assist driving either through controlling the car itself or providing indications to the driver. Examples include lane assistance, anti-lock brakes, adaptive cruise control and traction control.

TaaS

Transport as a Service describes the trend in moving away from ownership of modes of transport to consuming mobility solutions as a service when needed. It is a shift from the current transport model which is inefficient and costly to a model based on shared economy.

Kano Model

The Kano model is a method that is used to visually represent a customer requirement and categorize it into different types. It can be seen as a way with which the impact of different customer requirements on their satisfaction can be represented [3]. The Kano model provides a simple and effective way to compare different aspects of a product relative to each other. A diagram of the Kano model can be seen in Section 2.3

AD rig

The Autonomous Drive rig (AD rig) is a test apparatus that emulates an autonomous driving car and is used by Volvo to test different interior setups, ride scenarios and collect data about user experience.

MTM Technique

Methods time measurement technique is used in industries to analyze the methods involved in performing a manual operation and set a standard time for completing a task. This time value is used in accounting and further estimating cost of production.

TMU

TMU stands for Time Measurement Unit, which is a method for estimating how much time a manual operation or task takes to perform. Normally used in assemblies and industrial settings. The TMU can provide the time that is expected for a particular process to complete in relation to complexity and/or skilland such can be used to estimate the cost of a process.
1 TMU = 0.036 seconds

2.2 Autonomous Driving

An autonomous driving car is equipped with technology such as cameras, radars, lidars and ultrasonic devices to sense its environment and move on its own without the need for human control. Autonomous vehicles follow several classifications and definitions, but the commonly used one is provided by the Society of Automotive Engineers, USA. The following table shows the classification of vehicles based on their autonomous capabilities [4]:

Table 2.1: Levels of driving automation

Level	1	2	3	4	5
Role	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation
Detail	At least 1 ADAS feature	2 or more ADAS	Can take full control only under certain conditions	Can take full control within specified operating criteria	Completely driverless under all condition

AD technology has the potential to decrease traffic congestion, reduce the number of accidents and also improve the way city landscapes are planned. These promising benefits are the reason why automotive companies are making rapid progress in developing this technology. For example, 94% of all serious crashes are due to human error [5]. By eliminating the need for a human driver, many accidents can be prevented and lives saved. Several automotive companies have come up with innovative and radical concepts that try to re-imagine what the car can be. Even though many concepts have been in development since the early 80's [6], it is only in the past few years that autonomous cars have been realized. The Tesla autopilot systems that offer autonomous driving level 3 came out in 2015.

AD technology is not fully perfected and faces challenges in conditions that deviate from normal (snow, rain etc.) due to limitations from sensors and cameras. Adopting it should be done through careful investigation of all safety concerns. In this thesis, the team addressed one of the key concerns of passenger safety- loose items in the cabin. Since there is no driver in an AD car, there is no one to ensure that the passenger has secured their luggage safely. In the event of a crash, even though the crash impact itself was not fatal, the passengers could be seriously injured. This puts the liability on the car maker to provide storage and luggage retention solutions.t

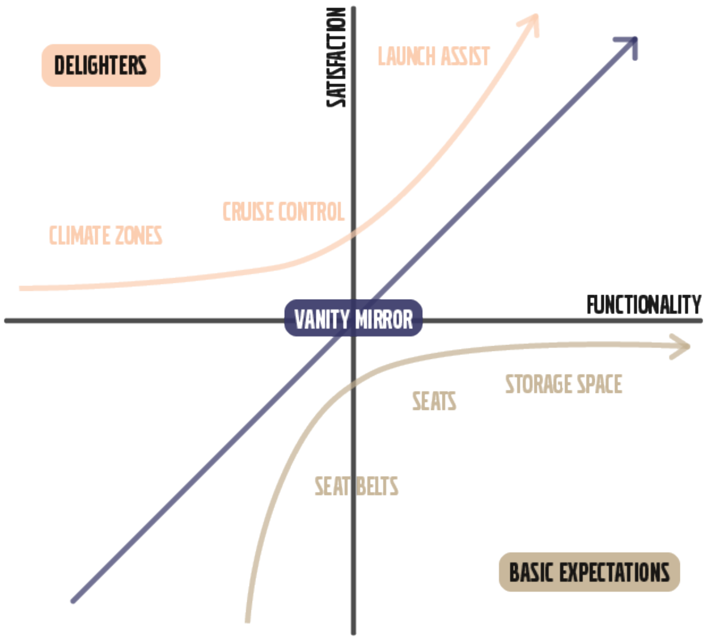

Figure 2.1: Kano model for features in a car

2.3 Interior Stowage

A commuter when sitting in a car interacts with different elements of the cabin as well as with other passengers. This interaction is complicated when the seating layout is different from normal like in buses where passengers in some seats sit face-to-face with strangers. To ensure a successful product, the team explored these social aspects in the process of brainstorming. Based on trends such as the Transportation-as-a-Service (TaaS) [7] and statements made by other car manufacturers, AD cars in the future can also be used for shared vehicles and public transportation. Under these circumstances, developing a concrete solution with a high degree of usability is necessary. Stowage spaces to put daily use objects such as a mobile phone, coffee cup, laptop bag or even larger bags (cabin bags, gym bag etc.) are some of the features in a car that have an irregular usage pattern. For example, some customers will always put their bag on the floor while some keep it on the seat next to them or even on their lap. This high degree of subjectivity demands a solution that is intuitively located so that anyone who wants to use it can identify it easily but when not needed, it should not disturb the passenger. This can be explained through the use of a Kano model as shown in figure 2.1. Current storage solutions in the car interior such as the storage compartment in the door do not have a restraint for the object and are restricted on the shape and size of the item that can be stored in them.

There is a growing trend with car interiors going towards eliminating cluttering in the cabin and having continuous and fluid surfaces. With this in mind, the team conducted a market research on current trends as well as future trends in the way stowage solutions are provided in car interiors. Few illustrations are discussed in detail in sections 2.4 and 2.5. In public vehicles, such storage spaces are limited and usually occupied on a first come first serve basis. The technical challenge addressed in this thesis is to utilize the cabin interior space in such a way that a dedicated luggage retention solution is provided for each passenger that does not cause any inconvenience to them. Making it adaptable to all types of luggage was the ideal goal. The available spaces in a car interior are listed in Appendix D, some of them are not equally accessible from all seats. For example, the passenger in the middle seat cannot utilize the door compartments conveniently as they have to reach out for it. It also creates a feeling of insecurity for the middle seat passenger who put their bag next to the door while there is another passenger sitting on the side seat closer to their bag.

If the team develops the safest luggage restraint but it turns out to be very complex to use, then it will not be implemented as a solution. When the car is not fully occupied, a passenger will put their items on the adjacent empty seat which is dangerous for the person sitting on the opposite side as the item can fly and cause serious injury in the event of a crash. This is very likely as there is no driver to ensure that all passengers have complied with the requirements on restraining luggage. The intuitive interiors of the car should essentially lead the passenger to naturally put their luggage in the designated storage space.

2.4 Shared Mobility: Current Trends

Partition between the driver seat and passenger area, modifications for easy ingress and maximized seating are some of the commonly seen traits in shared transport vehicles such as buses, trams, metros etc. Here the team describes two such examples showing modifications made to a standard car in order to make it suitable for shared transports.

London Cabs

The most well known taxi is the black London Taxicab. LEVC launched the 6 seater electric TX cab in 2019 which has a 3 by 3 face-to-face seating arrangement for the passengers. The front row seats, as seen in figure 2.2 fold up when not in use and the space available can be utilized to accommodate strollers, wheelchairs or even large bags. The safety concerns are virtually the same as that for a regular car when there are 3 or less passengers and all of them choose to sit in the rear seats. Due to the short wheel base, the distance between the knees of the passengers sitting in opposite seats is less and dangerous. The space next to the driver seat here is used for luggage storage and does not come with any restraining mechanism. This however does not raise concerns to the passengers as there is a vertical partition between the luggage area and the passenger area.

Figure 2.2: Interior view of LEVC TX4, obtained from the LEVC TX visualizer [8] (2019)

VW Berlin Taxi

A concept from Volkswagen from 2010 shows a car with a unique interior [9] aimed to be an airport pick up cab. Here the space next to the driver's seat is utilized to hold two cabin bags. The luggage is secured safely by the grill around the storage platform and can be seen by the passenger at all times. The customer does not need to store their luggage in the trunk and can instead enter the cabin directly where there is place for their luggage. This benefit of convenience could definitely raise customer satisfaction and the team has picked up on this idea. The concept was mainly intended to be used as an airport taxi and was therefore designed for 2 passengers with cabin luggage. The concept is similar to the London Cab except that in this case, the space for the cabin bags are explicitly defined and have a securing mechanism. Since the scope of this thesis was to design a luggage holder that is more for a general purpose, emphasis was laid on an interior setting with maximum number of seats.

Figure 2.3: Interior view of VW Berlin Taxi (2010)

2.5 Shared Mobility: Future Concepts

Volvo's 360c concept - a fully autonomous and electric solution is intended to taxi people from A to B in a comfortable and efficient manner. One use case of this concept is for a single business passenger as a an alternate instead of short-haul flights that are a hassle. Another use case is when the car is envisioned as an office/ house on wheels where people can socialize or have meetings. This case is of particular interest to the team because of the new safety concerns. Loose objects, in the case of a frontal collision, can fly and hit a passenger sitting on the rearward-facing seat. With this in mind, the team performed a market analysis to find different competitors that have explored similar seating arrangement and understand how they provide luggage restraints. The specific design layout and packaging solution was explored for three different concepts. Although there were many more concepts in the market, the team studied only the below three as the focal question was luggage storage solutions in the cabin rather than the layout itself. [10].

NAVYA: Autonom Cab

NAVYA, is a start-up that already has two models- the autonomous shuttle and the autonomous taxi available in the market. The company claims to have released the first Robotaxi in the market. The autonomous cab has more interior space since it removes the need of a driver and the cabin. It also has a 'campfire' seating arrangement (as seen in figure 2.4 below). The interior is however quite simple and does not have storage solutions to secure cabin bags or other things that passengers bring with them. Due to its long wheelbase and resulting spacious interior, based on intuition, the team thinks that people would keep their belongings on the empty seat nearby or on the floor, if all seats are occupied. To tackle such a situation, the team brainstormed to produce concepts which are intuitively located and easily accessible for use by the passenger.

Figure 2.4: Interior view of NAVYA Autonom Cab, from the 88th Geneva International Motor Show [11]

Mercedes Benz: Vision Urbanetic

This concept has a circular park bench seating arrangement. It is interesting to note the absence of a trunk. It was not mentioned explicitly on the company website about a dedicated storage solution but, from the videos and pictures describing the concept, the team gathered that the cockpit area at the front end (where the instrument panel would be located in a traditional car) could be used as a storage space. This, however, raises questions about safety if the luggage is not tethered in any way. A protective safety net, textile cover or steel grille could do the job of preventing the luggage from being thrown into the passenger area but due to the complex shape of the car, it might not be feasible. Another concern with this design is that the storage space is at a common spot for all passengers instead of being available at each seat, in other words, it is not personalized. This means that the passenger sitting close to it will be constantly disturbed by other passengers who want to place/ take their luggage. The team realized that this inconvenience could affect the ride satisfaction of the passengers and therefore tried to brainstorm for concepts focused on personalized solutions.

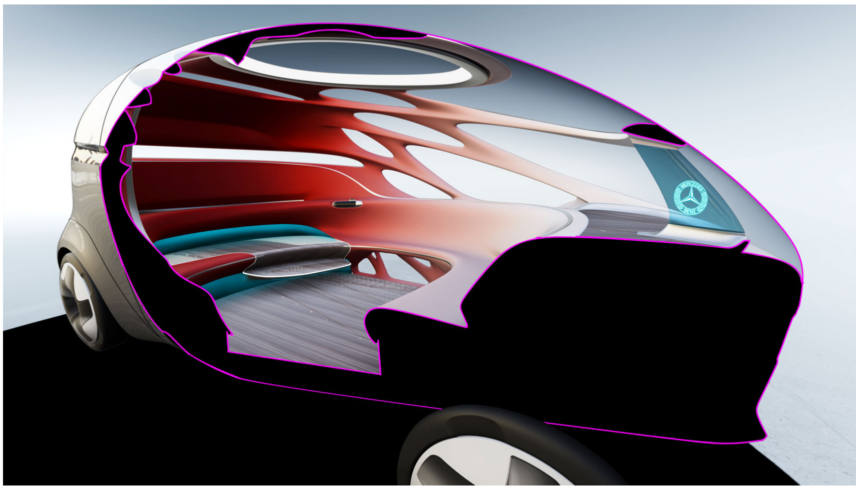

Figure 2.5: Interior view of Mercedes Benz: Vision Urbanetic with bench seating

Renault: EZ GO

This was the most disruptive concept and also the only one that addressed the problem of luggage storage in the cabin area. Firstly, it has a door that opens vertically upwards and the seats are designed very close to the side walls thereby creating free space in the central area and also enhancing social interaction. It has dedicated benches for placing luggage with belts to secure them as seen in figure 2.6. This spot is easily reachable for the passengers when they enter and exit the car without creating an inconvenience for other passengers. However, one thing remained unclear to the team- the lack of seat belts for the passengers, which could indicate that the car is designed for low speeds and hyperlocal applications.

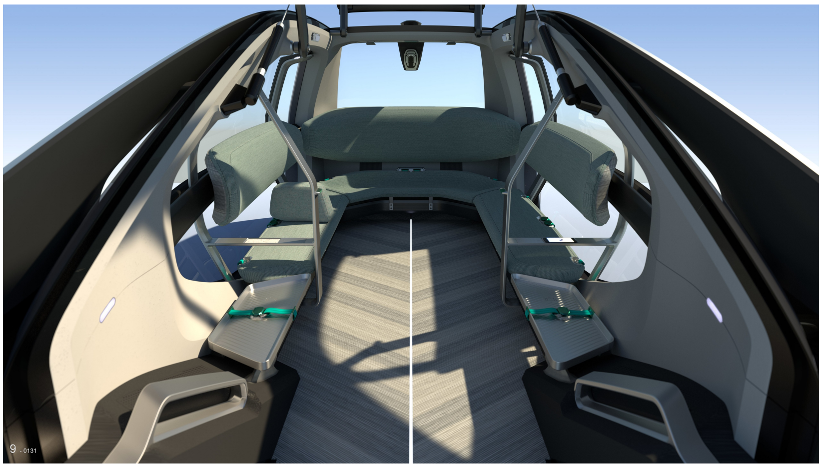

Figure 2.6: Interior view of Renault: EZ GO

Tesla Autonomous Car

A recent addition to this list is the vision that Tesla Inc. has for its fleet of cars. Announced on the 22nd of April, 2019 during the first Tesla Autonomy day, it envisioned current and future production Tesla vehicles to be able to autonomously work as a taxi fleet when the car is idle (i.e. when the owner of the car does not have any use for it).

Tesla estimates that ordinarily a car is only used for around $\frac{1}{10}$th of its life. This model (of allowing the car to operate itself as a taxi) would improve the useful life of the car, with it being in operation for at least $\frac{1}{3}$rd of the time. [12]. Although most analysts dismissed the time frame provided (around a year and three months), some critics such as Uber find this to be where automotive companies are eventually heading [12]. This may bring a huge shake up in the automotive industry.

Other notable players, who have begun active tests in the autonomous vehicle sector include Waymo, Uber, Ford and GM.

Chapter 3

Methodology

This chapter is intended to provide a description of the various steps and processes performed in the thesis. The sequence of items listed in this chapter also follows the sequence used while conducting the thesis work. The main phases include Data Collection, Data Evaluation, Concept Generation, Scoring, Advanced Design and Prototyping.

An initial plan to perform the thesis was laid out before the start of the project work. However, after familiarizing with Volvo and getting updated about the status of the Autonomous Car project, the team came up with additional methods and tools that could also contribute to the thesis and decided to accommodate them. The final methodology with which the team carried out the thesis is as described below.

3.1 Data Collection Tools

The first order of business as mentioned above was to gain as much knowledge as possible about the Autonomous Car project. All the attributes demanded from a luggage retention solution were studied and those relevant to this thesis were picked for further investigation. Next, to identify the current market, trends and requirements, the team applied both qualitative and quantitative methods of study. Table 3.1 mentions the approaches used in this thesis.

Table 3.1: Summary of methods used

Methods of Data Collection	Types of Data Collection	
	Qualitative	**Quantitative**
Surveys	x	x
Semi-structured interviews with experts	x	
Literature Review	x	x
Competitor Analysis	x	

1. Interviews
   Experts within the picked attributes as well as stakeholders (both internal and external to Volvo) were interviewed for roughly 30 minutes each. These people are closely associated to the project and gave the team a good overview of the purpose and hurdles with developing a solution that a customer will proactively use. The

requirements from stakeholders was also made clear to the team during the interviews. The interviews kept progressing throughout all stages of the thesis.

2. Travel Habit Survey
Since autonomous driving is not yet mainstream, there is no data available about customer requirements with regards to stowage in the cabin area. Hence, the team designed a general survey to understand the expectations from customers and their travel habits specifically, the items are carried by by them during their daily commute.

3. Literature Review
Research papers, journals, educational resources on the Volvo intranet, past theses, news and online articles were studied to build up on previous research as well as understand the complexities involved in acceptance of autonomous technology.

4. AD Experience Workshop
A workshop was organized by Volvo where a sample set of people were invited to experience riding in an autonomous vehicle. Different passenger scenarios were emulated and and detailed feedback was collected. Feedback data concerning luggage storage were included for this thesis work.

3.2 Concept Investigation Tools

After all the data was accumulated and evaluated, the team moved to the next stage of brainstorming to produce ideas and develop them into concepts. The tools used were:

1. Morphological Matrix
A list of sub-functions that needs to be performed by the product were defined and the morphological matrix was created having 6 options to realize each sub-function. The initial matrix went through several revisions till the one provided in table 5.1 was arrived at.

2. Lotus Method
There were several brainstorming sessions for defining the morphological matrix and also for generating ideas for different concepts. The Lotus Method tool was used to have a well-structured approach. The central theme or problem was selected and written down. After brainstorming, eight solutions or complements were identified and listed around it. Each of these solutions were further used as the center of the lotus and eight more associations were made. In this way a vast number of ideas were generated.

3. Focus Groups
The concept sketches were presented to different focus groups at Volvo in order to gain feedback and see if it was relevant to the company. Their inputs and suggestions were taken to rework and update the concept designs as can be seen in section 5.3

4. Pugh Matrix
The Pugh Matrix is a simple and effective way of scoring concepts based on certain key criteria. The Key Criteria might be identified from customer requirements,

stakeholder needs or even set by the team making the matrix themselves. Ranking the Key Criteria in order of importance (i.e. on a percentage scale) enables the comparisons to be seen as numerical values. This is also sometimes referred to as a Kesselring Matrix.

3.3 Methodology for Detail Design

The final part of the thesis was to develop the luggage retention solutions and make prototypes. The product designs were developed in CAD using CATIA. Material selection was performed using CES Edupack as well as by comparison of commercially available materials for similar engineering applications. The assembly time and cost was estimated using the MTM (Method Time Measurement) technique (refer section 2.1). Basic motion elements (also known as therbligs) are used in describing the various actions undertaken by an operator in the process of assembly. The basic motion elements used in the assembly of the thesis concept are provided in table 7.1.

Chapter 4

Data Evaluation

This chapter provides the reader with a comprehensive list of all the data collection methods (both qualitative and quantitative) as well as an analysis of the outcomes of the data collection. Further data can be found in the appendix.

It is good to note that not all analysis results have been published in this thesis in order to protect Volvo IP.

4.1 Interviews

The team briefly summarizes each interview here.

A. Jonas Göthlin, Senior Expert- Interior Studio Engineering

As the design head for the Autonomous Car project, Jonas gave the team insights into the design philosophy followed by Volvo.

The team conducted two interviews with Jonas. The first one was conducted during the early days of the thesis and the team collected general information. The team learned that the key element to keep in mind while brainstorming concepts is that it needs to be convenient - an extremely safe storage space can be designed but if people do not use it then it is next to useless. It needs to fulfill all requirements but should not be too complicated for the customer to use. Providing too many configurations will be confusing as well since every time a passenger changes the configuration, it will be difficult for the next person to reset the position.

After the initial meeting and toward the end of the initial design stage of the project, Jonas was contacted again to get some feedback as well as fresh perspectives on design. During the second interview, the team got valuable feedback on the second round of concepts. The interview was also conducted as a mini-brainstorming session which provided some ideas that were later developed in to concepts.

B. Joakim Hermansson, Solution Business Owner- In Car Experience *and*
Lars Blenwall, Product Strategy Manager

Joakim and Lars work closely with taxi fleet operators and develop business strategies for autonomous vehicle targeting the taxi market.

Since these vehicles were also projected to be operated in a shared-use scenario, a 3 x 3 campfire seating configuration was being considered to maximize revenue. People are often forgetful and as a result a way to remind them to take their items with them would be a good option to have. Also, since there is no driver, the storage space needs to be easily cleanable in case there is spillage or dirt anywhere. Having a dedicated place for phones with charging spot is also an amenity people desire. In fact, having additional features or functionalities for the customer would be a bonus. A general overview of other uses for an autonomous vehicle such as package delivery was also discussed.

C. Mats Olofsson, Technical Specialist- Interior Surface Materials *and*
Moa Löfgren Bergérus, Design Engineer- Foil and Grain

Moa and Mats are technical experts in their respective fields with over 10 years of experience. The interview was arranged to get a better understanding of surface materials used in car interiors, specifically for the interior trim.

The team got to learn about the surface reflection properties of interior materials. How to improve surface properties (especially for ABS and Polypropylene), how to achieve premium quality and what it means in terms of surface appearance, were some of the questions answered. The processes such as painting, coating and plating undertaken to get the desired appearance were discussed in detail. Some suggestions for materials to be used were PMMA, PC/ABS, NFPP, PET and Polyester fibres. The cheapest way to manufacture is to have something pressed. An interesting suggestion was made about the Muuto lamp which is made by a Danish design company. The lamp shell is made of pressed PET sheets. The benefit of using this is that the sheets can be layered to give different rigidity and stiffness at different sections.

D. Magnus Björklund, Attribute Leader- Safety *and*
Richard Nilsson, Attribute Leader- Safety

Magnus and Richard work with overall safety standards of the car.
This meeting was set up to understand the different crash scenarios and the way they impact the occupants. Autonomous cars come with reliable technology and are expected to obey the traffic rules all the time. While this can prevent many crash scenarios due to better control on the car compared to humans, it also opens up new unforeseen scenarios. They mentioned two such situations. The first one is when the autonomous car is waiting in traffic and as the signal turns green it will accelerate quickly to reach its specified speed limit. This could lead to a frontal collision with a vehicle that has skipped its red signal and comes in the way leaving little time for the autonomous car to react. Another situation would be when the autonomous car stops at a signal but the cars behind don't. According to the Euro NCAP, "Frontal crashes are responsible for more deaths and serious injuries than any other accident type" [13].

4.2 Travel Habit Survey

The survey got an impressive 1007 responses and the results are presented in Appendix A. The respondents were mostly in the age group of 23-46. It was surprising to see that a coffee cup received only 6% of the votes which was quite contrary to the team's expectations. The most commonly carried item was a backpack (37%) followed by a briefcase (16%) and a purse (16%). The team therefore decided to focus on providing solutions for these items and only considered those comments of the survey relevant to these items as the voice of customer. The following table shows the requirements derived from these comments.

Table 4.1: Voice of Customer

Verbatim	Need	Requirements
Lighting in the luggage compartment	Reminder to pick up their items	Intuitive location
The solutions available today are complex to assemble	Minimum number of steps to secure items	Convenience
They are not adjustable to suit different size of items	To secure any size, shape and weight of bag	Robustness
Rain = More people in taxis, protection for luggage	Their belongings should not get dirty	Cleanliness
Easy storage for laptop bag	Ability to access it quickly when needed	Proximity
They are under plastic covers with other things on top (charging cables for example)	Should be in an uncluttered location and reached easily	Accessible

Since the survey was sent out to the general public, the team designed it to be very simple. There was no specific questions such as bag size or weight included. The team proceeded to consider the standard sizes of backpack, purse and briefcase available in the market.

4.3 Literature Review

An analysis of existing solutions, trend in consumer culture and value added product development was performed.

A research paper titled 'Functional Customization: Value creation by individual storage elements in the car interior' was very relevant to the thesis topic. It explored the behaviour of car drivers in different use case scenarios regarding preferred storage location of their personal belongings. Cars are being pictured as an extension of home and office space and therefore needs to have additional features that make the journey relaxing. The author mentions that storage solutions for valuable CE (Consumer Electronics) devices gives a positive impression. 19 storage areas were identified in the car cabin for the study and observations were taken in four different scenarios namely, commuting, leisure, vacation and special occasion. The team used this as a guide to develop solutions for the available spaces which are presented in Appendix D. The authors concluded that passengers store smartphones not only within the primary reach, but also within primary field of vision. Another interesting result from the study was that closed compartments such as a glove box showed limited usage which could be because objects stored there are easy to be forgotten.

Svensk Standards, specifically the SS-ISO 27955-2010 [14] and SS-ISO 27956-2009 [15] concerning the securing of cargo in passenger cars and securing of cargo in delivery vans respectively were referred. The standards document provided the team with information about testing for cargo and the various limits to which they were tested. Although it could not be directly utilized, it gave a theoretical backing to make the decision on the limit on weight.

For more quantitative results - in order to get data for how people use vehicles and to better discern the user base of autonomous vehicles, the team reviewed a survey done in 2011 titled 'Taxicab Regulation and Urban Residents' Use and Perception of Taxi Services: A Survey in Eight Cities' [16]. A general idea of the user base (the European user base in particular) and the penetration level of taxi services was determined. The team examined the Swedish national travel survey 2015-16 [17] to further reinforce an understanding of the user base - this time devoted only to the Swedish public.

Accidents that seem minor today take on a whole new level of danger once the passengers move out of a traditional forward-facing belted-in position. "Some visions of the future give me the chills," said Steven Peterson, vice president of engineering at ZF. Frontal-impact crashes currently account for approximately 56 percent of all vehicle occupant traffic deaths, side impacts account for 20 percent of deaths, and "other — mostly rollovers" claim 24 percent of the occupant fatality total according to IIHS and the Highway Loss Data Institute [18].

4.4 AD Experience Workshop

The main purpose of the workshop was to understand user needs and requirements while travelling in a car without a driver. Studies were conducted on the human-human and human-car interactions that will be used to develop value-addition features in the interior. The participants were organized randomly such that people riding in the car did not know each other in order to replicate being in a shared vehicle. The test simulated most aspects of driving in a city, driving longer distances and people getting in and out of the car with various pieces and sizes of luggage.

Two surveys were provided by the organizers to all invitees, one just before the test drive and one right after. The first survey was general with an aim to understand the perception of people towards AD technology and their willingness to adapt to it. The second survey was more detailed and included questions relevant to this thesis. Specifics such as number, type, weight and approximate dimensions of the bags were collected. The selected concepts were further developed into advanced designs based on the results from these surveys as shown in Appendix B.

Table 4.2: Voice of Stakeholder

Verbatim	Need	Requirements
Things would fly around	Does not want to get injured by small objects that can be dangerous at high speeds	Full retention
How to get rid of garbage, the garbage bin not emptied, car becomes untidy very fast	Want a pleasant interior that is clean, smells good and not irritating	Cleanliness
Large compartments for personal storage - needs to be close transparent	Customer feels insecure when their items are far away and they are not able to see it	Personalized
Ambient space/volume lighting very positive	The cabin should not feel crowded and legroom should not be compromised	Premium feel

Chapter 5

Concept Investigation

The concept investigation stage of the study was split into three phases. Phase 1 involved identification of available storage spaces and initial brainstorming. In Phase 2 advanced concepts were produced followed by concept screening. Finally in Phase 3, the top 5 concepts were reworked and scored using a Pugh matrix to select the best concept.

5.1 Phase 1

Based on the results and comments from the initial survey (Appendix A) and interviews with stakeholders 4.1, a list of functions required from the solution was made. The team brainstormed to produce six options that satisfy each function and constructed the initial morphological matrix.

Using this, seven concepts were developed and sketched as seen in figures C.1 to C.7 (Short descriptions of which are available in Appendix C). They were categorised into different zones such as hybrid (*Entertainment* and *Jalouise*), under seats (*Glaslåda*, *Boxer* and *Rise Up*) and between seats (*SmileyFace* and *Pyramids*).

Since some of the concepts developed in this phase needed a change in the seat configuration, a focus group of engineers working with the seats were invited for a discussion. The general consensus in the group was to have concepts that required a minimum change of current architecture and to have it to be readily implementable in the car.

Although the current round of concepts were developed with the customer in mind, feasibility of production and the requirements from attribute owners meant that the concepts had to be rethought. The team went back to brainstorming in order to come up with new concepts and also to analyze some of the old ones for improvement.

Table 5.1: Morphological Matrix

Sub-Function	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**
Securing Mechanism	Elastic Rope	Belts	Net	Hooks	Magnets	Compartment
Should not disturb the passenger	Murphy Bed (Fold in when not in use)	Use colors to blend in with the cabin	Dedicated luggage 'area'	Detachable when not in use	No pointy edges	Accessible
Robust Design	No noise during use	Minimum components in the system	Sturdy	Safe location	Inter changeable parts	Protects content
Value Creation	Phone dock/ Magazine rack	App reminder	Interior lighting	Place for coffee, fruit, bread	Visual indicators	Individual space
Locking Mechanism	Buckles	One fixed, one rolled up	Both ends fixed	Push to open	Deadbolt	None

5.2 Phase 2

The new focus was on reducing the number of steps the customer had to perform, improving convenience and to consider packaging. During this phase, the team went for and received additional data from the AD rig. The 11 concepts produced in this phase can be seen in Appendix C from C.8 to C.18.

Once the concepts were drawn up in a style similar to the first one, the team began to screen the concepts in order to determine the best among them for further investigation.

Concept Screening

The new concepts were screened alongside the older ones to understand which would be better with respect to convenience to use and safety in crash. Feasibility was also considered (that is, how feasible the concept would be to implement in the current car) but not used as a criteria for the screening. The screening table along with the rating criteria used by the team can be seen in 5.2 and 5.3.

Table 5.2: Concept Screening Matrix

Name of Concept	Safety	Convenience
Pyramids	2	3
Guideline	3	5
Magnetic Hook	3	5
Entertainment	3	5
SmileyFace	4	4
Gravity Hook	4	5
Swan	4	5
Book	5	2
Boxer	5	2
Glaslåda	5	2
Jalouise	5	2
RiseUp	5	2
Flexibeltity	5	3
Check-In	5	3
Se XC	5	3
Volvo Net	5	3
Attic	5	4
Open Bottom	5	4

Table 5.3: Key for Screening Matrix

Key				
Much Worse	Worse	Average	Better	Much Better
1	2	3	4	5

An XY graph (figure 5.1) was made with the data above in order to get a visual representation of where each concept lies. Some concepts were visibly poorer than others in one area. For instance, the *Glaslåda* concept scored 5 in safety but only a 2 in convenience, whereas a concept such as *Pyramids* scored average on both factors even though it was unique and generally well regarded.

From the graph, the team decided to focus on the upper right quadrant which excluded every concept that was $x < 3$ and $y < 3$. These concepts included the *Magnetic Hook* (which was one of the variations of the Hook concept. The top 5 concepts that remained were *Gravity Hook* (figure C.10), *Swan* (figure C.18), *SmileyFace* (figure C.5), *Attic* (figure C.8), and *openbottom* (figure C.17).

Once the team had the above recommendations in place to proceed with investigation and advanced design, a presentation was made to some of the project stakeholders. The stakeholders were varied with members representing different departments. Since it was the first time some of the stakeholders were made aware of the progress within the project, the team presented all the concepts and studies from the initial phases.

From this meeting, the team gathered more useful advice and feedback. Most of the components had synergies that could be utilized; combining the *Swan* with the *Open*

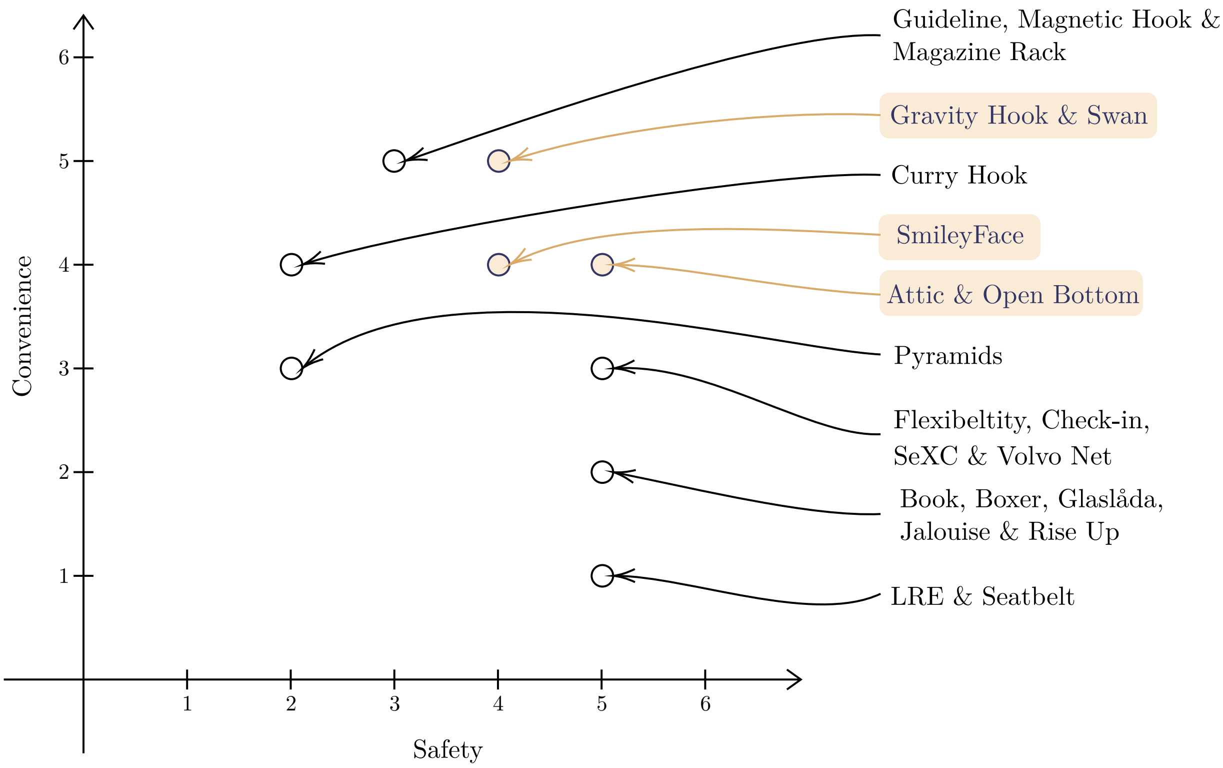

Figure 5.1: Safety vs. Convenience Screening Graph

Bottom concept such that the customer could have the safety of having a storage space underneath the seat and the convenience of being able to hook their bags near them easily. Some modifications to the initial seven concepts were brainstormed and possible causes and effects of implementing each solution was discussed.

5.3 Phase 3

After gathering all the suggestions and feedback, the team reworked the previous designs. The modifications that took place are described below.

SmileyFace was modified such that the barrier between the bars, went all the way to the floor to prevent the bags from crossing over to the other half of the passenger section (as seen in figure C.19). In addition to this improving its safety rating, there was the benefit of protecting the passengers' legs in the event of a crash and also acting as a hand support to assist ingress and egress.

Open Bottom got a new variant which the team took to calling the *Trap Door*. Here the safety net that was initially envisioned was replaced with a translucent lid that served a similar purpose. It was combined with the *Swan* concept and the combination was referred to as the *Trap Door + Swan* (C.22).

The *Attic* concept was split into two alternatives. This is because the team, along with the stakeholders saw the potential offered by the concept but felt that it needed to be more robust and provide a solution for not letting bags slip out. To this end the team developed *Rubberised Attic* (C.20) and *Johnny English* (C.21). Both concepts offered a safe way to carry small form products (especially laptops) and provided a lock system such that the product would not fall out in case of a crash.

Next, the team began concept scoring.

Concept Scoring

Since all the newer designs were modifications of previous designs that had already passed the initial screening, the team decided that a further screening would be unnecessary. Instead a Pugh Matrix was made to score the different concepts that had passed the screening and their modifications. As the Pugh matrix required to have a benchmark, the team considered existing products that serve a similar function i.e. retention. Cargo safety net [19] and seat belt proved to have the highest similarity and were therefore chosen as choices for benchmarking the generated concepts. It was initially decided to take the seat belt as the benchmark in the Pugh matrix. Considering its success as a widely accepted safety feature along with its simplicity and ease of use, the seat belt seemed like a good standard to compare with. However, when the process of concept scoring began, the team quickly realized that the seat belt was not an even comparison. This is because many of the concepts were too dissimilar in design to be adequately compared on basis of design or functionality. Also, the safety record of the seat belt was too good that all the other concepts seemed inferior. Therefore, the scoring process was restarted with the Safety Net as the reference.

In the first Pugh matrix- table 5.4, the top 5 concepts from phase 2 of concept generation were scored. The *Smiley Face* concept received the lowest score and was eliminated. The remaining 4 concepts were *Swan, Hook, Attic, Open Bottom.* Based on the inputs received in phase 3, *Swan* and *Open Bottom* were combined in to 1 concept. These 3 concepts were each then developed in to 2 alternatives thereby resulting in 6 concepts which were scored in the second Pugh matrix- table 5.5. The top scorers were the 2 versions of the *Open Bottom + Swan* combined concept. Therefore, the team concluded to pursue this as the main solution. The Gravity Hook concept was selected as the secondary solution for further development due to it being unique and patentable.

Table 5.4: Pugh Matrix showing the top 5 concepts of phase 2 scored against a Safety Net

Key Criteria \ Concepts	Importance Rating	Safety Net (Reference)	SmileyFace	Hook	Swan	Attic	Open Bottom
Safety	0.4		S	+	+	++	++
Ease of Use	0.1		++	+	+	+	++
Intuitiveness	0.02		++	+	++	++	S
Cost	0.1		-	++	++	S	-
Adaptability	0.02		- -	-	++	S	- -
Ergonomics	0.1		++	+	+	++	+
Simple	0.05		+	++	++	S	+
Transferable	0.02		- -	++	++	-	- -
Personalised	0.04		+	- -	+	+	++
Scope of Thesis	0.03		+	+	+	+	+
Feasibility	0.05		-	+	+	-	-
Robust (In terms of Capacity)	0.04		++	-	S	- -	+
Value Addition	0.03		+	S	S	S	S
Sum of Positives (+)			4	6	6	3	5
Sum of Positives (++)			4	3	5	3	2
Sum of Negatives (-)			2	2	0	2	2
Sum of Negatives (- -)			2	1	0	1	2
Sum of Sames			1	0	0	3	1
Weighted Sum of Positives (+)			0.15	0.7	0.72	0.17	0.32
Weighted Sum of Positives (++)			0.52	0.34	0.42	1.04	0.88
Weighted Sum of Negatives (-)			-0.15	-0.06	0	-0.07	-0.15
Weighted Sum of Negatives (- -)			-0.08	-0.08	0	-0.08	-0.08
TOTAL			0.44	0.9	1.14	1.06	0.97

Table 5.5: Pugh Matrix showing only the phase 3 concepts scored against a Safety Net

Key Criteria \ Concepts	Importance Rating	Safety Net (Reference)	Magnetic Hook	Gravity Hook	Johnny English	Rubberised Attic	Trap Door + Swan	Safety Net + Swan
Safety	0.4		S	S	++	++	++	++
Ease of Use	0.1		+	+	+	+	++	++
Intuitiveness	0.03		-	- -	-	S	+	+
Cost	0.1		S	++	-	-	-	-
Adaptability	0.06		++	++	+	+	- -	- -
Ergonomics	0.04		+	S	++	+	+	+
Value Addition	0.04		S	S	+	+	++	S
Transferrable	0.06		-	++	-	-	S	S
Personalised	0.04		S	S	++	++	++	++
Scope of Thesis	0.04		+	+	++	++	++	++
Feasibility	0.03		+	++	+	+	+	+
Robust (In terms of Capacity)	0.06		++	++	- -	- -	++	++
Sum of Positives (+)			4	2	4	5	3	3
Sum of Positives (++)			2	5	4	3	6	5
Sum of Negatives (-)			2	0	3	2	1	1
Sum of Negatives (- -)			0	1	1	1	1	1
Sum of Sames			4	4	0	1	1	2
Weighted Sum of Positives (+)			0.21	0.14	0.23	0.27	0.1	0.1
Weighted Sum of Positives (++)			0.24	0.62	1.04	0.96	1.36	1.28
Weighted Sum of Negatives (-)			-0.09	0	-0.19	-0.16	-0.1	-0.1
Weighted Sum of Negatives (- -)			0	-0.06	-0.12	-0.12	-0.12	-0.12
TOTAL			0.36	0.7	0.96	0.95	1.24	1.16

Chapter 6

Design and Material Selection

Here the various stages that were undertaken after final concept generation will be discussed. Since a large portion of the work done (especially in modelling) was with reference to proprietary 3D models from Volvo, the team has taken care to ensure that no images that are crucial to Volvo's R&D are released. Because of this, some of the concepts will be shown as standalone.

6.1 Design

The two solutions that the team fixed on was the **Open Bottom + Swan**, *Appendix C.17* and C.18 and the **Gravity Hook**, *Appendix C.10*. The team broke down the *Open Bottom + Swan* into its constituents and made two further modifications on them (two each for the *Swan* and *Trap Door* concept). After some brainstorming between, it was decided to make two models for the Gravity Hook as well. This resulted in a total of six models being created.

The maximum load limit set by the team was 12kg for the Open Bottom and the Swan solutions. 5kg was the limit set for the Gravity Hook. The 12kg limit was determined from a Tufts survey which stated that the recommended weight a commuter should carry (in a backpack) is 26 pounds [20], roughly equivalent to 12kg. The 5kg limit for the *Gravity Hook* was placed based on the average calculated from the AD Experience Workshop survey results as well as the fact that engineers from the concept center had advised the team to not load more than 5-6kg while testing the ABS prototype.

All designs were done in CATIA V5. Visualizations are in Teamcenter Visualization Mockup 10.1.

6.1.1 Gravity Hook *(Patent applied for)*

The Gravity Hook was designed as a versatile solution to restrain small form luggage such as purses, small pouches or even scarves. It does not rely on any component of the car to perform (for instance the *Open Bottom* concept requires space under the seat) and can theoretically be implemented on any vertical surface, curved or flat. The initial design reflected this as can be seen in figure 6.1.

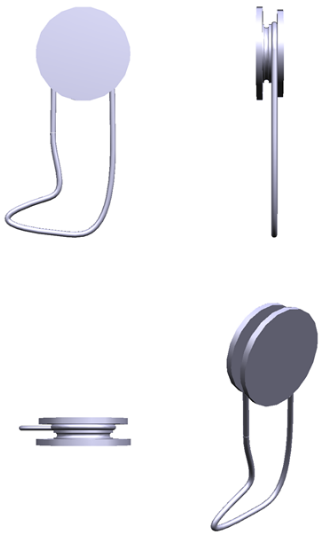

Figure 6.1: Clockwise from top left; front, side, top and isometric views of the concept Gravity Hook (standard)

However, in order to improve the safety rating of the hook, the team decided to provide a screw mechanism in the back and a protective sheathe for where the lanyard or restraint rope would go. Figure 6.2 show the modifications that were made.

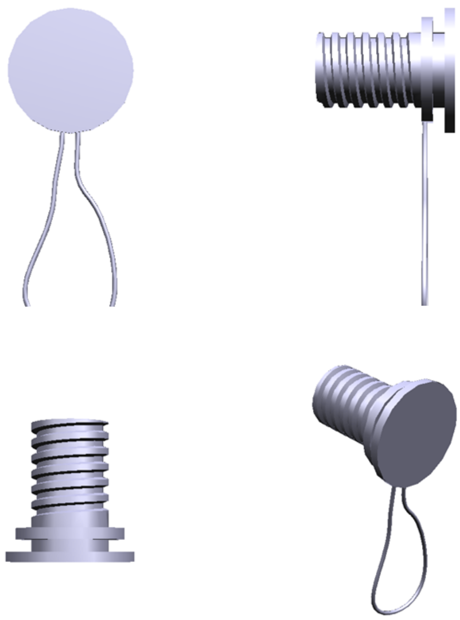

Figure 6.2: Clockwise from top left; front, side, top and isometric views of the concept Gravity Hook (screw)

Since the parts were not meant to carry heavy loads (up to a maximum of 5kg) the team decided to proceed with 3D printing a prototype. Images of the prototype are provided in figure 6.3.

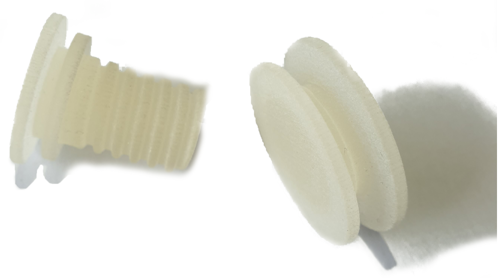

Figure 6.3: Prototype of the concepts Gravity Hook (screw) and Gravity Hook (standard)

6.1.2 Swan

The Swan was also defined as a versatile restraining solution that can take more load than the Gravity Hook. However, regarding position, it turned out less versatile as it had to go between the passengers legs and placed close towards the seat edge (Appendix C.18).

The issue with this was that the product had to be large enough to comfortably hold a bag strap without breaking but also avoid any hindrance to the occupants of the car. Another issue was the snagging of clothes to it or brushing of legs.

Two designs were made based on this: one that was deep (figure 6.4) and had a sharp angle of incline in order to minimize the amount of projection from the seat, and the second design was shallow (figure 6.5) and had a smaller angle so that it could hold larger bag straps.

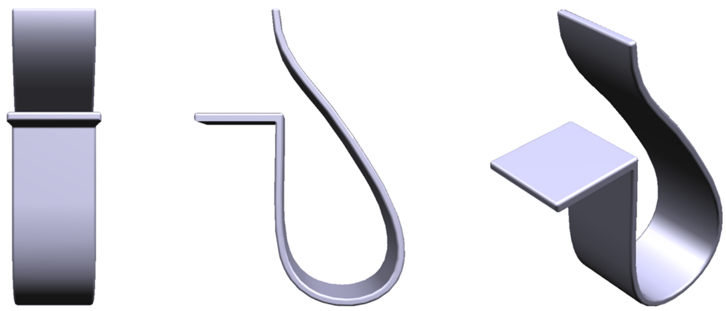

Figure 6.4: From L to R; front, side and isometric views of the concept Swan (Deep)

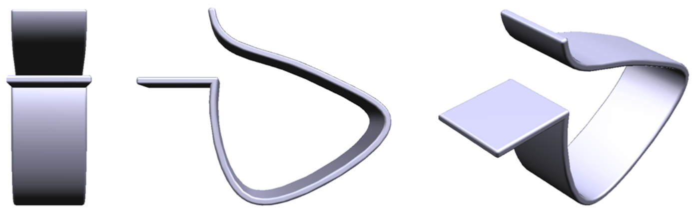

Figure 6.5: From L to R; front, side and isometric views of the concept Swan (Shallow)

6.1.3 Open Bottom

The team learned that the most common way people place luggage when using a means of transport is either by placing their items on the seat beside them (if they are seated and the seat beside them is empty) or to place it on the floor between their feet (if the seat beside them is occupied or they are standing). Furthermore, it was observed that most of the luggage they carried were laptop bags, medium backpacks or groceries. In the weekends though, luggage was even less. This corresponded with the findings from the AD Experience Workshop. The *Open Bottom* concept is based on this observation.

The team was provided with a model of the seats that Volvo was working with for the Autonomous Car. The seats conveniently were of a fixed nature as compared to the existing seats which sit on rails. The seats had more space below them which provided the team with a region to work on. Designs were developed for the two variants of the solution.

The first variant was the *Trap Door* (figure 6.6), where the length of the door was 75% of the vertical space available and it opened partially. It was designed to be transparent so that the customer can view the items they store inside. This reduces the number of cases of passengers forgetting their items in the car. A simple locking mechanism was also provided in order to allow the door to lock in place when fully closed.

The second variant was the *Safety Net* (figure 6.7). It implemented the safety net already in use behind the seats of certain Volvo variants. The net being elastic, allows larger volume items to be placed in the space compared to the *Trap Door*. For prototyping, the team wanted to see how both the concepts would look like in the car. Hence, it was decided to make 3 of the seats containing the *Trap Door* and the other 3 containing the *Safety Net*.

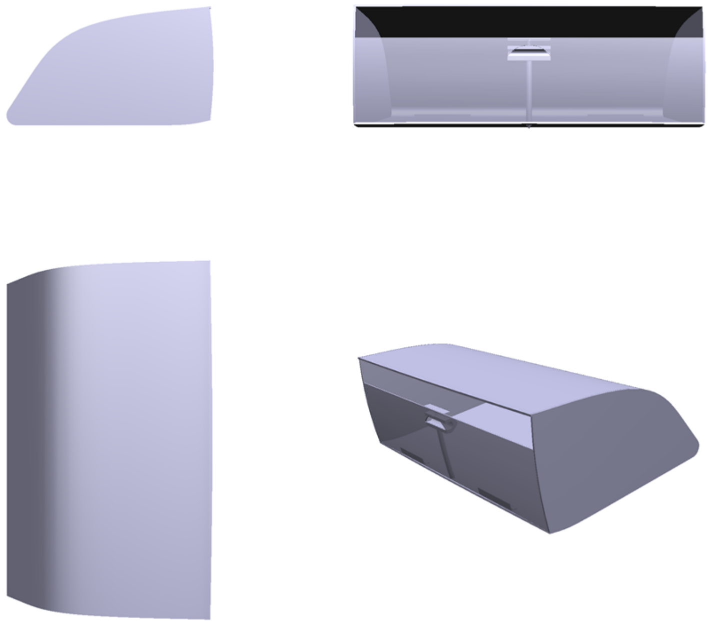

Figure 6.6: Clockwise from top left; side, front, top and isometric views of the concept *Trap Door*

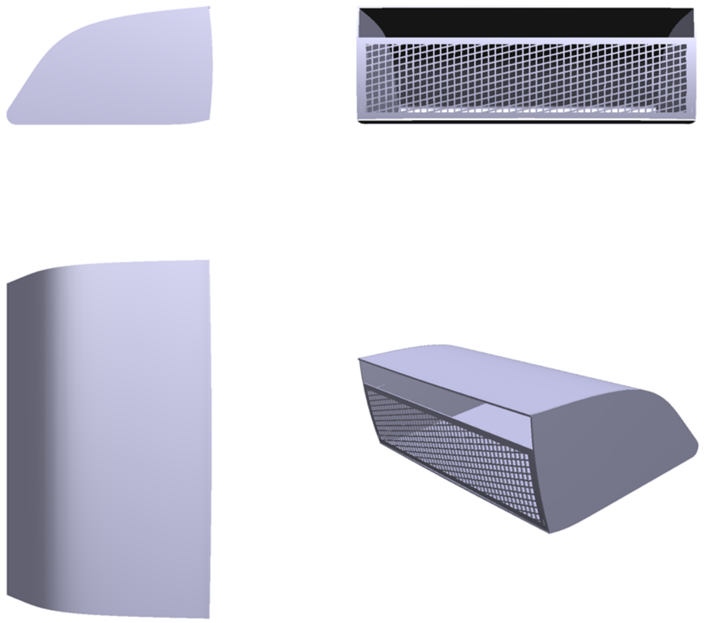

Figure 6.7: Clockwise from top left; side, front, top and isometric views of the concept *Safety Net*

6.2 Material Selection

The appearance of the interiors influences the perception of quality of the vehicle. This can be achieved either by choosing materials with good surface texture or applying surface treatments such as paint coating, galvanizing or textile stitching. The choice of materials also decides the mechanical performance of the product and its carbon footprint. The team reflected on these three core values of Volvo- Quality, Safety and Environment during the process of material selection. The process was based on the material requirement guidelines for the interiors.

The document provided by Volvo for the requirements on all interior materials had both detailed test methods as well as more straight-forward criteria. All material properties listed in tables in this section were obtained from CES Edupack [21] software unless specified otherwise. In the case of *Trap Door*, the material selection was done methodically in stages using CES EduPack as the stress calculations could be carried out by hand. However, in the case of the other products, the forces were acting in complex directions. The team did not carry out CAE testing to estimate the stresses. A market search to find commercially available materials used in similar engineering context was performed. The general requirements for a product in the car interior are listed below followed by the case by case investigation for each product.

- The product will be exposed to **water, salt and other common drinks such as coffee and coca cola** and its performance should not be affected.

- All materials used in the interiors of Volvo cars are subjected to the Climate Variation test and must qualify as fully-functional during and after the completion of the test from which, the team obtained- Maximum operating temperature as +75 °C and Minimum operating temperature as -30 °C.

The process will be described in detail for each product below-

6.2.1 Gravity Hook

The performance of the gravity hook depends on the its two components- the elastic string and the hook head. ABS was the suggested material for the hook head. The team performed a market search and found that it was indeed a widely used material for critical automotive parts in the interior trim. A close competitor was PC+ABS blend as it provides improved stiffness, lower temperature toughness and better heat resistance when compared to ABS. The most relevant properties of the two materials have been compared in table 6.1.

Table 6.1: Comparison of material properties for the concept Gravity Hook

Materials / **Properties**	ABS	ABS+PC
Price (SEK/m^3)	2.56×10^4	4.78×10^4
Yield Strength (MPa)	34.5 - 49.6	53.1 - 62.1
Impact Toughness, G (kJ/m^2)	1.08 - 6.39	2.34 - 9.8
Creep resistance [25]	Moderate	Excellent
Processing [25]	Excellent	Acceptable

When items are latched onto the Gravity Hook, creep due to the constant load from long journeys can arise and lead to failure. Therefore, ABS+PC was selected to be the better alternative for this application due to its higher strength and creep resistance despite being expensive and having poorer processability.

The material selection process for the elastic string followed that of the Open Bottom: Safety Net (refer section 6.2.3) as they have similar requirements on mechanical strength and elasticity.

6.2.2 Swan

Design requirements

- The opening flap of the product needs to be flexible so that it can open horizontally by a minimum of $1cm$ when the occupant exerts a force using their fingers.

- Once a bag is restrained to the product, the bottom of the Swan will experience a pulling force estimated at a maximum of $3600N$ ($12kg$ mass experiencing a deceleration of $30g$) from the bag strap during the event of hard braking. A high yield strength is therefore demanded to prevent the product from failure.

- Due to its location in a constricted region, the thickness needs to be as small as possible.

With these in mind, a market search yielded the popular options for household load carrying hooks as Steel, Die cast iron, Solid zinc, Polycarbonate and ABS. Since the product needs to be durable for bag weights up to $12kg$, ABS and Polycarbonate were eliminated because the size of the product would be too big which cannot be accommodated at the intended location in the car. Since the remaining three materials satisfy the mechanical strength requirement needed, they are compared based on other design requirements to choose the best alternative.

In the targeted application, the product is exposed to frequent brushing with the passenger, bags or other things that are brought into the car. This could lead to scratches or indents on the surface. In order to avoid this and maintain premium quality, the product needs to have high wear resistance. Vickers hardness value gives a good estimate of the surface resistance to indentation.

In a crash scenario the product can experience a high force and it is safer to have a material that absorbs significant crash energy through plastic deformation instead of a brittle material. Therefore, elongation to failure is an applicable selection criterion.

Table 6.2: Comparison of material properties for the concept Swan

Properties \ **Materials**	AISI 1010 Steel	Solid Zinc	Gray Cast Iron
Price (SEK/m^3)	4.5×10^4	1.75×10^5	1.8×10^4
Yield Strength (MPa)	172 - 315	100 - 140	65 - 98
Vickers Hardness (HV)	88 - 128	30 - 40	90 - 216
Elongation to failure ($\%strain$)	29 - 45	40 - 90	1 - 2

For steel, the team decided to consider the commonly used automotive steel grade- AISI 1010 Carbon Steel [22]. Based on the values seen in the table, the team eliminated Solid zinc due to its low hardness. Gray cast iron was eliminated due to its brittle nature (low elongation). This leaves AISI 1010 Steel as the best choice but any steel grade with comparable properties is an equally good choice.

In order to have the appearance of the product match with the premium interiors of a Volvo car and also provide corrosion resistance, the team decided on two suggestions for surface modification:

- Surface coating with black matte paint.
  For this case, a suitable alternative would be to use bake-hardening steels. These steel grades undergo hardening when subjected to a paint baking operation and show a rise in yield strength by about $40MPa$.

- Wrapping with black headliner fabric.
  Using the same textile as that used in lining the car roof provides for a uniform theme in the car interior.

  These suggestions were not pursued due to limitations on time.

6.2.3 Open Bottom

Trap Door

Design requirements

- The trap door needs to be **transparent** so that the passengers can see their belongings and don't forget it when alighting. This eliminated metallic material.

- Owing to the location of the product close to the leg space, it is subjected to kicking by the passengers as well as abrasion from dirt on the floor. This translates to a requirement on **flexural strength** for protection against kicking and **abrasion resistance** against dirt. A minimum limit of $2MPa$ was set for the flexural strength.

- As there was a strong requirement on the safety of the passengers, the Trap must prevent its contents from flying out during a crash scenario. This was ensured by incorporating a deadbolt in the product design. However, since the deceleration rate is high during a crash, the trap door itself must be shatter-proof and absorb high impact energy before breaking. Therefore, **Toughness** was required and a minimum was set at $2kJ/m^2$.

  These criteria were used for Stage 1 selection. After omitting Ceramics and Composites due to their brittleness and complex recyclability respectively, 36 materials were obtained. The results can be seen in figure 6.8.

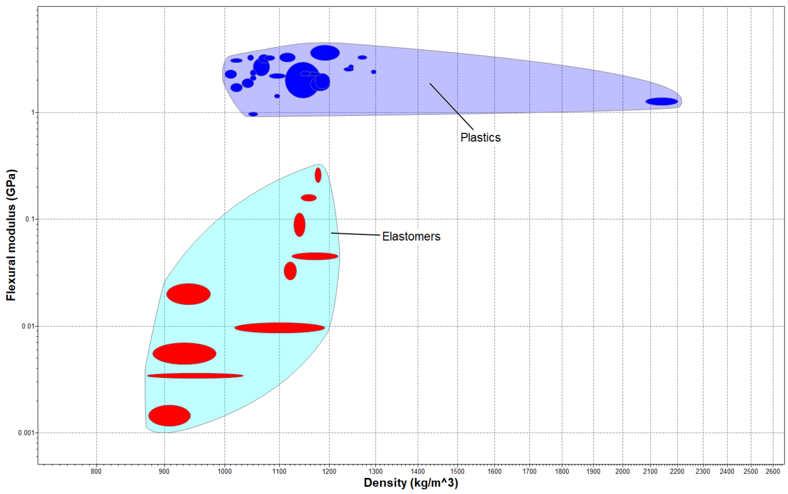

Figure 6.8: Stage 1 screening of materials for the concept *Trap Door*

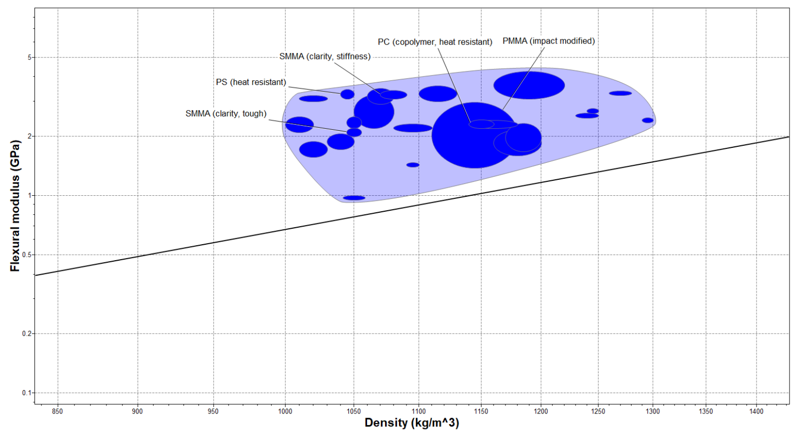

Figure 6.9: Stage 2 screening of materials for the concept *Trap Door*

- Moderate stiffness ensures that the product remains in position and does not deform easily when the contents stored inside exert a force on it. This puts a requirement on **Flexural Modulus** and was used in Stage 2 selection with $E^{1/3}/\rho$ set as the Performance Index. All materials with a Flexural Modulus of $1GPa$ or more were selected. 19 materials were now remaining as seen in figure 6.9.

Finally for Stage 3 of selection, a cost vs. mass trade-off plot was used as seen in figure 6.10. 5 materials that had the lowest price and density were chosen and compared to make the decision. SMMA being an uncommon polymer in the automotive industry was eliminated. Polystyrene was eliminated due to poor recyclability. The remaining 2 alternatives- PMMA and PC are compared in table 6.3.

Table 6.3: Comparison of material properties for the concept *Trap Door*

Properties \ Materials	PMMA	PC
Price (SEK/m^3)	2.8×10^4	3.84×10^4
Impact Toughness, G (kJ/m^2)	0.203 - 0.85	6.41 - 9.16
Resistance to cleaning chemicals	Low	Moderate
Flexural Modulus (GPa)	3.16	2.4
Yield Strength (MPa)	53.8 - 72.4	$\sim$ 60

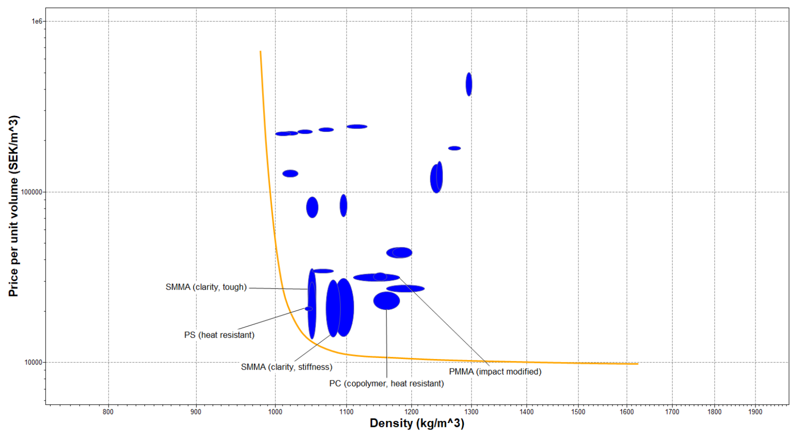

Figure 6.10: Stage 3 screening of materials for the concept *Trap Door*

Although PC has less yield strength and is about 35% more expensive than PMMA, it's superior impact toughness, resistance to cleaning chemicals and flexibility makes it the better choice. An added motivation for this choice came when the team performed a supplier survey which revealed the wide availability of recycled grades of PC, thus having advantages from both an environmental and economic perspective.

Safety Net

This concept had the same design requirements as the *Trap Door* except for two which are listed below:

Design requirements

- There was no need for transparency as the inside of the compartment is visible through the check pattern in the safety net and the size of the check was designed accordingly.

- The material for the cords of the safety net had to be elastic with moderate yield strength.

The results found from the market search could be classified into two classes:
Thermoplastic polymer fibers- Nylon, Polypropylene, Polyester and HDPE.
Braided fibers- Rubber core made of Polyurethane rubber or Latex rubber braided with an outer covering made of Polypropylene, Polyethylene, Cotton, Polyester or Nylon.

The second class of choice have a disadvantage as they are made of 2 different material fibers woven together. The extra steps involved in breaking down the fibers and separating them makes it expensive for recycling. Therefore, the team decided to eliminate this option. However, it could be considered if the supplier company makes use of recycled textile fibers in the process of manufacturing the safety net thereby attributing a lower carbon footprint to the product.

Table 6.4: Comparison of material properties for the concept *Safety Net*

Materials / Properties	Nylon (PA6)	PP	Polyester	HDPE
Price (SEK/m^3)	3.12×10^4	1.16×10^4	1.54×10^4	1.38×10^4
Yield Strength (MPa)	38.6 - 48.2	31.9 - 36.4	50 - 55	19.3 - 26.9
Young's Modulus (GPa)	0.944 - 1.18	1.37 - 1.58	2.8 - 3	0.92 - 0.96
Elongation at yield ($\%strain$)	14.6 - 27.7	8.09 - 11.1	3.5 - 8 (1)	13 (1)

The remaining 4 materials were compared on the most relevant properties for the application as seen in the table 6.4. HDPE was eliminated due to its low yield strength. Polypropylene and Polyester have lower elongation when compared to Nylon (almost 3 times better) and were therefore eliminated. This results in Nylon as the best choice. Volvo sells the Protective Nylon Net [19] to prevent cargo from moving forward into the passenger section. The function served by the *Safety Net* is similar but with a smaller stopping distance which can be achieved by increasing the diameter of the nylon net.

Chapter 7

Assembly and Cost

A product, no matter how well designed for the customer and the stakeholder (in this case Volvo) will not be implemented in the project if its manufacturing cost is high or assembling it is unergonomic to the factory worker. Furthermore, the cost of the product should also justify its inclusion. The following chapter deals with how the team allowed provisions in the design for assembly.

7.1 Design for Assembly

The concepts generated although deemed to be completely sufficient for the purposes of study and prototyping, were not entirely feasible when considering scaled up production volumes. The team consulted *Leif Svensson*, a manufacturing engineer within Volvo for feedback on improving the design of the products for assembly. From the discussion, certain principles of Volvo which the team had not taken into account before were made clear. Some of these principles are outlined below:

Principles

1. The third hand solution principle wherein any component that needs to be mounted or fixed on another component must be able to support itself at the designated location during installation so that the worker has both their hands free to operate the installation tool effectively.

2. Components that need to be assembled in Y_0 (i.e. components on the floor of the workspace such that the operator has to bend to gain access to it) should be avoided.

3. Components having several smaller parts that require assembly to go through, if ordered from a supplier, should arrive fully assembled. This saves time and as a result also cost of labour.

These principles, specifically the first one, necessitated redesign to the concept. The team learned that the seats were not produced by Volvo at the main plant at Torslanda but were produced by a supplier who delivered them pre-assembled as a unit which are then inserted and bolted onto the body-in-white at Volvo.

7.1.1 Redesign

It was determined that the *Silicone Trap*, *Safety Net* and *Gravity Hook* would not require a redesign. However, the *Swan* required modifications to better fit in with the Third Hand Solution principle as mentioned above.

The redesign involved providing both the *Swan (Shallow)* and the *Swan (Deep)* with a rib along an end so that it could position itself without having to be held in place by hand. The redesign can be seen in figure 7.1.

Figure 7.1: The redesign of the concepts Swan (Shallow) and Swan (Deep)

7.1.2 Assembly

The team considered the assembly involved based on the following assumptions:

Assumptions

1. The seat shall be assembled by Volvo instead of being sourced from a supplier.
2. The assembly shall take place at the main Torslanda factory.
3. The other seat parts (such as the foam, or the supports) are added independently of the concepts.
4. Only one product is installed at a time.
5. Tooling costs shall not be considered since these costs are covered by the Manufacturing and Purchase departments. Tooling costs are normally not included when manufacturing parts at Volvo.
6. Cost of assembly and labour shall be as provided by Volvo Time Measurement Units (See Chapter 2.1 for an explanation on Time Measurement Units).
7. The installation TMU of the concepts will be taken using the TMU for installing a load retention eye in the Volvo XC40 as a reference.

The specific way of measuring time will be using the MTM technique (see section 2.1 for a brief explanation). The framework of MTM relevant to the concept assembly (which includes how the work processes break down) is provided below:

Table 7.1: Therbligs used in the assembly of the concept

Basic Motions	**Explanation**
Reach (R)	Move the hand to a particular location
Grasp (G)	To hold a part firmly in order to restrain or aid in assembly
Move (M)	Move an object to a particular location
Position (P)	To orient an object
Release (RL)	Tends to follow Grasp (G) where the part is let go
Turn (T)	Rotations of the wrist or hand
Assemble (A)	Part is fitted to another part

Three main installations will be described. The installation of the *Gravity Hook*, the installation of the *Swan* and *Trap Door*, and the installation of the *Swan* and the *Safety Net*. None of the assembly processes take into consideration the act of manually finding one of the parts and having to select them to place in the appropriate position.

Process of Installing the Gravity Hook

Table 7.2: Process Instruction Chart for the Gravity Hook

Type	Operation Description	TMU
P	Place the gravity hook within the provided opening	60
A	Screw the hook in place	120

Process of Installing the Swan

The *Swan* was provided with a standard M8 screw hole on its end that was meant to be fitted on to the seat. The *Swan* was also to be positioned under the seat foam in such a way that the only parts that were visible were the opening flap of the product. The following table shows an overview of the engineering operations:

Table 7.3: Process Instruction Chart for the Swan

Type	Operation Description	TMU
P	Position the swan on the seat frame	60
A	Tighten one (1) screw to swan	120

Process of Installing the Trap Door

The *Trap Door* has more parts in its construction than the previous two which were single part products. The parts include:

Hinge ×2
Deadbolt ×1
Front cover ×1

The following table shows an overview of the engineering operations:

Table 7.4: Process Instruction Chart for the Trap Door

Type	Operation Description	TMU
A	Assemble one (1) hinge to one end of the floor of the seat	240
A	Assemble one (1) hinge to the other end of the floor of the seat	240
P	Place deadbolt mechanism (1) onto the front cover	60
S	Screw deadbolt (1) in place	240
G	Grasp the front cover (1)	30
P	Position it onto the hinge (2)	60
A	Screw the hinge (2) in place	480

Process of Installing the Safety Net

The *Safety Net* was provided with hooks on the back of the net apparatus. In order for a more ergonomic assembly process, the *Safety Net* needed to be assembled at an elevated position (i.e. not on floor level). The following table shows an overview of the engineering operations:

Table 7.5: Process Instruction Chart for the Safety Net

Type	Operation Description	TMU
P	Place the four (4) Hooks in the appropriate positions	120
S	Screw the hooks in place	240
A	Position the left handle into the hooks provided	120
A	Place the right handle with some tension into the second hook provided	180

7.2 Cost

Total manufacturing cost incorporates the following three costs [23]:

Cost of **Direct Materials**: This includes the cost of all materials and supplies utilized during the manufacture process. This includes any waste (in the form of scrap or faulty materials) as well.

Cost of **Direct Labor**: This is the cost of all the production services or labor involved in the manufacturing of the product and includes the assembly cost.

Overhead Costs: This includes the various costs that go into manufacture but are not directly involved in the production. Such costs include the cost of electricity, tooling, salaries of the employees, etc.

For the current solutions to be mass produced (assuming it will be produced and assembled at the Volvo Torslanda plant) there will be new tooling and machinery required. For the purposes of cost calculation in this section, only the cost of direct materials and direct labor will be estimated. Furthermore, the cost of scrap materials or faulty products shall not be considered.

The costs were calculated based on material costs from CES Edupack. 100 TMU was taken to be equivalent to 1 SEK [1].

7.2.1 Gravity Hook

The *Gravity Hook* has two components - the screw and the elastic cord. Installation means simply screwing it in while the elastic cord is in place thereby resulting in low assembly cost.

Table 7.6: Direct Material Cost of the Gravity Hook

Direct Costs			
Part	Material	Volume of Product(cm^3)	Cost (SEK)
Screw Head	PC/ABS	5.236	0.25
Thread	Threaded Nylon	0.3768	0.018

Table 7.7: Direct Labor Cost of the Gravity Hook

Labor Costs		
Part	TMU	Cost (SEK)
Gravity Hook	180	1.8

Table 7.8: Total Cost of the Gravity Hook

Total Costs	
Part	Cost (SEK)
Gravity Hook	2.068

[1] Value received from Volvo

7.2.2 Swan

The *Swan* was designed with simplicity and usability in mind and as a result is a single piece product. Adding an additional material over the *Swan* for aesthetics was considered but not implemented in this analysis in order to keep the product as simple as possible.

Table 7.9: Direct Material Cost of the Swan

Direct Costs			
Part	Material	Volume of Product (cm^3)	Price (SEK)
Swan (Shallow)	Sheet Metal (Steel)	2.684	0.121
Swan (Deep)	Sheet Metal (Steel)	2.738	0.123

Table 7.10: Direct Labor Cost of the Swan

Labor Costs		
Part	TMU	Cost (SEK)
Swan (Shallow)	180	1.8
Swan (Deep)	180	1.8

Table 7.11: Total Cost of the Swan

Total Costs	
Part	Cost (SEK)
Swan (Shallow)	1.921
Swan (Deep)	1.923

7.2.3 Trap Door

The *Trap Door* contains subcomponents- the deadbolt mechanism meant to lock the cover in place, and twin locked hinges to prevent it from opening all the way. Only the cost of the trap was considered here.

Table 7.12: Direct Material Cost of the Trap Door

Direct Costs			
Part	Material	Volume of Product (cm^3)	Cost (SEK)
Trap Door	Recycled PC	117.563	3.292

Table 7.13: Direct Labor Cost of the Trap Door

Labor Costs		
Part	TMU	Cost (SEK)
Trap Door	1350	13.5

Table 7.14: Total Cost of the Trap Door

Total Costs	
Part	Cost (SEK)
Trap Door	16.792

7.2.4 Safety Net

The *Safety Net* was designed to be easily mounted and demounted so that it can be removed to wash when dirty.

Table 7.15: Direct Material Cost of the Safety Net

Direct Costs			
Part	Material	Volume of Product (cm^3)	Cost (SEK)
Safety Net	Braided Nylon	59.606	1.86

Table 7.16: Direct Labor Cost of the Safety Net

Labor Costs		
Part	TMU	Cost (SEK)
Safety Net	660	6.6

Table 7.17: Total Cost of the Safety Net

Total Costs	
Part	Cost (SEK)
Safety Net	8.46

Chapter 8

Conclusion and Future Work

Final thoughts and closing remarks

8.1 Conclusion

Over the 20 weeks of performing the thesis work, the team:

- Conducted detailed observations and analysis of customer requirements (both internal and external to Volvo)
- Brainstormed and conceptualized designs relevant to the gathered information
- Modified the concepts as per the new information gathered at each stage of development
- Made detailed engineering designs in CAD of promising concepts
- Scanned and suggested the best choice of material
- Outlined assembly and cost prices
- Installed a proof-of-concept in Volvo's AD rig

The designs should undergo additional rounds of testing such as CAE and fully realized prototypes. Several changes can be expected in the product such as changes in the seat arrangement, wheelbase, roof line (which would provide future designers with more freedom) or even the entire shape of the car. The autonomous car project is still in the concept phase and different interior layouts are being tested out. The team has ensured that the dominant designs as well as other impressive designs that were not investigated further due to time constraint were conceptualized and designed with an eye on future proofing them. For instance, the *Gravity Hook* only requires a vertical surface on which it can be screwed to. This allows it to be transferable and still relevant even though changes may occur in the layout later on. Similarly in the case of the *Swan* concept, it can theoretically be placed under any seat and is not dependant on the dimensions or the type of seating.

Suggested Improvements

The team believes the thesis could have benefited from the following:

- More time spent on testing and refining the dominant designs. The team only produced functional prototypes that was installed in the AD rig and not full scale engineering tests.

- Interacting with suppliers would have provided a better insight about the availability of recycled grades of plastic materials and also their price, processability and carbon footprint.

8.2 Future work

The team realized the potential for the thesis to be continued beyond its planned 20 weeks and as such have a tentative proposal for any work that would be conducted in the future:

- Conduct simulations on the different CAD models to understand the loads and stresses in the different products. If the materials choice and design do not meet the mechanical requirements, it needs to be reiterated in order to produce a more robust design.

- Conduct a second round of surveys with focus groups of the relevant attributes to gain a deeper understanding of how stakeholders perceive the designs. This information would be vital in further investigations.

- To revisit the older concepts and see if they can be utilized as is or with some modification when the final design of the car is frozen.

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Appendices

Appendix A

Travel Habit Survey (Results)

A survey was designed to understand what items are carried by people who commute on a daily basis and the requirements they have in terms of storage options. The survey received 1007 responses out of which 709 responses are in Swedish and 298 in English.

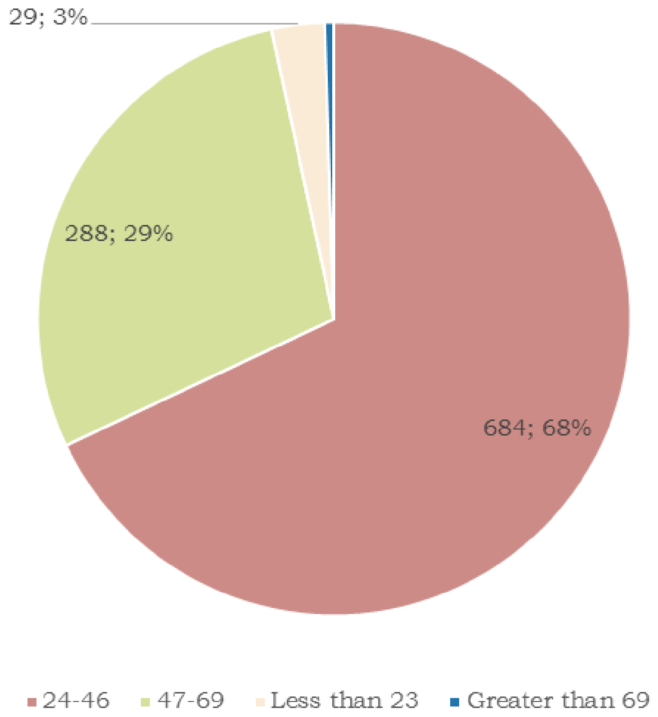

Figure A.1: Age group of the survey respondents

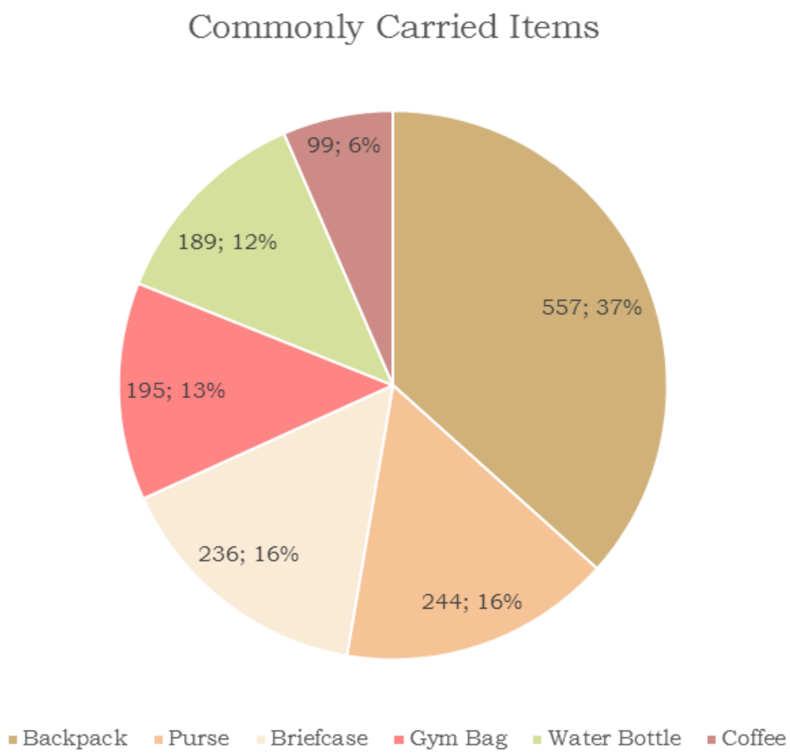

Figure A.2: Most common items carried and the share of respondents that carry them

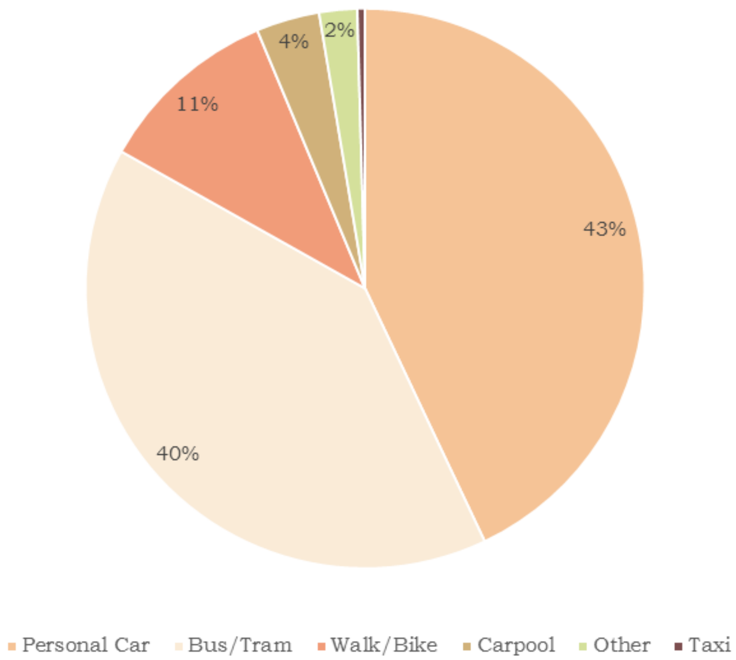

Figure A.3: Travel choice of respondents in the age group 23-46

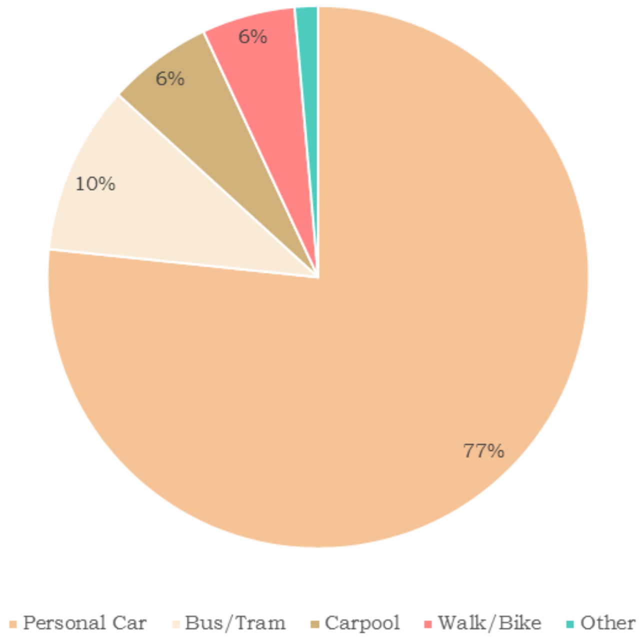

Figure A.4: Travel choice of respondents in the age group 47-69

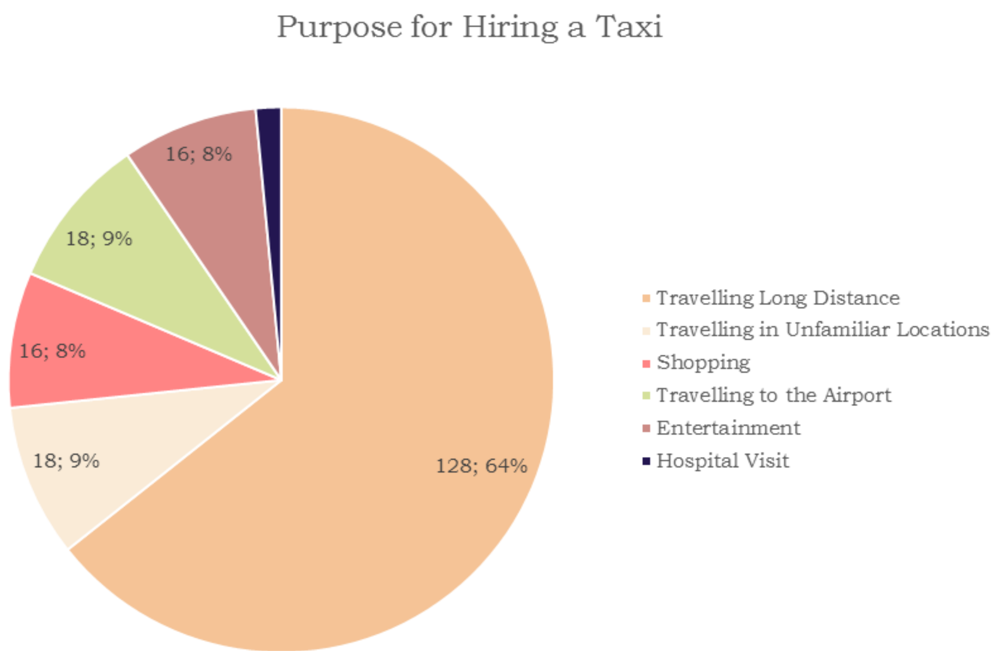

Figure A.5: Most common reasons for hiring a taxi and the share of respondents that use this service

Appendix B

AD Experience Workshop (Results)

The following pie chart and table is the summary of relevant results evaluated by the team from the survey responses obtained from participants at the Autonomous Drive Experience Workshop. It details the commonly carried bag dimensions. The dimensions were used while making the detailed design for the Open Bottom concepts.

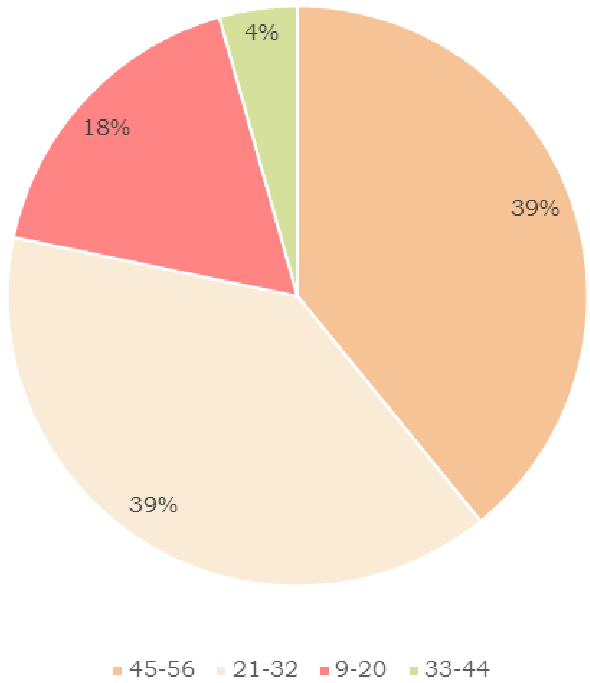

Figure B.1: Bag size in litres

Table B.1: Amount and dimensions of bags carried by people participating in the survey

Number of items	Dimensions (L x W) (cm x cm)	Area(cm^2)	Dimensions (L x W x B) (cm x cm x cm)	Volume(L)
1	15 x 20	300	15 x 20 x 30	9
1	10 x 40	400	10 x 40 x 40	16
1	20 x 20	400	20 x 20 x 30	12
2	20 x 25	500	20 x 25 x45	22,5
1	15 x 40	600	20 x 30 x 40	24
5	30 x 30	600	20 x 30 x 40	24
4	20 x 40	800	20 x 40 x 60	48
3	30 x 30	900	30 x 30 x 50	45
1	25 x 40	1000	20 x 40 x 25	20
1	25 x 45	1125	20 x 25 x 45	22,5
1	30 x 50	1500	30 x 50 x 30	45
1	30 x 60	1800	30 x 60 x 30	54
1	40 x 50	2000	40 x 50 x 20	40

Appendix C

Concept Generation

C.1 Glaslåda

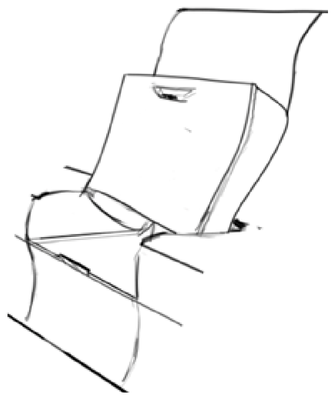

Figure C.1: Glaslåda

C.2 Boxer

Figure C.2: Boxer

C.3 Rise Up

Figure C.3: Rise Up

C.4 Pyramids

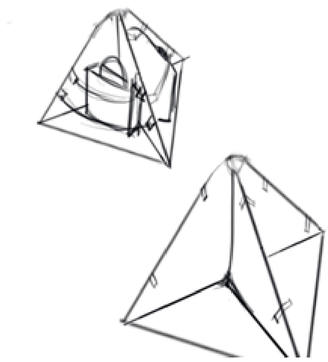

Figure C.4: Pyramids

C.5 Smiley Face

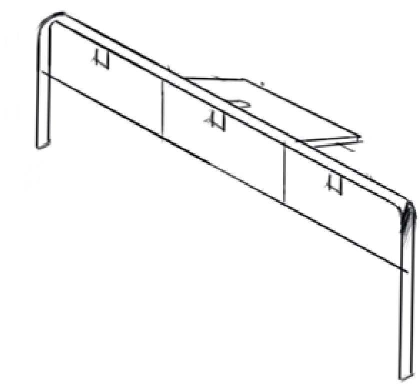

Figure C.5: Smiley Face

C.6 Jalouise

Figure C.6: Jalouise

C.7 Entertainment

Figure C.7: Entertainment

C.8 Attic

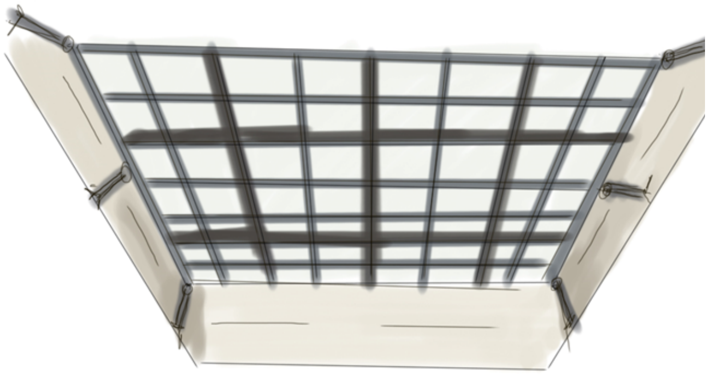

Figure C.8: Attic

C.9 Flexibeltity

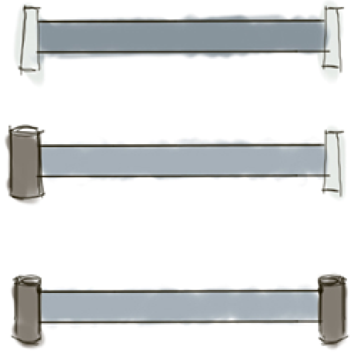

Figure C.9: Flexibeltity

C.10 Hook

Figure C.10: Hook Concept

C.11 Book

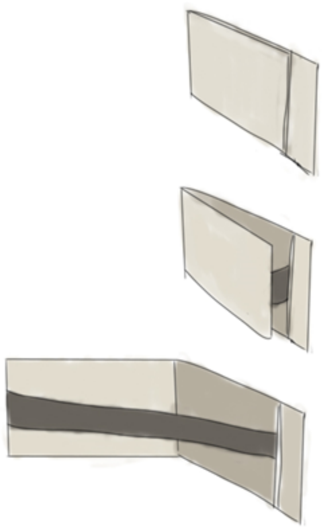

Figure C.11: Book

C.12 Check-In

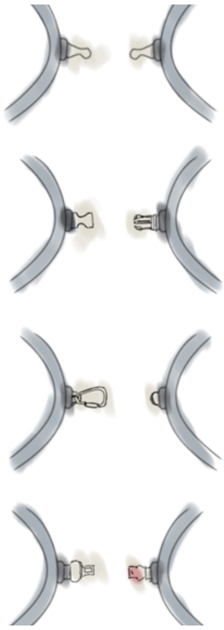

Figure C.12: Check-In

C.13 Se XC

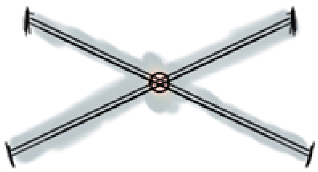

Figure C.13: Se XC

C.14 Volvo Net

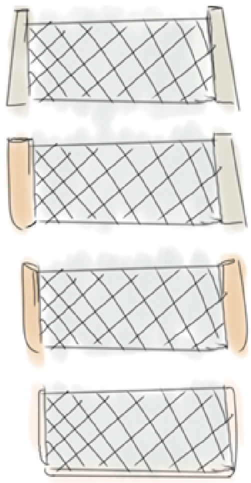

Figure C.14: Volvo Net

C.15 Miscellaneous Concepts

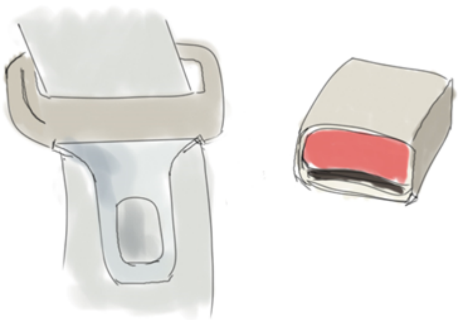

Figure C.15: Load Retention Eye, Seatbelt and Curry Hook

C.16 Guideline

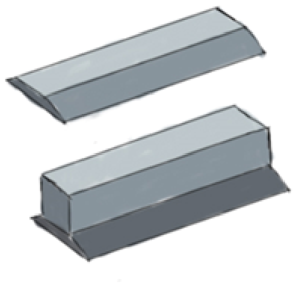

Figure C.16: Guideline

C.17 Open Bottom

Figure C.17: Open Bottom

C.18 Swan

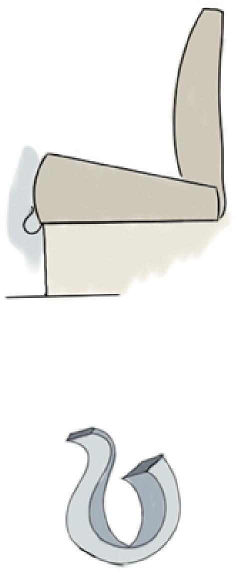

Figure C.18: Swan

C.19 SmileyFace (Modified)

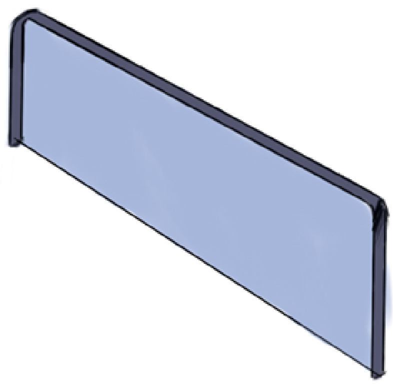

Figure C.19: SmileyFace (Modified)

C.20 Rubberised Attic

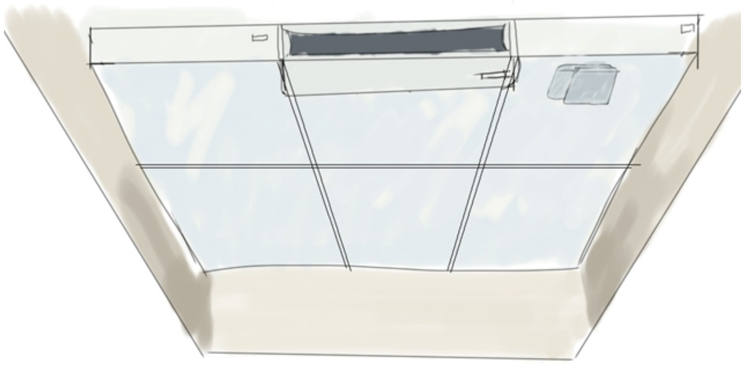

Figure C.20: Rubberised Attic

C.21 Johnny English

Figure C.21: Johnny English

C.22 Trap Door + Swan

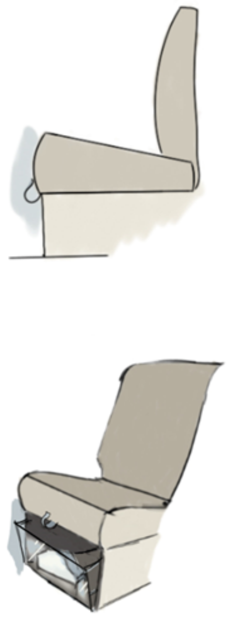

Figure C.22: Trap Door + Swan

Appendix D

Storage areas available in a car interior

Seating back panel	Ceiling
Front seats	Windshield
Rear seats	Glove box
Under the seats	Dashboard
Floor front driver	Center console middle
Floor front passenger	Center console sideways
Floor rear driver	Sideways
Floor rear passenger	Cup holders
Hook	Trunk
Door Compartments	