

Next generation of trunks in battery electric vehicles

Master's thesis in Product Development

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Cover: CAD-model of the designed trunk solution.

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Abstract

The development of battery electric vehicles (BEV) has gained momentum during recent years and the adoption rate will continue to increase. In 2020, 33 BEV models are expected to be released to the European market, compared to only six models in 2017. This is one of many examples of the development on the international BEV market. This project is based on the possibility to benefit from the new architecture and new components in modern BEVs, when designing the car's trunk. The project is limited to battery electric midsize station wagons for the European market and it is only looking at storage compartments at the rear part of the car. The first part of the project aims at analyzing technological prerequisites, customer needs and if there are any legal requirements that must be considered when developing the trunk. Flexibility and ease of use are the most important customer needs. The technological analysis showed that compared to a similar internal combustion engine car, a station wagon BEV will have more space for the trunk. The legal requirements have little impact on the design of the trunk. These findings were then used to find an effective concept that could be developed into an innovative and improved trunk solution for station wagons BEVs. This resulted in a trunk with an automatically height adjustable load floor in two sections, and a closed compartment for secure storage and cooling of groceries. The design presented, is the first iteration and multiple refinements are needed before the product can be implemented. The solution offers a high volume, flexible and easy to use trunk solution.

Keywords: trunk, boot, electric vehicle (EV), battery electric vehicle (BEV), station wagon, car, automotive.

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1 Introduction

This is the report for the master's thesis project "Next generation of automotive trunk storage". The thesis is done in collaboration with AFRY, which is the largest consultancy firm in Sweden and works mainly with engineering and design.

1.1 Background

Electric vehicles (EV) have developed rapidly the last decade. The launch of the battery electric sports car Tesla Roadster in 2008 and the battery electric hatchback Nissan Leaf in 2010 marked the beginning of a new era in the automotive industry (Wagner, 2019). In 2010, less than 1000 battery electric vehicles (BEV) were sold in the EU, eight years later, in 2018, more than 148 000 BEVs were sold (EEA, 2019). 2018 were only 1% of the total new registered cars in the EU were BEVs (EEA, 2019). The growth continued in 2019 and in the third quarter 51,8% more BEVs were registered compared to the same quarter in 2018 (ACEA, 2019). According to Bunsen et al. (2019) the market for EVs will continue to grow with an increasing pace. They mean that emission policies and cost decreasing technological development will have a major impact on the market penetration of EVs. Bunsen et al. (2019) projects that almost 50% of the new registered cars in Europe will be BEVs or plug-in hybrid vehicles (PHEVs) by 2030.

The number of new BEV models, that are coming to the European market is constantly growing. In 2017, six new models were released, however in 2020, 33 new models are expected to be released on the European market (Grelier et al., 2019). According to Grelier et al. (2019) the number of new models each year is expected to stabilize around 30 and the total number of BEV models available to the European market will reach 100 in 2022.

The components of a BEV is very different compared to a car with an internal combustion engine (ICE). Münster et al. (2016) states that "The large volume components of combustion engines, transmission and exhaust gas systems are ceasing to exist, whereas other installation spaces, e.g. electric motors, power electronics and energy storage (batteries) are being added." Other parts that are not needed in a BEV is the fuel tank and the drive shaft to the rear wheel since four- and rear-wheel-drive BEVs usually have a motor on the rear axle.

In BEVs, based on platforms that are solely designed for an electric drive train, the battery pack is normally placed under the floor, between the wheel axis (Chatelain et al., 2018). The battery placement and the nonexistent large volume components enable new design solutions in a BEV. An example of this is the "frunk" (abbreviation for front trunk), which is a storage space under the car's hood. The frunk can be found in many BEVs, for example in Tesla Model 3/S/X, Volvo XC40 Recharge, Polestar 2, Jaguar I-PACE, Porsche Taycan, BMW i3 and Audi e-tron.

It is not only the front of the car that can have new storage solutions in BEVs. The electric drive train can also enable new solutions in the back. For example, the Rivian R1T, which is a battery electric

pickup truck, has a storage space behind/under the rear seats. The compartment can be reached through hatches on both sides of the car. In general, the available space in the rear of the car increases in a BEV, which enables new solutions for the trunk. Also, the frunk is an enabler for new design solutions in the back of the car, things previously placed in the trunk can be placed in the frunk, which free up space.

Another thing that makes a BEV different compared to an ICE is the need for a charging cable and the storage of it. The cable can be wet and dirty and must be easily accessible at any time for charging. Also, the higher availability of strong electric power differentiate the BEV from the ICE vehicle. This can be a basis for new cargo applications. Volkswagen is one of many original equipment manufacturer (OEM) that plans to launch multiple new BEVs the upcoming years. They are however one of few OEMs that has shown a battery electric station wagon, the Volkswagen ID Space Vizzion. The segment for battery electric station wagons is, except the Volkswagen ID Space Vizzion unexploited at moment. One of the main selling points for station wagons are their trunks and loading capacity. Taking advantage of these new opportunities for the trunk, can in the long run improve the competitiveness of battery electric station wagons. It will positively affect the adoption of BEVs and a more sustainable transportation system.

1.2 Purpose

The purpose of this project is to understand customer needs, legal requirements and technological possibilities for trunks in midsize battery electric station wagons. These findings should result in an innovative and improved trunk design, that benefits from the new prerequisites of battery electric vehicles.

1.3 Delimitations

In order to have a market segment that is homogeneous enough to make any conclusions, the study will be delimited to the European market. The study will also be limited to the trunk of the car. This delimitation is made to increase the level of details in the final design. No other luggage compartments will be covered in the project. It may however be relevant to look at the interplay with other luggage compartments such as the passenger area and the frunk. The trunk space is limited to the area behind the rear seats of the car. Any folding of the rear seats to increase the size of luggage compartment in the back of the car are outside the scope of this project. The possibility to fold the seats will however be a taken into consideration when designing the trunk. To decrease the design space further and enable a design that can be general for a car segment, the study will cover only battery electric midsize station wagons.

1.4 Problem statements

The project will be divided into three stages, for details see chapter 2 and Figure 1. In each part, a number of problem statements are to be analyzed. Below are the different chapters presented and the associated problem statements.

Part 1: Understanding the market, customers, technological conditions and legal restrictions.

- What are the customer needs?
- What are the technical system boundaries and interfaces?
- What are the relevant legal aspects?
- What are the requirements that must be met?

Part 2: Generate and eliminate concepts for trunk solutions.

- What design concepts should be used in the final solution?

Part 3: Design an innovative and improved trunk solution.

- What design should the next generation of automotive trunk have?

2 Method

The methods used for the development of the trunk solution is a modification of the product development theories presented by Ulrich & Eppinger (2016). The method described by Ulrich & Eppinger (2016) (in brief on page 12 to 16) is a traditional waterfall process that can be applied to most product development projects. However, to tailor the process to the specific needs and prerequisites in this project, some modifications are made. The "Opportunity identification" is part of the background to the project and is regarded as fixed. Some parts of "Product planning" can also be found in the background to the project and some parts will be disregarded in order to focus on the design part of the project. The "Concept development", the "System-level design" and the "Detail design" phase are the main scope of the project, since they are most relevant for fulfilling the purpose of the project and answering the problem statements. The "Testing and refinement" and "The production ramp-up" phase are later stages of the development process and are not in the scope of this project. However, some product validation is included to have an indication whether the design is effective or not. The overall development process of the project is displayed in Figure 1. The outcome of this report should be seen as the first design iteration which needs improvements before it becomes commercialized. Important areas for improvements and opportunities that have appeared during the project are described and discussed in the report.

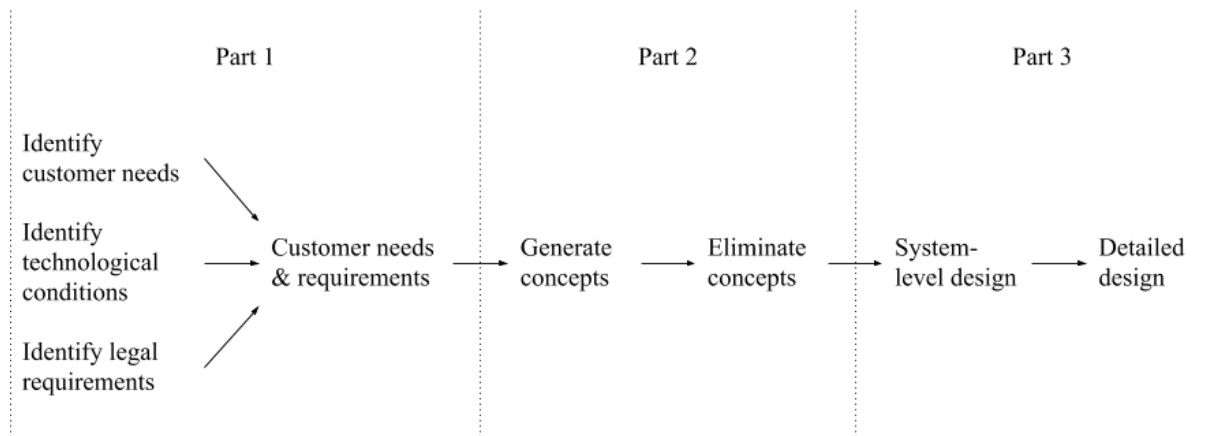


Figure 1: The overall development and design process of the project.

In the following sections the methods for the different parts of the project are described.

2.1 Part 1: Customer needs, technological conditions and legal restrictions

The questions in Part 1 were studied in a literature review, by having interviews and doing observations. The aim with these three methods was to have multiple perspectives on the problem statements in part 1. The methodologies used are described in detail below.

2.1.1 Literature review

The following things were studied in the literature:

- **Customer needs.** Searching for general trends and user studies of the trunk and the car in general, that could be translated into customer needs.
- **Technological aspects.** Analyzing technological possibilities and challenges related to the trunk in a BEV.
- **Benchmarking.** Looking at the bestselling cars today and how the trunks compare when it comes to trunk volume and functionality.
- **Legal aspects.** Investigating what legal aspects that are relevant for the development of the trunk.
- **Future trends.** Searching for both specific and more general trends in society, that might have an impact on how a car and its trunk might be used in the future.

2.1.2 Interviews with automotive experts and car dealers

The following things were studied by having interviews with experts from the automotive industry:

- **Customer needs.** Interviewing car dealers and people working in the automotive industry to get their view on what customer needs are relevant for the trunk.
- **Technological aspects.** Interviewing experts from the automotive industry to get an understanding of what major technological aspects that are relevant for the trunk in BEVs.
- **Future trends.** Interviewing experts from the automotive industry and car dealers regarding, for this project, relevant trends in the automotive industry.

For this kind of interviews, Mann (2016) recommends that the interviews are semi-structured. This enabled the interviewees to talk freely about the subject, at the same time as it was possible to have answers for specific details. The aim was to find interviewees from different companies and organizations. In total, six people with different expertise in the automotive industry were interviewed. The interviewees come from AFRY, NEVS and Autoliv. In addition to the experts, seven car dealers were interviewed, all selling different car brands.

2.1.3 Observations of existing solutions

15 different car models were studied at the car dealers. Ten of the cars are midsize station wagons and five are BEVs of different sizes. Measurements were taken to understand how the trunk of a modern car is shaped. All features were noted, and pictures were taken of all the trunks. The material was also used later in the concept generation phase.

2.1.4 Customer needs

The relevant data from the literature review, interviews and observations were analyzed and summarized into a customer needs list. As recommended by Ulrich & Eppinger (2016), all the needs were rated, based on their importance for the customers. This rating was done by the author and is based on an aggregation of the findings from the chapter. Customer needs that could be derived from multiple different sources and customer needs that had strong arguments backing their importance were rated as "very important" in the customer needs list. Customer needs, with less solid foundation were rated "important" and customer needs with only some indications as backing, were rated as "not important".

2.1.5 Requirements

The requirements are based on the literature review, interviews and observations. The most important customer needs, technological prerequisites and the legal requirements lead to a number of minimum requirements. The requirements were translated into a number of metrics with associated marginal values, which any of the solutions must meet in the upcoming development.

2.2 Part 2: Generate and eliminate concepts for trunk solutions

The next step in the development process was to find solutions that satisfy or preferably exceed the expectations of the customers, at the same time as it meets the technological and legal requirements.

Product concepts were generated in parallel with the data gathering and data analysis, which is recommended by Holmdahl (2010). It makes the development process more dynamic and generates a continuous learning process.

2.2.1 Concept generation

In the concept generation phase, concepts were generated based on the findings in the earlier phases. Three main methods were used to generate concepts:

- **Interviews.** As previously mentioned, people working in the automotive industry and car dealers were interviewed, to collect data for the first part of the project. The interviewees were also asked for general ideas and solutions to the problems they have highlighted. Concepts were then created from the relevant ideas from the interviews.
- **Benchmarking.** Concepts were generated based on existing trunk designs and solutions.
- **Brainstorming.** Two types of brainstorming were used. Unstructured ones with the team working with the project took place several times. A structured one was held at AFRY, where people working in the automotive industry were invited. The participants received some background to the project and what the purpose of the brainstorming session was a couple of days before it took place. Based on recommendations by C. Wilson (2013) four focus questions were used during the brainstorming. This was done to make it easier for the participants and to have ideas that solves

actual problems found in the previous parts of the project. Afterwards, the ideas were grouped and translated into a number of concepts.

2.2.2 Eliminate concepts

The elimination of concepts was done in a number of steps and some of the concepts were also improved during this phase of the project. In the first step, concepts were eliminated if they did not meet all the metrics that were translated from the requirements in part one. Concepts were also eliminated if they were outside the scope for this project or lacked relevance for the project.

The remaining concepts after the first elimination already met the legal and technical requirements, which meant that the legal and technical aspects could be excluded from the elimination criteria for the following elimination steps. The elimination criteria used for the next part of the elimination were therefore solely based on the customer needs. The customer needs were translated into a number of criteria that were used in the second and third part of the elimination. This approach made sure that any resulting concept is closely tied to the customer needs. Except for the elimination criteria that were directly translated from the customer needs, two extra criteria were added after a discussion with the team at AFRY. These criteria were added based on the expertise of the engineers at AFRY and they represent important parameters that are general to product development of cars.

The remaining concepts after the first elimination were combined and improved to create a solution for the overall design. The second part of the concept elimination was based on structured methods that eliminate concepts based on decision matrices. Ulrich & Eppinger (2016) recommends an approach with two steps, "Concept screening" and "Concept scoring" (pp. 152-159). The first step "Concept screening" compares the concepts to a reference concept. The reference was a simple concept that is similar to existing solutions in car trunks. The screening was done by the author and three engineers from AFRY. The step was iterated twice, to confirm the outcome.

In the final step, "Concept scoring" was used to eliminate one of the two remaining concepts for the main structure of the trunk. The elimination criteria were first weighted, then each concept was given a score from one to five for all criteria. This was done by the author and three engineers from AFRY. The "Concept scoring" is a method suggested by Ulrich & Eppinger (2016) and it uses a reference concept when deciding the scores for the concepts.

Concepts that did not cover the overall design of the trunk were studied separately and were either eliminated, needed further analysis or included in the final solution. A concept was eliminated if it had substantial downsides or the functionality were already in the resulting concept for the overall design. If the concept was not eliminated, it was either included in the design or in need of further analysis to understand if the concept could be eliminated or not.

2.3 Part 3: Design an innovative and viable trunk solution

In part 3 of the project, the product design started to take shape. The first step was to decide the main components and make a system level-design. The second and final design step in this project is the detailed design. This methodology is based on the recommendations by Ulrich & Eppinger (2016) (p. 15). After the design was completed it was also evaluated by engineers at NEVS.

2.3.1 System-level design

The system level design is the first design step of the final solution in the project. According to the Ulrich & Eppinger (2016) it should include "the definition of the product architecture, decomposition of the product into subsystems and components, preliminary design of key components" (p. 15). This was applied to the resulting concept and a system level-design was made.

2.3.2 Detailed design

The detailed design phase was the last design part of the project. The aim was to deliver a detailed, three-dimensional, CAD-model and a description of the functionality of the trunk. The CAD-model was created in CATIA v5. The first step was to replicate the shell of the rear part of the body. This was done by taking measurements and looking at pictures of a midsize station wagon. The shell was modified so it represented how a future battery electric midsize station wagon might look like. Other products with similar functionality as some of the parts in the resulting concepts were studied to find suitable technical solutions. If there were multiple candidates for the solution, these were compared, and the most effective solution was used. The features and the safety concepts were not included in the CAD-model due to time constraints.

2.3.3 Evaluation of design

The final step of the process was an evaluation of the design. The design was showed to automotive engineers at NEVS and they were asked to give feedback on the solution. They were asked to give general comments of pros and cons with the design, and also to answer some questions about specific parts of the design. This was done to create a starting point for future design iterations.

3 Part 1: Customer needs, technological conditions and legal restrictions

The first part of the project was about understanding the market, how the customers use their cars and trunk, what technological and legal aspects that must be considered during the development of the trunk. Three different methods were used to do this, a literature, interviews and observations. In the end of the chapter, the findings are summarized into a customer needs list and a list of requirements.

3.1 Literature review

In the literature review, the market, how the trunk is used, future trends, legal and technological restriction were studied. The outcome from the literature study is presented below.

3.1.1 Defining the market

BEVs are more expensive than comparable cars with ICE, the battery prices are a major cost driver in BEVs (Mehta & Hamke, 2019). The battery prices have declined and are predicted to do so also in the future (Mehta & Hamke, 2019). Until now the battery capacity of BEVs has also increased, but for some models it has now reached a capacity that are equivalent with ICE cars (for example the Tesla Model 3 has a distance range of 560 km according to the WLTP test procedure (Tesla, 2020)). This means that the range might be sufficient and that the decreasing battery prices also will lead to a decreased total car cost. In Table 1 the prices for the most popular BEVs are presented.

Model	Units sold	Type of car	Price (SEK)
Tesla Model 3	64 043	Compact executive car	549.900
Nissan Leaf	24 488	Small family car	397.000
VW e-Golf	19 680	Small family car	387.900
Hyundai Kona EV	16 964	Subcompact crossover SUV	364.900
Audi e-tron	11 177	Mid-size crossover SUV	799.000
Jaguar I-PACE	9 540	Compact luxury crossover SUV	939.900
Kia Niro EV	8 060	Subcompact crossover SUV	444.900
Hyundai Ioniq Electric	6 631	Compact car	389.900
Tesla Model S	6 515	Full-size luxury car	939.900
Tesla Model X	5 743	Mid-size luxury crossover SUV	1.034.900

Table 1: Prices and sales volumes of the best selling BEV models (only midsize and large vehicles) in Europe, January to September 2019. The volumes are based on data from Pontes (2019) and the prices are for the Swedish market and they are retrieved from the OEM websites in February 2020. All prices are for the lowest priced specification of each model and without any governmental grants.

Table 1 shows large variation in BEV prices, the Hyundai Ioniq Electric is the cheapest starting at 389.900 SEK. Adding some extra equipment, the price will increase beyond 400.000 SEK. A station wagon which is in the scope of this project is also larger and will probably be even more expensive. However, prices are expected to decline in the future. Another important factor, which according to (Bireselioglu et al., 2018) is often underestimated by the customer, is that the cost of operating a BEV is lower compared to an ICE vehicle due to lower operation cost and less need for maintenance.

Taking all this into consideration, the price segment that will be targeted in this report will start at 400.000 SEK. The customer who buys a BEV in the upcoming years are also likely to be more concerned about the climate change and want to decrease the negative impact he or she has on the climate. The targeted customer for this project is someone who can afford a car for at least 400.000 SEK, has a need for a station wagon, likely has a family and is more concerned about the climate change than the average person.

3.1.2 Trunk use

Zarazua de Rubens et al. (2020) did a survey in Sweden where they asked people, among many things, for what purposes they used a car the previous week. The valid sample size was 885 people. 91% owned a car, the average age was 50 (with a standard deviation of 12,9), 51,8% were women, 48,2% had a university education, 14,7% lived in a single household, 42,6% lived in a household with children, 64,4% lived in a detached house, 66,8% lived in a household with a yearly income between 300.000 SEK and 900.000 SEK and all type of municipality sizes were well represented among the respondents. In Figure 2 the proportion of survey respondents that used a car at least once the previous week for different purposes is presented.

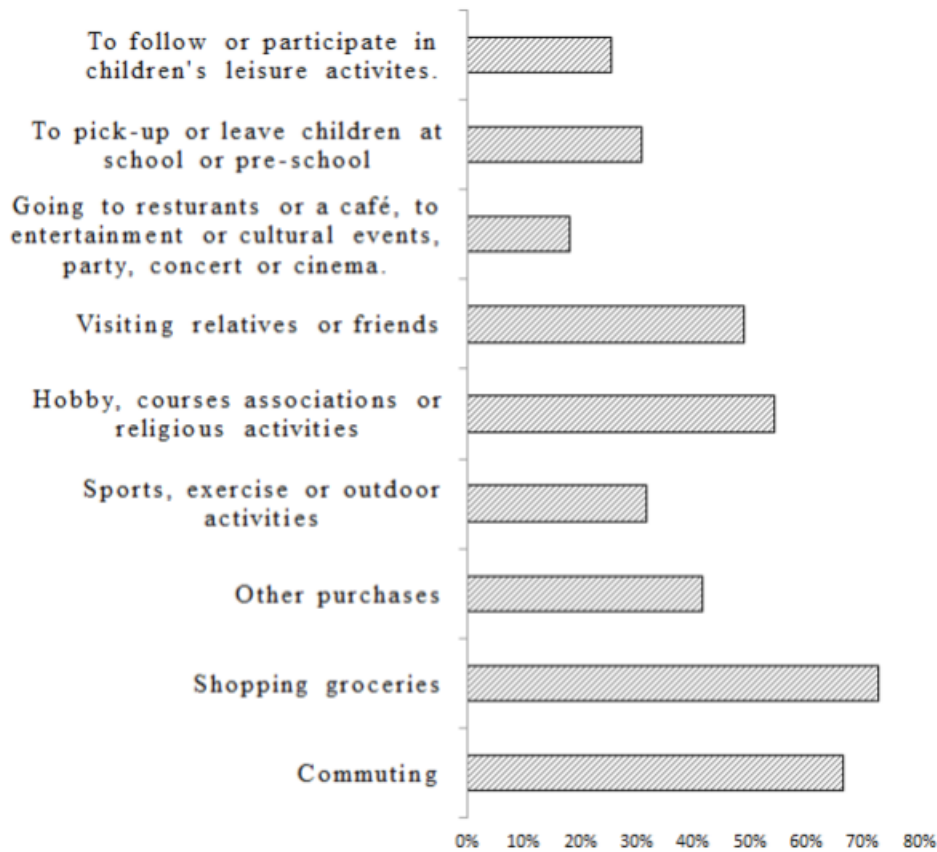


Figure 2: Proportion of survey respondents that used a car for different transportation purposes at least once the previous week. The Figure is based on data from Zarazua de Rubens et al. (2020).

Figure 2 displays that the car is being used for a broad variety of different purposes. The data shows that shopping groceries and commuting are important areas when it comes to how the car is used by the sample. Both these areas were also the most frequent ones. Many people used their car multiple times for grocery shopping and commuting (Zarazua de Rubens et al., 2020). Around 50 percent of the respondents used the car for "Visiting relatives or friends" and "Hobby, course associations or religious activities". The other activities had substantially lower using rates, however all were used of at least 18% of the respondents the previous week.

From the data in Figure 2 it is possible to elicit customer needs for the different usage areas. Potential needs for each of the categories are presented below and are based on a brainstorming session by the author:

To follow or participate in children's leisure activities:

- Transportation of sports equipment.
- Transportation of music instruments.
- Transport cargo that is dirty and/or wet.

- Bringing food and beverages for the activities.

To pick-up or leave children at school or pre-school:

- Transportation of school bags.
- Time efficient solutions to fit a hectic everyday living.

Going to restaurants or a café, to entertainment or cultural events, party, concert or cinema:

- Transportation of appropriate clothing for the occasion.
- Easy access of umbrella.
- Staying clean when loading and unloading the trunk.

Visiting relatives or friends

- Transportation of luggage for longer visits.

Hobby, course associations or religious activities:

- Transportation of needed equipment, for example music instruments, painting materials etc.

Sports, exercise or outdoor activities:

- Transportation of needed equipment, for example bags with clothing, golf bags, dog cages, skies, bikes, fishing and hunting equipment
- Transport cargo that is dirty and/or wet.
- Bringing food and beverages for the activities.

Other purchases

- Transportation of for example goods from a hardware stores and other heavy and bulky cargo.

Shopping groceries

- Transportation of grocery bags.
- Keeping groceries cool.

Commuting

- Transportation of clothes and other equipment related to the work.

A similar survey to the one by Zarazua de Rubens et al. (2020) were made in Great Britain in 2006, which is presented by Lucas & Jones (2009). The study consisted of 8 400 randomly selected British households.

In similarity with the study by Zarazua de Rubens et al. (2020) it showed that the car is being used for a variety of different purposes and that it is an important part of many people's lives. Lucas & Jones (2009) display that much of the traveling by car is done as a passenger, except when it comes to commuting and business-related journeys which most of the time is done only by the driver.

In a master thesis project by Kandukoori & Pinnamaneni (2018) a number of interviews were done, with the purpose to understand the customer needs for a trunk. How the sample was made is not stated in the report, but in total 14 people were interviewed. All of them were men and the age were between 22 and 54. There are multiple gaps in the data that is presented by Kandukoori & Pinnamaneni (2018), but there are some useful parts that can be translated into customer needs for the trunk. A summary of the interviews is presented in Appendix A. It becomes clear that a car is used for a variety of different purposes and that people store and transport a range of different goods in their cars. 9 out of the 14 interviewees mentioned shopping groceries as something they use their car for on a regular basis. Commuting was done regularly by many of the interviewees, 8 out of 14. Also bringing a cool box is something that multiple interviewees mentioned as something they do on longer trips. The following things did at least of the interviewees store in their car: snow shovel, umbrella, towing rope, blanket, jumper cables, washer fluid, reflective vests, oil, tools, pressure pump, extra light bulb, ice-scraper, brush for snow, washing equipment, de-icing spray, napkins, vacuum cleaner, bike holder, roof racks and cooling water (Kandukoori & Pinnamaneni, 2018). The interviewees in the study by Kandukoori & Pinnamaneni (2018) also talked about some negative experiences they have had connected to the trunk, some examples of these are presented below:

- No possibility to hold the load floor in place when loading/unloading the storage compartment below the load floor.
- Curved side walls of the trunk make it more difficult to fit luggage when the trunk is fully loaded.
- Pockets on the trunk walls make it more difficult to fit luggage when the trunk is fully loaded.
- Difficult and/or time consuming to use securing equipment and hooks.
- Lack of securing options.
- Rubber mat makes it difficult to load/unload heavy luggage.

The interviewees in the study by Kandukoori & Pinnamaneni (2018) also mentioned some ideas and some preferences they have regarding the trunk, the most relevant ones are listed below.

- The trunk should be flexible for different transportation purposes.
- A dedicated tool storage solution.
- Flat access to the trunk.
- All luggage to be easy to reach.

- Warning triangle to be easily accessible at all times.
- Possibility for cooling (of beverages).
- Possibility to organize the luggage.

Transporting groceries are one of the trunk's main functions. Kim et al. (2013) have highlighted a potential problem with transporting and storing groceries in the trunk. Frozen and refrigerated food can on a warm and sunny summer day reach a temperature that can lead to bacterial growth in a fairly short amount of time (Kim et al., 2013). According to Kim et al. (2013): "The temperature of refrigerated foods (egg, milk, and fresh meat) reached 20 °C within 40 min". The authors emphasize that frozen and refrigerated food only should be kept at limited amount of time in the trunk and that it should be placed in a freezer or refrigerator as soon as possible, especially during warm and sunny days.

3.1.3 Technological aspects

There is yet no dominant design for the placement and the design of battery packs in BEVs. Different car manufacturers use different solutions. There are however some indications for a flat battery pack between the wheels as the most effective design Chatelain et al. (2018). Important factors for the placement of batteries and battery design are according to Arora et al. (2016) the vehicles center of gravity, mechanical stress on the chassis, battery cooling and safety. Due to safety reasons, Arora et al. (2016) mean, that the battery pack should be placed separated from the passenger area and away for the collision areas in the front and the rear of the car. Based on this, Arora et al. (2016) state the following regarding battery placement:

“An ideal space for such storage is in the centre of the vehicle beneath the vehicle floor, but because of the limited ground clearance in passenger vehicles, any such support structure must be carefully designed to use the available space for maximum effectiveness.”

One of the leading OEMs on the BEV market, Tesla, uses a "skateboard" platform for their vehicles, it is a flexible platform that is BEV specific (Hossay, 2019, pp. 231-232). The skateboard platform is displayed in Figure 3.

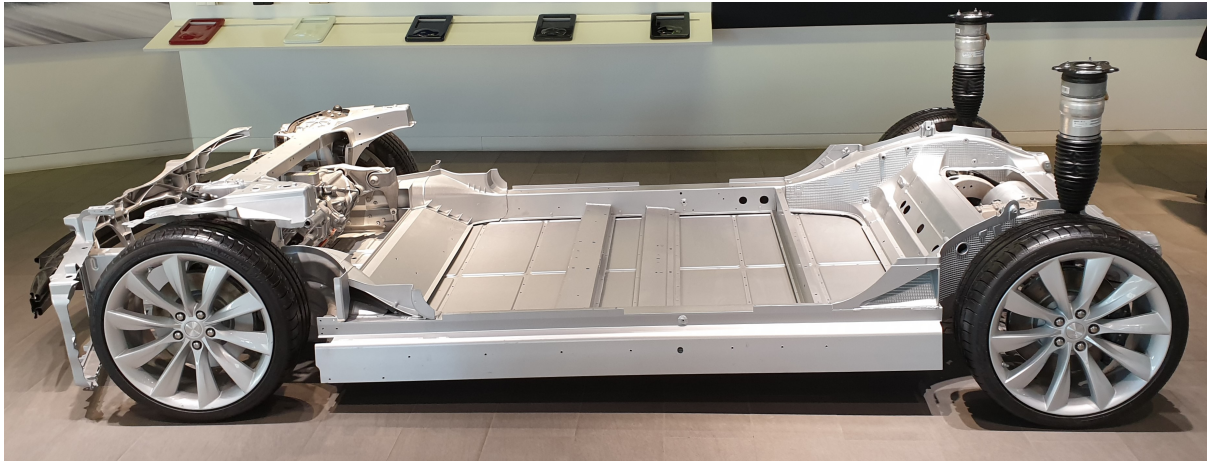


Figure 3: The Tesla skateboard platform for Tesla Model S and Model X.

Tesla Model 3 is based on a similar skateboard platform, where the battery is placed between the wheel axis and the motors are placed between the rear wheels and the front wheels (for the four-wheel drive version) Tesla (2018). The design is in accordance with what Chatelain et al. (2018) predict as a future dominant design and it fulfills the parameters for an effective battery design and location by Arora et al. (2016). The Jaguar I-pace has a similar architecture, see A2Mac1 (2019) for details. The Nissan Leaf's battery pack is also placed under the seating area of the car, see Figure 4.



Figure 4: Cutaway of Nissan Leaf, showing the location and design of battery (Wikimedia Commons, 2013).

The design and the location of batteries are important factors for the trunk since it has a direct impact on the available space in the rear of the car. Rear motors are common among premium BEVs, see Table 2. The rear motor decreases the available space in the rear of the car, this is space that otherwise can be used for new storage solutions. Figure 5 shows an example on how the rear motor in a Tesla Model S and Model X takes up space which otherwise could be used for increased trunk volume.

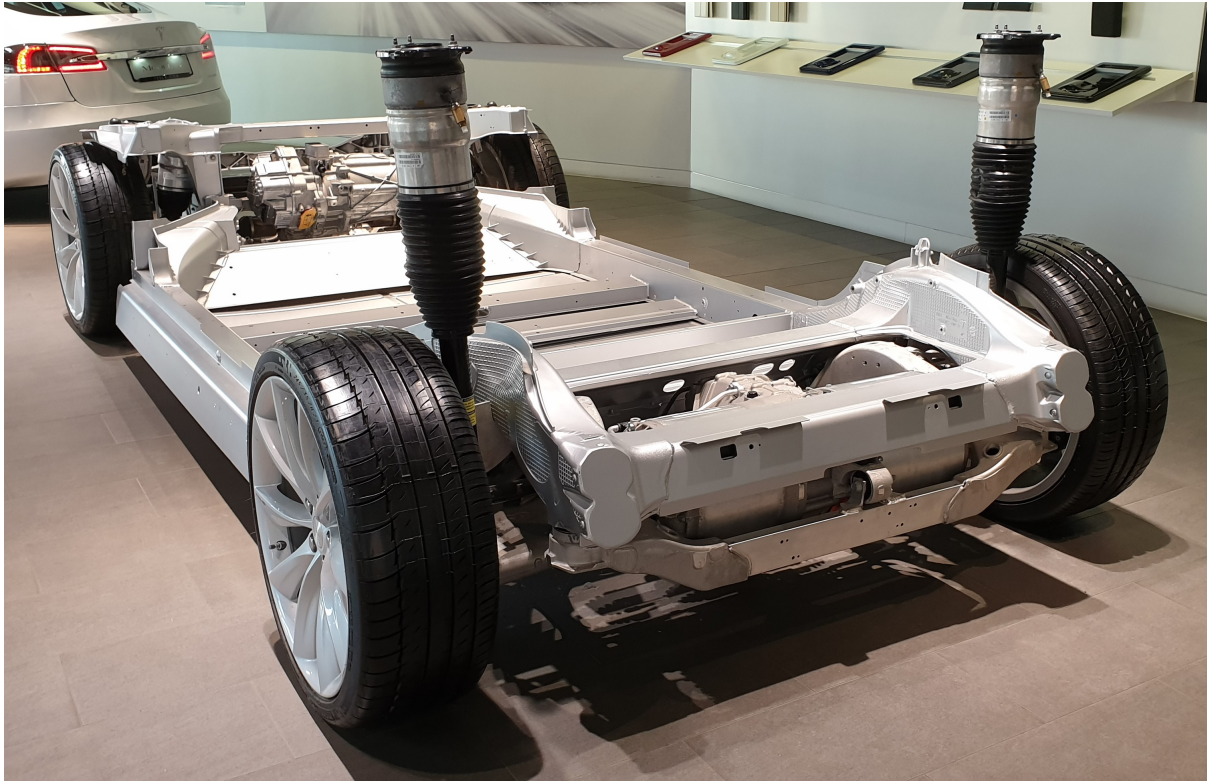


Figure 5: The rear part of the Tesla skateboard platform.

When taking a closer look at the Tesla platform in Figure 5 it is possible to see that the beams holding up the rear part of the car have been cut. The beams hold up the rear bumper and the trunk of the car.

A technology that would have a positive impact on the space in a car are in wheel motors (IWMs), also called hub motors, which might be the future for BEVs (W. Wang et al., 2019). According to W. Wang et al. (2019), IWMs are still in a development phase and not ready to be implemented in a car yet. However, the technology is promising and have multiple benefits compared to a centralized power train. It has potentially a higher efficiency, it enables new chassis designs and it creates more space in the vehicle (W. Wang et al., 2019). However, a major drawback with IWMs is the increased unsprung mass (W. Wang et al., 2019).

Model	Propulsion	Motor location
Tesla Model 3	AWD or RWD	Front and rear or rear
Nissan Leaf	FWD	Front
VW e-Golf	FWD	Front
Hyundai Kona EV	FWD	Front
Audi e-tron	AWD	Front and rear
Jaguar I-PACE	AWD	Front and rear
Kia Niro EV	FWD	Front
Hyundai Ioniq Electric	FWD	Front
Tesla Model S	AWD	Front and rear
Tesla Model X	AWD	Front and rear

Table 2: Best selling BEVs in Europe January to September 2019 (Pontes, 2019), propulsion wheels and motor location. AWD: all-wheel drive, FWD: front wheel drive, RWD: rear wheel drive.

A frunk, which is an abbreviation for front trunk, can be found in many BEVs. A storage compartment in the front of a car can often also be found in sports cars with rear engines. The difference between sports cars and today's BEVs is that the frunk is an extra storage compartment, in addition to the trunk. Not all BEVs has a frunk, for example the Nissan Leaf, VW e-Golf, Hyundai Kona EV, Kia Niro EV and Hyundai Ioniq Electric are without funks. However, all of Tesla's models and the electric SUVs from Audi and Jaguar have frunks.

3.1.4 Benchmarking

To get a holistic view of the best available trunk design solutions on the market today, both the best selling large and midsize BEVs and the best selling midsize station wagons in Europe are a part of the benchmarking. Table 3 shows the ten best selling midsize and large BEVs in Europe, for the first three quarters of 2019.

Model	Units sold	Type of car	Trunk volume (l)
Tesla Model 3	64 043	Compact executive car	425
Nissan Leaf	24 488	Small family car	435
VW e-Golf	19 680	Small family car	341
Hyundai Kona EV	16 964	Subcompact crossover SUV	330
Audi e-tron	11 177	Mid-size crossover SUV	605
Jaguar I-PACE	9 540	Compact luxury crossover SUV	505
Kia Niro EV	8 060	Subcompact crossover SUV	451
Hyundai Ioniq Electric	6 631	Compact car	455
Tesla Model S	6 515	Full-size luxury car	744
Tesla Model X	5 743	Mid-size luxury crossover SUV	n.d.

Table 3: BEV sales by model in Europe, midsize and large vehicles, January to September 2019 (Pontes, 2019).

Table 4 shows the best selling ICE midsize car models in Europe for the first three quarters of 2019. There are 13 models in the table and some models has both a station wagon version and a sedan version. The units sold are the total sales of both versions.

Model	Units sold	Trunk volume (dm ³)
Mercedes-Benz C-Class	113 122	490
VW Passat	90 621	650
BMW 3-series	86 793	500
Audi A4/S4/RS4	80 952	495
Skoda Superb	51 734	660
Volvo V60	48 549	529
Opel Insignia	36 976	560
Ford Mondeo	30 782	525
Peugot 508	30 164	530
Mazda 6	16 810	506
Renault Talisman	12 060	572
Kia Optima	9 901	552
Subaru Outback	4 562	512

Table 4: midsize car sales by model in Europe, January to September 2019 (Demandt, 2019a) (Demandt, 2019b). Some of the models includes both sedan and station wagon, only the trunk volumes of the station wagons are presented.

The volume is only one of many important aspects when it comes to the trunk. To get a better understanding and be able to compare different design solutions in the trunk, some of the models in Table 3 and 4 will be studied in detail. The results from the study will be presented in section 3.3.

3.1.5 Vehicle regulations

Vehicle regulations in all European countries are decided by the transportation division of UNECE (UNECE, 2020a), which is a part of the United Nations. UNECE applies the regulation of WP.29, which is described by UNECE (2020b) in the following way: "Regulation (WP 29) offers a unique framework for globally harmonized regulations on vehicles. The benefits of such harmonized regulations are tangible in road safety, environmental protection and trade". Based on information from Carhs (2019), Wikipedia (2020) and studying the regulations by UNECE in detail, regulation R17, R32 and R42 are regarded as relevant for the design of the trunk in this project. R17, R32 and R42 either effect the inside construction of the trunk or the rear part of the car.

Regulation R17 applies, among several things, to: "Vehicles of category M₁ with regard to the design of the rear parts of seatbacks and the design of devices intended to protect the occupants from the danger resulting from the displacement of luggage in a frontal impact" (UNECE, 2014). The test procedure is described in detail in UNECE (2014). The following paragraph gives a brief overview of the test procedure

To simulate luggage, two types of test blocks are used. Blocks of type 1 have the dimensions 300 mm x 300 mm x 300 mm and a mass of 18 kg. Blocks of type two have the dimensions 500 mm x 350 mm x 125 mm and a mass of 10 kg. When tested, two blocks of type 1 are placed on the load floor, 200 mm from the backs of the back seats and 50 mm apart. One type 2 block is placed on a temporary shelf, so the center of mass of the block is centered between the roof and the top part of the seatbacks (excluding head restraints). See Figure 6 for test layout. A crash is then simulated using a test rig and a deceleration function. The back seats and any cargo net must be able to withstand the forces from the test blocks in a simulated crash. Some deformation is allowed both in seatbacks and in the partitioning system, see paragraph 5.16.1 - 5.16.5 in UNECE (2014).

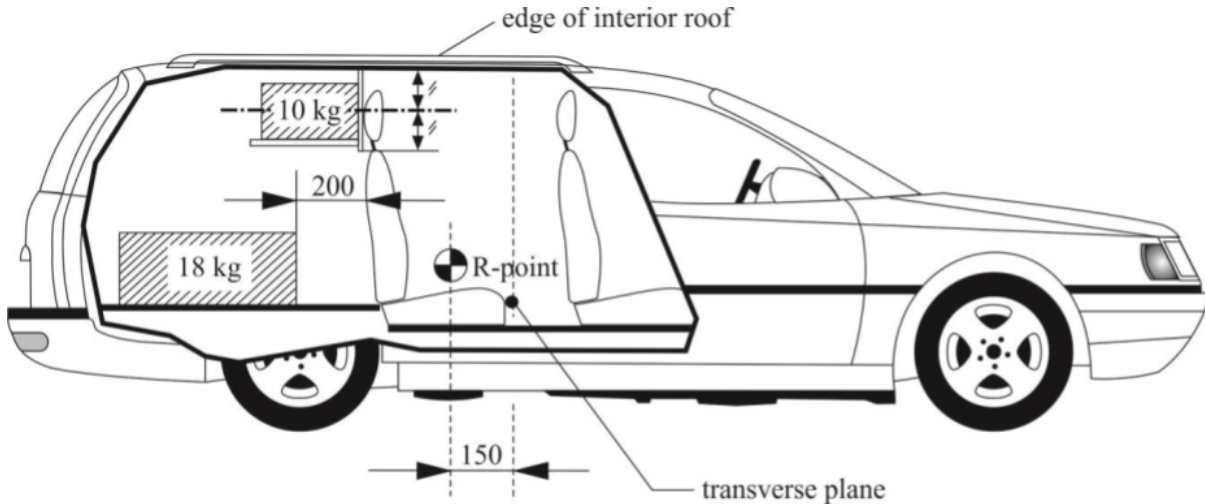


Figure 6: Test layout of UNECE's vehicles regulation R17. Copyrights UNECE (2014).

Regulation R32: "applies to the behaviour of the structure of the passenger compartment of private (passenger) cars when subjected to rear-end collision" (UNECE, 1993). When designing the trunk, it is decisive that any modification of the rear part of the vehicle meets the requirements in R32. The following paragraph is an overview of how the test is done based on the description in (UNECE, 1993).

The test vehicle is standing still and is impacted from the rear by an impactor. The impactor has rigid construction made of steel with a mass of 1100 kg. The impacting surface is covered with a 20 mm layer of plywood and it should be at least 2500 mm wide and 800 mm high. The impacting surface has a ground clearance of 150-200 mm. The impactor strikes the vehicle with a speed of 35-38 km/h. The following requirements should be met for test approval (UNECE, 1993):

- The vehicle's structure shall not be deformed in any major ways by the test, for details see paragraph 5.1 in UNECE (1993).
- "After the test, no rigid component in the passenger area shall constitute a risk of serious injury to the vehicle's occupants."
- "The side doors of the vehicle shall not open under the effect of the impact."
- The opening of a number of doors sufficient to enable all the occupants to emerge shall, after the impact, continue to be possible without the use of tools."

Regulation 42: "applies to the behaviour of certain parts of the front and rear structure of passenger cars when involved in a collision at low speed" (UNECE, 1980). Similar to R32, R42 might have an influence on how modifications of the rear end of a vehicle can be made to enable new trunk designs. The following paragraph gives an overview of the parts in R42 that is relevant for this project based on the information in UNECE (1980).

The vehicle's rear-end is hit by an impactor at low speed (4-4,25 km/h). The rear corners are hit by the

impactor at low speed (2,5-2,6 km/h). The center line of the impact area hits the vehicle 445 mm over the ground. The impact area on the impactor is 810 mm wide and 114 mm high. This means that the highest part of the vehicle that is hit by the impactor is 502 mm (445 mm + 114/2 mm). See Figure 7 for details of impactor.

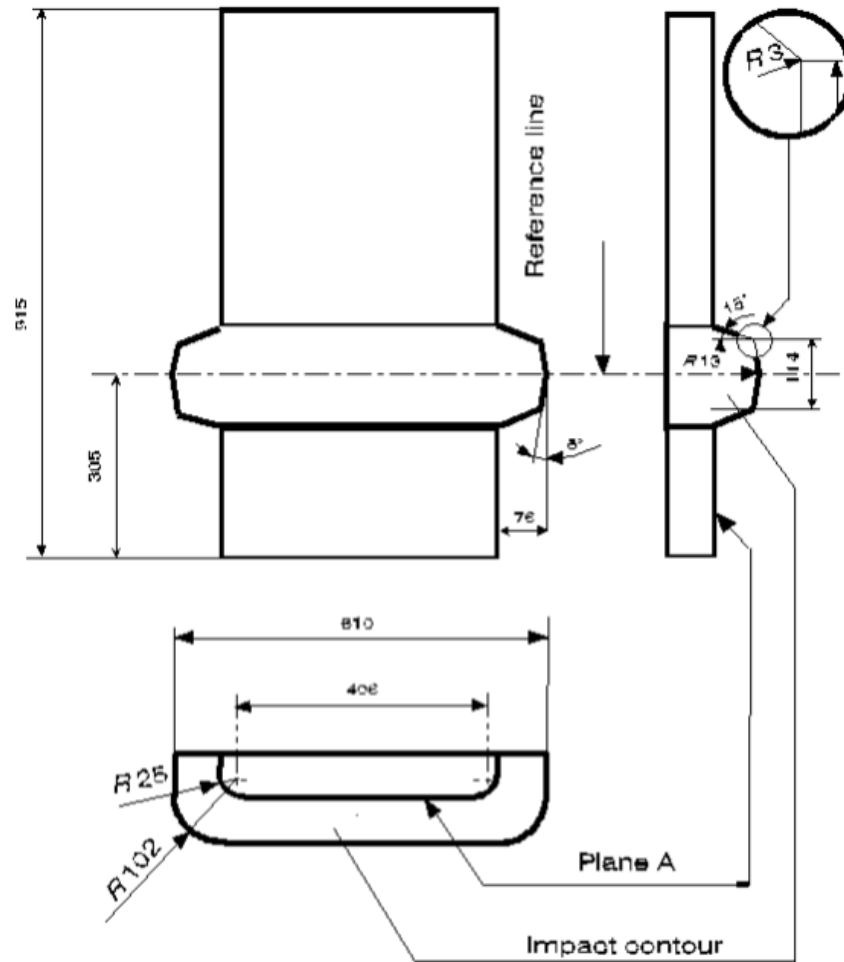


Figure 7: Impactor in vehicle regulation R42 by UNECE. Copyrights UNECE (1980).

After the test, the following requirements should be met (UNECE, 1980).

- "The lighting and signalling devices shall continue to operate correctly and to remain visible."
- "The vehicle's bonnet (hood), boot lid (trunk lid) and doors shall be operable in the normal manner."
- "The vehicle's propulsion, suspension (including tyres), steering and braking systems shall remain in adjustment and shall operate in a normal manner."
- The vehicle's cooling system shall work correctly.

Another important aspect is that a car for the European market must be fitted with certain safety equipment that needs to be stored in the car. The mandatory equipment varies between countries, but

to meet most national requirements in Europe the car should have a warning triangle, a fire extinguisher, a first aid kit, high visibility vests and spare bulbs (European Commission, 2016).

The regulations by UNECE are developed to ensure the safety of vehicles. The safety ratings by Euro NCAP have also had major impact on the general safety of cars. None of the tests by Euro NCAP do however involves any luggage and the impact it might have on the safety of the tested vehicle, see Euro NCAP (2019) for detailed test protocol.

There are studies that suggest that the regulations by UNECE do not represent a real case scenario. Vroman et al. (2003) states that the requirements in R17 are too soft and that the rear seats are not designed to protect the passengers from more realistic luggage scenarios in a crash. Tests by Vroman et al. (2003) shows devastating results on luggage that pushes into the passenger compartment. Z. Wang et al. (2016) sees the same problem and suggest that seatbacks should be reinforced and they especially emphasize the split seat-back as the weak part of the design.

3.1.6 Future trends

It is not relevant to only look at how cars and trunks are used today, therefore some future trends are also analyzed. Trends that might impact the trunk design in terms of new needs and opportunities are studied.

Car sharing

Car sharing has gained popularity in recent years and the advantages are many compared to a traditional private car ownership, both from a car owner's point of view and for the society (Shaheen et al., 2019). The adoption of EVs is positive for car sharing since EVs has a lower operation cost compared to ICE vehicles (Mehta & Hamke, 2019). Car sharing in Europe will continue to grow and the main reasons for this are according to Chicco et al. (2018) "the rising population living in the cities, the popularity gained by car sharing services, the rising costs of owning a car and lastly the increasing awareness of citizens about environmental issues". The OEM Lynk & Co plans to solely offer leasing of their cars to customers and as a part of the service, they will also offer the customers the possibility to share their car with other people (Rabe, 2016).

Last-kilometer transport

Alternative transportation for the last-kilometer transport have started to gain popularity globally. Bikes have for a long time been an efficient way for transportation in cities. But during recent years also e-bikes and e-scooters have become more a more popular for last-kilometer transportation (Mehta & Hamke, 2019). E-bikes and e-scooters might be according to Mehta & Hamke (2019) be important to reduced traffic congestion in cities.

In-car delivery

The OEM Volvo Cars offers "In-car delivery" which is a service for delivery of e-commerce products directly to the trunk of Volvo vehicles. Both retail products and groceries can be delivered to the trunk

(Volvo Cars, 2020). The service is only available on a few markets. The global e-commerce retailer Amazon offers a similar solution to their American customers, although it is limited to a few regions and a limited number of car brands (Fries, 2018).

3.2 Interviews

Interviews were held with people working in the automotive industry and car dealers. The people from the automotive industry have all many years of experience in their specific field of expertise. The years of experience among the car dealers vary from a few months to multiple years. Below are the relevant parts of the interviews presented.

3.2.1 Interviews with car dealers

In total seven interviews were held with car dealers in Trollhättan and Gothenburg. Representatives from different brands were asked about what their customers emphasize when buying a new station wagon and who their customers are. All the data gathered from the interviews is presented in Appendix C.

The main outcome from the interviews is that all different kinds of customers buy station wagons, but the most common ones are families with kids. Companies are also a major customer segments, where the end-users in this case are mostly families and salespeople. The car dealers mean that the trunk of a station wagon must be suited for all different kind of purposes, e.g. everything from transporting, groceries, baby strollers, golf bags and dog cages in everyday life, to going on vacations or transporting building material from the hardware store. When buying a station wagon many customers take measurements to make sure that their specific items will fit in the trunk, this is according to the interviewees much more important than the actual volume. According to the interviewees, very few customers consider any safety aspects in the trunk, except the cargo net between the trunk and the passenger compartment. Having a flat load floor seems to be mandatory for station wagons. The salesperson for BMW highlighted that some customers have requested a deeper space underneath the main load floor. The salesperson for Volkswagen has experienced that some customers feel that the trunk is too deep in some vehicles, since they cannot reach items that are placed against the seatbacks. He explains that some OEMs has a wall that can be folded up to divide the trunk and make it less deep. All the station wagons that were studied have some sort of felt material in the trunk, but according to the car dealers the majority of customers buy a rubber/plastic mat to put on the load floor.

When talking to most car dealers the trunk seems to be low prioritized by the customers when they buy a new car. The customers are satisfied as long as they can fit some specific items (baby stroller, golf bag etc.). For example, when asked about trunk volume one of the car dealers of the premium brands said the following: "No one cares about the volume. The customers look and make a judgment if it is big enough. Vanity is more important than trunk volume." Some of the car dealers were asked about the spare wheel and they said that barely no one buys it anymore. None of the cars that were studied were equipped with a spare wheel as standard.

3.2.2 Trunk experts at NEVS

Two lead engineers at NEVS were interviewed with the purpose to understand what is important when designing a trunk in a station wagon and what new possibilities appear with BEVs. The interviewees highlighted the advantage with having a frunk. They mean that all mandatory safety equipment and tire repair kit can be placed there. According to them, the frunks in today's BEVs are not suited for the everyday use, since they are difficult to use and lacks effective handles for opening and closing. People are also not used to have a frunk, so many BEV owners do rarely use the frunk. Important parameters for the trunk in a station wagon are according to the engineers:

- The overall volume.
- Trunk-lid opening height.
- Trunk opening dimensions.
- The ability to withstand high spread loads and point loads.

Other important features that should be included in the trunk are:

- Air outlets.
- Cover the body in white.
- Handles for closing the trunk-lid.
- Sound system.
- Possible to change rear lights and reach fuses.
- Most customers want a cargo net and a visibility cover.
- 12V-outlet for cool box.
- Different kinds of hooks.
- Effective sound proofing, especially around the wheelhouses.

The interviewees mean that most customers want felt material in the entire trunk and that rubber mats are rarely used as a standard material. The material should be durable and easy to clean. For most station wagons the same material is used in the trunk as in the passenger area, since it is all a part of the same space. There is often a high demand for appearance in station wagon trunks. Traditionally the load floor has been made of wood, but some companies develop load floors out of composites. The interviewees also lifted a sustainability aspect of the trunk and the recycling of the car. They mean that it is important to not mix materials in a component, because that makes recycling more difficult.

The lead engineers at NEVS said that the available space for the trunk in a BEV is similar to the available space in an ICE vehicle. It becomes available space in other parts of the BEV, but not the rear part

of the car. If IWM are used in the car there will be more space in the rear of 4WD and RWD cars. A problem they have faced when designing a station wagon trunk are that the volume of the trunk is often compromised in benefit for other properties of the car. They mean that the trunk is a "forgotten" area of the car. When asked about the future of trunks the mentioned things as in car delivery as something that gain popularity and that the car ownership will change to car sharing. This might create a need for private storage in a car and that a car can be tailored for different purposes, so the user picks a car for the specific need he or she has today.

3.2.3 Chassis experts at AFRY

In this interview two chassis experts were asked mainly about the possibilities and changes in a BEV chassis compared to the chassis of an ICE car. The interview was focused on the rear part of the chassis. Some questions on their view on the trunk were also asked. The chassis experts mean that the drive train of today's BEVs take a similar amount of space as the drive train in a ICE car, independent of drive wheel configuration. However, they pinpointed one major difference and that is the none existing exhaust system on a BEV. In general this takes up much space in an ICE car. The wheelbase is not affected by the battery pack, it is other parameters that sets the wheelbase.

When asked about the structure of the rear of the car they said that the rear bumper must have a certain height and that the design of the rear part of the car must be stable and rigid. The overall performance of the rear part of the chassis is very important and there must be room for shocks and springs. Despite all these parameters they mean that there is room for big improvements in the rear of the car. Some of the structural components as the two beams that hold up the rear bumper and give the construction strength are however a necessary part of the chassis. They also talked about the opportunities with IWM and that it is something that might be used in the future.

With their many years of experience in the automotive industry they also gave some input on the design of the trunk. They mentioned the following things as important aspects in a trunk:

- There should be room for a dog cage or a golf bag.
- Transportation of grocery bags should be easy and safe.
- The loading height should be as low as possible.
- The width of the trunk is important.
- Materials should absorb sound effectively.

3.2.4 Seat expert at AFRY

To understand how the luggage in the trunk might injure the passengers in a collision, an engineer who is an expert on seats at AFRY were interviewed. The seatbacks can according to him be heavily deformed by the luggage in a collision. If there is a person in the middle seat the deformation is even bigger. The

engineer points out the split seatbacks as the major weakness and where the major deformations occur. To improve the strength of the seatbacks, strong, heavy and expensive materials are needed.

According to the seat expert, it is important that the cargo moves as little as possible in a collision and it is better if the cargo hits the seatbacks low, where they generally are stronger, than higher up. Also, preventing the cargo from gaining momentum, for example by making sure that it is in direct contact with the seatbacks, is important. He suggests a solution where a net is pulled out from the load floor, close to the seatbacks, and placed over the luggage to secure it.

3.3 Existing solutions

All trunks of the bestselling midsize station wagons and the most popular BEVs in Europe were studied in detail. Some trunks and features are presented in detail below and an overview of the data gathered is presented, for all details see Appendix B.

3.3.1 Overview of station wagon trunks

All station wagon trunks in the study have cargo hooks in the corners of the trunk, for securing goods. Most of the cars also have at least one hook for a bag, 12V-outlets and the possibility to fold the rear seats from the trunk. Some cars have mesh pockets and different straps for securing small items. The amount of space underneath the main floor varies a lot between the different car manufacturers and Skoda has managed to have multiple storage compartments under the load floor and the possibility to drop the load floor in the Skoda Superb, see Figure 9 and 10. The Mercedes C-Class, on the other hand, only has a single small storage compartment under the load floor. The warning triangle is located in different places in the cars studied. Some of the cars had the warning triangle easily accessible in the trunk lid whilst other had it under the load floor. Most cars were equipped with tire repair kit, first aid kits and reflective vests, the most common storage of these items are under the load floor.

3.3.2 BMW 3-Series

The trunk in a BMW 3-Series had multiple features that made it excel from the other cars. The trunk is displayed in Figure 8. It has a two sub floors which maximizes the volume underneath the main load floor. The compartment that is closest to the trunk-opening uses the full width of the trunk which enables storage for the visibility cover and the cargo net. The BMW 3-series station wagon also features ledges that stops the cargo from moving around whilst driving, but also enables easy loading and unloading, through its rubber inserts, which can move vertically. The rubber is in contact with the luggage whilst driving, but when the car stands still the rubber is lowered and has no contact with the luggage.

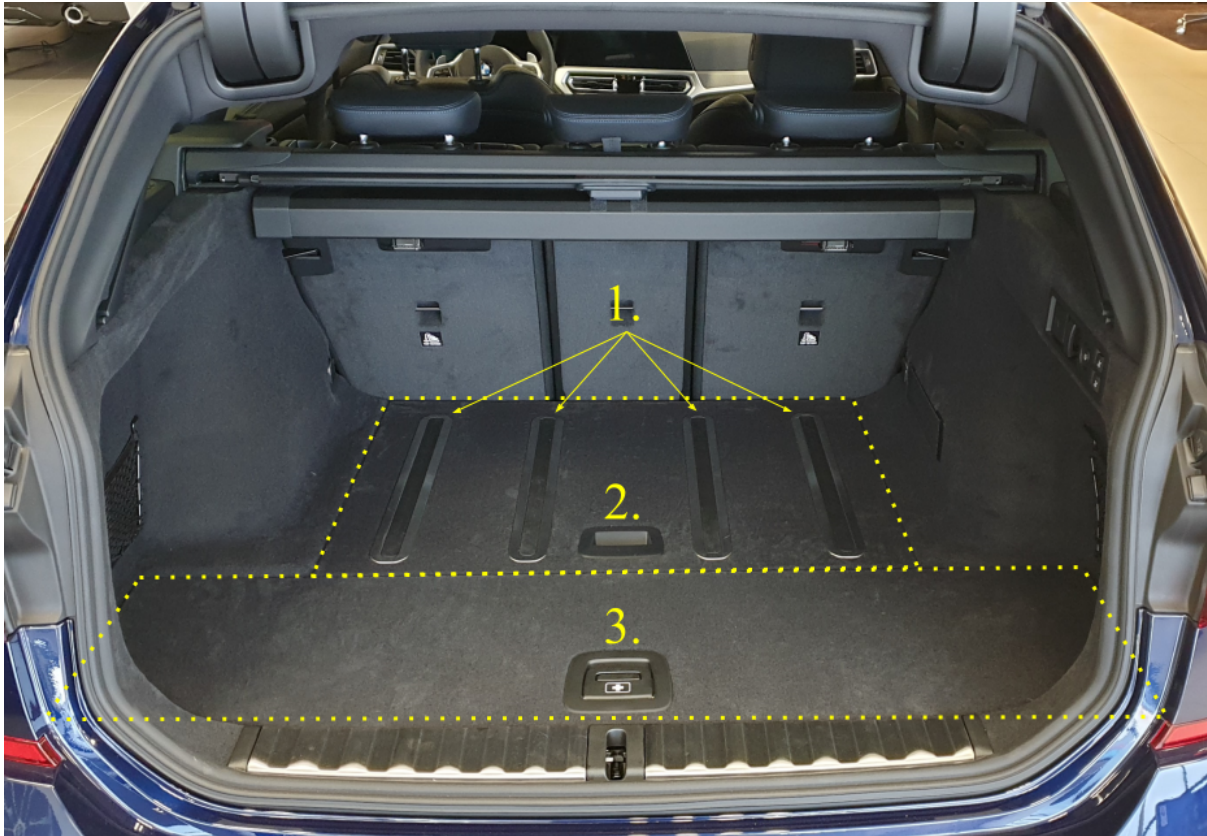


Figure 8: The trunk of a BMW 3-Series station wagon. 1. Shows the metal and rubber ledges in the inner part of the trunk. When loading and unloading the trunk, the luggage is only in contact with the metal, which makes it easier to slide luggage in and out of the trunk. When driving, the rubber part of the ledges rises up and stops the luggage from moving around in the trunk. 2. and 3. display the two separated storage compartments under the main floor. Compartment 3 has room for the cargo net and the visibility cover.

3.3.3 Skoda Superb

Skoda Superb station wagon has one of the longest trunks, it measures 115 cm at its longest point. It also stands out from other trunks with a load floor that can be dropped approximately 11 cm, Figure 9 displays the floor when it is leveled with trunk opening and 10 displays the floor in the dropped level. The result of this function is approximately 130 l extra storage volume. The Volkswagen Passat station wagon has a similar solution, however it is not as easy to operate as the one in the Skoda Superb. The load floor in the Skoda Superb can also be folded into a trunk-divider, see Figure 11, this feature can be used as support for grocery bags. Having a trunk-divider becomes extra relevant when the trunk is very long, since it is more difficult to place things against the backseats. There is also an extra storage compartment under the sub floor in the Skoda Superb, this compartment is adapted for a spare wheel, but without the spare wheel it becomes useful for storage of other items.



Figure 9: The trunk of a Skoda Superb, with load floor leveled with the trunk opening.



Figure 10: Dropped load floor in a Skoda Superb. The load floor is lowered approximately 11 cm, compared to level in Figure 9.



Figure 11: Folded floor in a Skoda Superb for division of the trunk.

3.3.4 Renault Talisman

The Renault Talisman has a support-wall that can be folded up from the floor and be used as a divider in the trunk, see Figure 12. The solution makes the trunk less deep and support for example bags with groceries from moving around in the trunk and help them stand upright.



Figure 12: Trunk divider in a Renault Talisman

3.3.5 Tesla Model 3

The Tesla Model 3 is a sedan and has a very different trunk compared to a station wagon, see Figure 13. It has no dedicated space for a spare wheel, but the compartment underneath the load floor is 63 cm long, 39 cm wide and 26 cm deep. This shows some of the possibilities with BEVs.



Figure 13: Tesla Model 3 storage compartment under the load floor, it is approximately 63 cm long, 39 cm wide and 26 cm deep.

3.4 Customer needs

It became clear that people use their cars for a variety of different purposes. To meet all the different needs from the customers the trunk must be versatile and flexible. Shopping groceries is one of the most common things people do with their cars, which also put specific requirements on the trunk. Transporting groceries should be simple and easy. Keeping groceries cool is also important. Users seem to have a need for storing things permanently in the car. What people have in their cars varies, which further emphasizes the need for flexibility. For example, jumper cables and oil is something that will not be of any use in BEVs. If people will start to share their cars with others, which Lynk & Co plans to offer their customers, it will be relevant with secure storage in the car. By having a secure storage compartment the car "owner" can keep things away from the people they share their car with. In-car delivery of valuable items might also create a need for hidden and secure storage protect it from thieves. The last-kilometer transportation in cities is another aspect that needs to be considered in the development of the trunk. The possibility to park the car outside the city center and take a fully charged e-scooter or e-bike the

last part of the journey might be the future of transportation.

The interviews with the experts and the car dealers show that it is important to have a flat load floor and that the floor should be leveled with the trunk-opening. The engineers working with trunks emphasized the importance of trunk opening dimensions and volume, while the car dealers said that most customers do not care about the measurements. The customers only want to make sure that they can fit specific items such as baby strollers, golf bags and dog cages. The engineers expressed the need for 12V-outlet to power for example a cooling box. The engineers also talked about the trunk's importance for noise in the car, they mean that it is important with effective sound proofing in the trunk to keep the noise low in the passenger area. Having a low loading height, easy to use cargo securing solutions and durable material properties were also highlighted by the engineers. Even though all the studied station wagon trunks have some sort of felt material, the car dealers mean that most customer use a rubber/plastic mat to protect the floor and to ease cleaning.

All the trunks that were studied, except the ones in Audi A4 and the Kia Optima PHEV, have flat load floors which are leveled with the trunk opening. All trunks in the station wagons have some sort of cargo hooks, 12V-outlet and either some hooks for bags and/or mesh pockets. Most cars also have some sort of storage compartment underneath the main floor. How refined the compartment is varies between the vehicle, but most cars have room for permanent storage of some small items.

In addition to the needs that are expressed by customers or derived from how they use the car, there are some customer needs that the customers are unaware of. Crash safety related to the trunk is neglected by Euro NCAP and the regulations by UNECE are too far from real world circumstances. The literature and the interview with the seat expert do however point out major safety issues related to the trunk. The customers believe they buy a safe car when it has a high Euro NCAP rating and are based on the car dealer interviews unaware of the safety aspects of transporting luggage in the trunk. Since safety is an important parameter when buying a car, this should be reflected in the customer needs for the trunk as well.

The customer needs found in this chapter are summarized and rated based on their importance for the customer. A list of these customer needs is presented in Table 5. This will be the foundation for the concept generation phase of the project.

Number	Need	Importance
1	Effective transportation of standard items ¹	3
2	Effective transportation of bulky items ²	3
3	Cooling of groceries	2
4	Charging of e-bikes/e-scooters	1
5	Possible to divide the trunk space	2
6	In-car delivery	2
7	Secure storage compartment	2
8	User stays clean when loading and unloading	2
9	Fit a hectic everyday living	3
10	Be safe in crash	3
11	Suited all different kind of transportation needs	3
12	Easy to clean	2
13	Possible to organize the luggage	2
14	Easy to slide luggage in and out of the trunk	3
15	Flat load floor which is leveled with the opening	2
16	Flexible	3
17	Securing equipment is easy and fast to use	3

Table 5: The elicited customer needs for the trunk from the findings in this chapter. The needs are rated according to how important they are for the customer: 1. not important, 2. important and 3. very important. The rating is done by the author and is an aggregation of the outcomes from the literature review and the interviews. ¹ see Table 6 for what is included in standard items. ² see Table 7 for what is included in bulky items.

To get a better understanding of what is included in "Standard items" and "Bulky items", Table 6 and 7 display items for the different categories, which the customers might want to transport. The tables are based on data from the literature review and the interviews.

Standard items	Importance
Grocery bags	3
School bags	3
Laptop	3
Clothes	3
Umbrella	3
Food and beverages	3
Bags with sports clothing	3
Cool-box	3
Other retail products	2
Suits and dresses	2

Table 6: Standard items that customers might want to transport in their trunk. The items are rated based on their importance for the customers: 1. not important, 2. important and 3. very important. The rating is done by the author and is an aggregation of the outcomes from the literature review and the interviews.

Bulky items	Importance
Music instruments	2
Painting and art material	2
Baby stroller	3
Dog cage	2
Golf bag	2
Luggage for long trips	3
E-scooter	1
Folding bike/e-bike	1
Sports equipment	2
Furniture	1
Fishing equipment	1
Hunting equipment	1
Bike carrier	1
Roof racks	1

Table 7: Things that customers might want to transport in their trunk. The items are rated based on their importance for the customers: 1. not important, 2. important and 3. very important. The rating is done by the author and is an aggregation of the outcomes from the literature review and the interviews.

3.5 Technological prerequisites

Based on the literature study and expert interviews, most future BEVs will have a battery that is placed underneath the passenger area between the wheel axis. This design does not interfere with the trunk of the car. Many BEVs today have 4WD, with motors both in the front the rear. A rear motor takes up space between the rear wheels which otherwise potentially could be used for the trunk. In the interviews it became clear that one of the main advantages from a trunk point of view, when comparing a FWD ICE vehicle with a FWD BEV, is that the BEV has no exhaust system. The need for suspensions is the same and the fuel tank in most vehicles is placed underneath the back seats. However, many of the cars that were studied were designed to carry a spare wheel, even though none of them were equipped with one. The trend with no spare wheel can be seen in Tesla's models, none of them have a dedicated spare wheel area (even the tire repair kit is optional when buying a Tesla).

Since many BEVs have a frunk, it would be a suitable place to store permanent items and the charging cable. If doing so, the trunk could be optimized for flexibility and everyday use. The accessibility of items like charging cable, warning triangle, reflective vests and tire repair kit would be better when the trunk is fully loaded, if they are placed in the frunk. No spare wheel and no exhaust system also enable new trunk storage solutions. Behind the rear wheels and the wheel suspension there are no major limits except the two beams that hold up the rear bumper and create rigidity in the cars, see Figure 14. This allows among many things for a deep storage compartment under the main floor which increases the storage space.

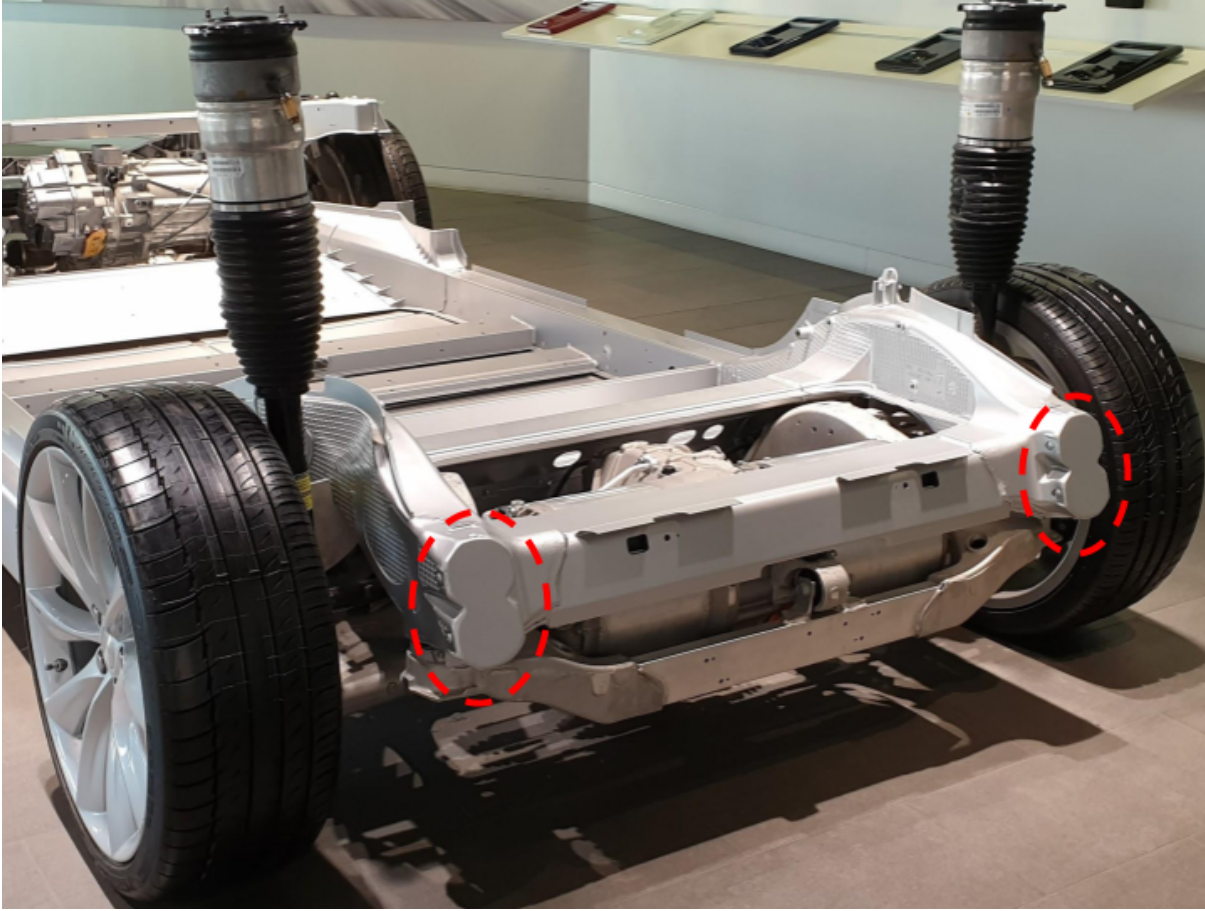


Figure 14: The marked area shows where the two beams are placed on Tesla's skateboard platform.

3.6 Legal requirements

The regulations by UNECE will influence the design of the trunk since the cars are tested in certain ways and the design must be approved in these tests. R17 is the most relevant test for the interior of the trunk. If it is possible to lower the load floor it is likely that the vehicle will perform better in the test, since the test blocks will impact the back seat further down and closer to the fixing points of the seatbacks.

The height of the impactors in R32 and R42 limits the trunk opening since the rear bumper must be on a height that matches the specifications of the impactors in R32 and R42. In the R32 the impactor strikes at a height of 150 mm - 1000 mm. In R42 the impactor strikes at 502 mm above the ground. The result of this is that the trunk opening cannot be any lower than 502 mm. R42 also results in limitations for where to place rear lights and the design of the trunk lid. Some damping of the impact is also needed to ensure the functionality of the car after the impact. R32 and R42 makes solutions with trunk openings that are extra low unfeasible.

3.7 Requirements

The requirements for the trunk have been based on section 3.4-3.6. The only customer needs included in the requirements are safety and items that the trunk must be able to transport, which are items rated 3 in Table 6 and 7. These are the most fundamental aspects in the development of the trunk and they are possible to translate into measurable metrics, and are therefore in the list of requirements. All items that are rated 3 in importance in Table 6-7 have been included in the list of requirements that the final product must meet. The legal requirements UNECE R17, R32 and R42 must be fulfilled. The last requirement in the list, is that the solution must fit with a modern battery electric station wagon. All requirements are presented in Table 8 and how they correlate with the seven metrics which have been established based on the requirements.

Requirement		Metric							
		1 Volume	2 Depth	3 Width	4 Height	5 Trunk floor height	5 Rear bumper height	6 Passenger protection in crash	7 Modification of car architecture
Transportation of	Grocery bags	■	■	■	■				
	School bags	■	■	■	■				
	Laptop bag	■	■	■	■				
	Bags with clothing	■	■	■	■				
	Umbrella	■	■	■	■				
	Food and beverages	■	■	■	■				
	Cool-box	■	■	■	■				
	Baby stroller	■	■	■	■				
	Luggage for longer trips	■	■	■	■				
	Sports equipment	■	■	■	■				
	Be safe in a crash					■	■	■	
Meet regulation	UNECE R17					■	■	■	
	UNECE R32						■	■	
	UNECE R42						■		
	Fit in modern battery electric station wagons						■	■	

Table 8: List of requirements that any solution must meet and correlating metrics.

The metrics from Table 8 are given marginal values which the product must fulfill. The values are presented in Table 9.

3 PART 1: CUSTOMER NEEDS, TECHNOLOGICAL CONDITIONS AND LEGAL RESTRICTIONS

Nr.	Metric	Marginal value	Type	Comment
1.	Volume (l)	490	Lower	Based on the lowest value in Table 4
2.	Depth (mm)	900	Lower	Based on the length of a standard baby stroller
3.	Width (mm)	800	Lower	Based on the width of a standard baby stroller
4.	Height (mm)	650	Lower	Based on the needed height to fit a big grocery bag
5.	Rear bumper height (mm)	540	Lower	Minimum height to fulfill UNECE R42
6.	Passenger safety	Y	Y/N	Y if the solution is as good as current solutions
7.	Design feasibility	Y	Y/N	Y if it meets the conditions in section 3.5

Table 9: The metrics in the table are marginal values which the product must fulfill.

4 Part 2: Generate and eliminate concepts for trunk solutions

This chapter consists of two main parts, the first step is to generate concepts that solves the customer needs and meet the technical and legal prerequisites. The second step is to systematically eliminate concepts until there is only one solution left.

4.1 Concept generation

To generate concepts, a number of key areas are chosen based on the findings in previous parts. Everyday use is the first and most important area to generate concepts on. Important parameters are cargo capacity and how good the solution is for transporting groceries. Also, items like baby strollers and golf bags are things that easily have to be transported in the trunk. The solution should also be easy to use, flexible, adaptable and have a high safety. Functions like cooling, secure storage and transportation and charging of last-kilometer transportation means are also going to be in focus. Innovative concepts that enable the customer to use the trunk in a new way will be searched for.

As a part of the concept generation phase Ulrich & Eppinger (2016) recommends "functional decomposition" to better understand the product. In the functional decomposition, the product development team decompose the problem into different functions the product must have in order to operate. Concepts are then generated based on these functions. However, applying functional decomposition to this project is of little value, since the functional decomposition either becomes too simple and unspecific or too complex. The simple functional decomposition is as follows: input to the trunk is cargo, then the trunk transports the cargo and finally the output is transported cargo. This is too obvious, to add any value to the concept generation. In the complex version the input is every potential type of item, any potential user would transport in the trunk. Then the functional decomposition should include how each specific item is loaded, transported and unloaded. The output is the transported item. The complexity of the functional decomposition increases even further when different types of items are to be transported at the same time.

Using a detailed functional decomposition could also result in not exploring the full design space, since the concept would be limited to functions that are thought of by the product development team. The development phase for the trunk is in a too early stage and the complexity of the problem makes the functional decomposition to an unsuitable method. However, in future design iterations of the trunk, when the overall functionality is set, a functional decomposition is likely to be effective. Especially when the problem is no longer complex, only complicated.

A decomposition was instead made on the customer needs (see Table 5 and the technological prerequisites in section 3.5). This approach ensures a solution that is strongly connected to the users' preferences, at the same time as it benefits from the new technological opportunities generated by the BEVs. Some concepts are generated based on only the customer needs or the technological prerequisites, while some concepts are generated with both in mind.

To generate concepts a number of different methods are used. The first step is to look at existing products and how they are designed to meet the customer needs. Car trunks were examined in section 3.3 and concepts are generated based on the findings in this section. Solutions that have not made it to the market, in form of concept cars and ideas found on the internet, are also a source of concepts. The interviews held during the project have included questions about new solutions and customer needs that are not met by today's products. Concepts are generated based on these ideas as well. Brainstorming is also used to provide a great quantity of concepts. A session was held with employees working in the car industry at AFRY. Finally, the author of the report conducted multiple brainstorming sessions, with the customer needs, future trends and solutions from other industries as foundation.

The generated concepts are presented below with a short description. The concepts are categorized based on their origins.

4.1.1 Existing

The following solutions were found when visiting car-dealers and looking at existing solutions:

1. **Multiple floor hatches** - see Figure 8. The BMW 3-series has two hatches in the load floor, this maximizes the available space under the main load floor.
2. **Friction/none-friction ledges** - see Figure 8. The BMW 3-series has four metal ledges which make it easy to slide luggage in and out of the trunk. When driving, rubber inserts in the ledges rise and create higher friction.
3. **Two level floor** - see Figure 9 and 10 of the trunk of the Skoda Superb. Floor that can be lowered for more trunk space.
4. **Support wall** - see Figure 11 and 12 of Skoda Superb and Renault Talisman. Folding wall that can be support for luggage and also makes the trunk less deep.
5. **Hooks** - hooks on the sidewalls to hang grocery bags, shopping bags etc.
6. **Cargo hooks** - hooks in the corners of the load floor for securing cargo using straps.
7. **Straps** - straps on the sidewalls.
8. **Mesh pockets** - for keeping smaller items in place.

The following solutions were found searching the internet for innovative trunk storage solutions:

9. **Sliding floor** - the SAAB 9-5 1999 has a load floor that can be slided out, see G. Wilson (1999).
10. **Segways in the trunk** - Concept car from Saturn with two Segways in the trunk, see Impact Lab (2008).

11. Pull-out rear bumper - Concept car from Audi with a rear bumper that can be pulled out like a drawer, see Net Car Show (2000).

12. E-skateboards - VW ID. 3 Space Vizzion have room for two e-skateboards under the load floor, see Rabe (2019).

4.1.2 Interviews

The following ideas were introduced by the different interviewees:

13. Custom trunks - the trunk experts at NEVS presented an idea where cars in car sharing groups have different use areas and that the trunks are custom made for the purpose.

14. Safety net - net that is pulled over the cargo. The net is fixed to the floor, close to the seatbacks. The operation could be done manually or automatically.

4.1.3 Brainstorming

The brainstorming session were held around four focus question. The ideas from each focus question are presented below. Similar ideas are combined into one concept.

Focus question 1 - How can we make the transportation of grocery bags simple, fast and safe?

Nets, hooks and lines which secures the grocery bags

15. Bar with hooks - bar with hooks for grocery bags. Folded up from the and also gives support to the bags. See Figure 15.

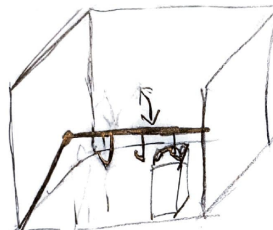


Figure 15: Bar with hooks.

16. Cargo net - net that is placed over the grocery bags. See Figure 16.



Figure 16: Cargo net.

17. Dividing net - net on roll on the side. The net makes the trunk less deep and supports the grocery bags. See Figure 17.

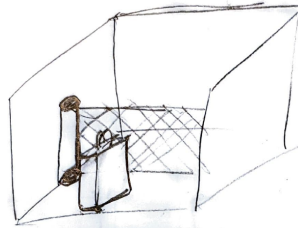


Figure 17: Dividing net.

18. Lines from the roof - lines that secures the bag in its handles. Lines are attached to the roof. See Figure 18.

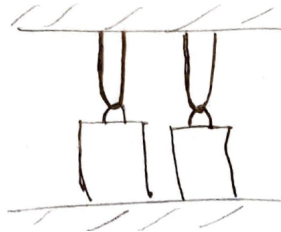


Figure 18: Line from roof.

19. Line from side to side - line that secures the bag in its handles. Line goes from side to side in the trunk. See Figure 19.

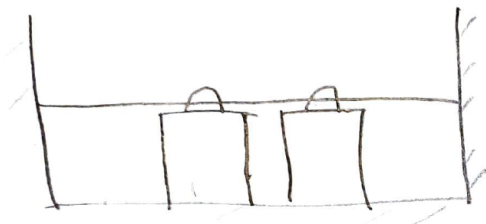


Figure 19: Line from side to side.

20. Movable support - movable support on rails that can be adjusted in the x-direction of the trunk. See Figure 20.

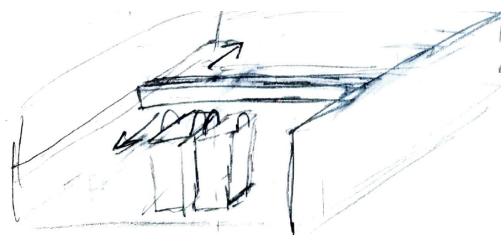


Figure 20: Movable support.

21. Bar from the side - bar that supports the grocery bags. Folded out from the side wall. See Figure 21.

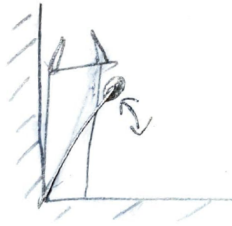


Figure 21: Side bar

Walls and compartments for grocery bags

22. Compartments - compartments in the load floor to place the grocery bags in

23. Hatch and support - hatch in the floor that also acts as a support wall. See Figure 22.

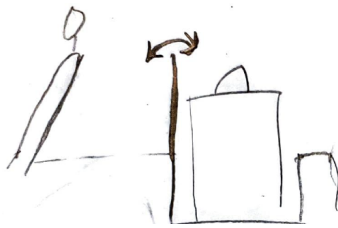


Figure 22: Hatch in the floor.

24. Shelves - shelves that make it possible to transport multiple bags on top of each other. See Figure 23.

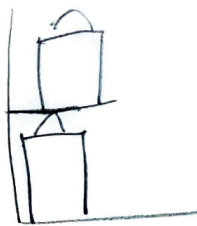


Figure 23: Shelves.

Load floor materials that prevents the grocery bags from moving

25. Foam floor - foam floor that adapts after the cargo and prevents the grocery bags from moving. See Figure 24.

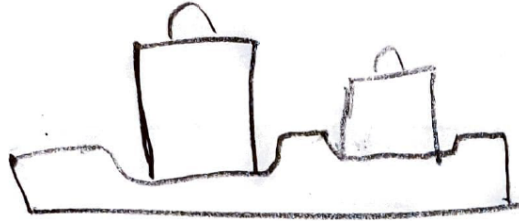


Figure 24: Foam floor.

Custom bags/boxes and solutions for cooling

26. Custom bags/boxes - bags or boxes that are custom made for the car, which the user brings inside the supermarket. Some of the boxes can have integrated cooling. Secured in the trunk by Velcro or some sort of rails.

27. Integrated cooling - cooling integrated in the floor or some storage compartment in the trunk.

Focus question 2 - How can we maximize the loading capacity and still have a flat load floor that is leveled with the trunk opening?

Small compartments that maximizes the volume under the main floor

28. Tetris - Block that are adapted after the shape of the cars BIW. The blocks can be moved and changed.

Ideas related to the roof

29. Roof lifting - lifting mechanism in the roof which frees up space on the load floor.

Adjustable floor

30. Height adjustable floor - one or multiple sections in the load floor that can be adjusted in height. See Figure 25.

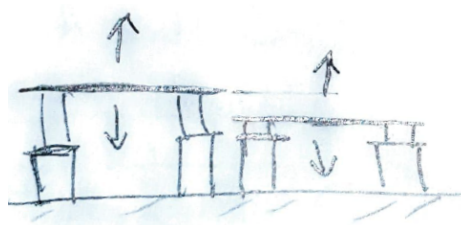


Figure 25: Height adjustable floor.

Folding rear bumper

31. Folding rear bumper - rear bumper that can be opened. Makes it possible to have low loading height and a flat load floor. See Figure 26.

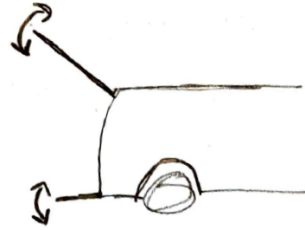


Figure 26: Folding rear bumper.

Load floor ideas

32. Air balloon - balloon that can be inflated and deflated to adjust the load floor. See Figure 27.

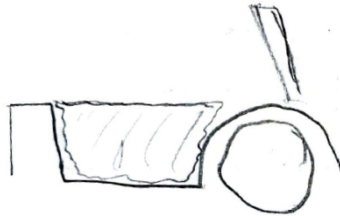


Figure 27: Air-balloon.

33. Elastic beams - The load floor is made out of a number of beams which are flexible in one direction which makes it possible to put items between and underneath the beams. See Figure 28.

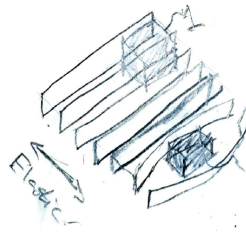


Figure 28: Elastic beams.

34. Bean-bag - bean bag that makes the load floor flexible. See Figure 29.

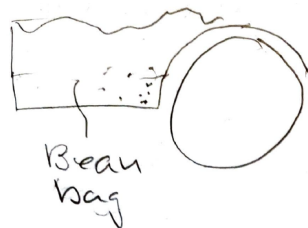


Figure 29: Bean bag.

35. Rolling cylinder - rotating cylinder in the trunk with multiple shelves that can be rotated to reach the different shelves. See Figure 30.

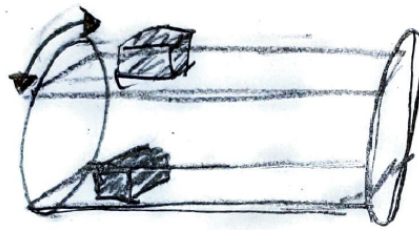


Figure 30: Rolling cylinder.

36. Multi-level floor - Multiple levels in the floor that optimizes the trunk for different purposes.

Focus question 3 - How can we make the trunk safe in a collision?

37. Airbag - airbag that prevents the cargo from entering the passenger compartment. See Figure 31.



Figure 31: Airbag.

38. Seat-back beams - beams that makes the seat-back stronger. See Figure 32.

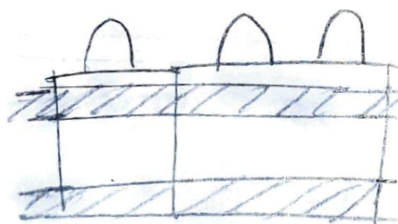


Figure 32: Beams.

39. Curtain - curtain that shoots our from the roof the prevent the cargo from entering the passenger area. See Figure 33.

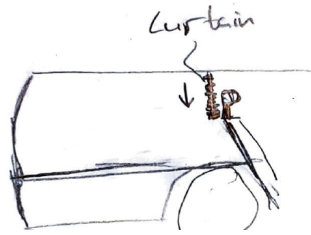


Figure 33: Curtain/net

40. Low floor - Have a lower load floor, so the seatbacks are impacted further down where they are stronger. See Figure 34.

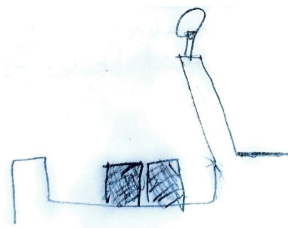


Figure 34: Low floor.

41. MC-protection seat-back - material in the seat-back that becomes hard when impacted. Similar material can be found in MC-protection.

Focus question 4 - Other ideas for innovative trunk solutions?

42. Elastic bag - an elastic bag that is held up by the trunk lid and increases the volume of the trunk. See Figure 35.

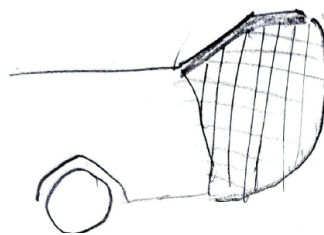


Figure 35: Elastic bag.

43. Tilting floor - floor that tilts according to the forces on the cargo caused by acceleration, braking and turning of the car.

44. Trunk-opening net - net that prevents items from falling out when trunk-lid is open. See Figure 36.

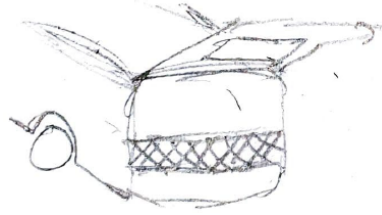


Figure 36: Trunk-opening net

- 45. **Removed wheelhouses** - for improved trunk capacity.
- 46. **Car adapted baby stroller** - a baby stroller that is custom made for the car's trunk.
- 47. **In-car delivery cooling box** - for in-car delivery of groceries that needs cooling.
- 48. **Active suspension** - suspension that is lowered when loading/unloading the trunk.
- 49. **Under the car compartment** - compartment for long items that is placed under the car.
- 50. **Camper van bed** - shelf that can be pulled down from the trunk roof, like a camper van bed.

4.1.4 Ideas from the author

- 51. **E-scooters** - room for e-scooters under the main floor, which can be charged.
- 52. **E-bike/bike** - room for folding e-bikes/bikes under the main floor, which can be charged.
- 53. **Hatch and cooling** - Hatch in the load floor to compartment big enough to fit multiple grocery bags. The compartment has integrated cooling.
- 54. **Integrated bike rack** - A bike rack that is custom-made to fit the trunk and can be kept for example under the load floor or under the car.

These are the concepts generate during the project. They cover completely different problems and customer needs that have been highlighted in Chapter 3, which shows the complexity of the product that is being developed. The concepts will be categorized, improved and eliminated in the next part of the project.

4.2 Concept elimination

The next step is to eliminate the concepts one by one. Those concept that have clear drawbacks and cannot be improved are eliminated by a number of hard requirements. After the first screening the remaining concepts are improved and put through a second and third elimination. This result in one remaining concept for the overall design of the trunk.

4.2.1 Elimination 1

In the first concept elimination phase, the concepts are analyzed separately according to the metrics in Table 9. All the criteria in the first elimination are hard requirements which implies that a concept is eliminated if it does not meet any of the requirements. The result of the first elimination is presented in Table 10. The concepts were also put into three categories: "Main structure", "Feature" and "Safety". Concepts in "Main structure" do in some way solve how the overall layout and design should be of the trunk. "Feature" covers solutions and functionalities that can be added to the "Main structure". "Safety" are concepts, which aim is solely to increase the safety for the passenger.

Number	Category	Concept	Relevant	Scope	Volume	Depth	Width	Height	Rear bumper height	Passenger safety	Design feasibility	Result
1	Main structure	Multiple floor hatches	P	P	P	P	P	P	P	P	P	P
2	Feature	Friction/none-friction ledges	P	P	P	P	P	P	P	P	P	P
3	Main structure	Two level floor	P	P	P	P	P	P	P	P	P	P
4	Feature	Support walls	P	P	P	P	P	P	P	P	P	P
5	Feature	Hooks	P	P	P	P	P	P	P	P	P	P
6	Safety	Cargo hooks	P	P	P	P	P	P	P	P	P	P
7	Feature	Straps	P	P	P	P	P	P	P	P	P	P
8	Feature	Mesh pockets	P	P	P	P	P	P	P	P	P	P
9	Main structure	Sliding floor	P	P	P	P	P	P	P	P	P	P
10	Feature	Segway in the trunk	F									F
11	Main structure	Pull-out rear bumper	P	P	P	P	P	F				F
12	Feature	E-skateboards	F									F
13	Feature	Custom trunks	P	F								F
14	Safety	Safety net	P	P	P	P	P	P	P	P	P	P
15	Feature	Bar with hooks	P	P	P	P	P	P	P	P	P	P
16	Safety	Cargo net	P	P	P	P	P	P	P	P	P	P
17	Feature	Dividing net	P	P	P	P	P	P	P	P	P	P
18	Feature	Line from roof	P	P	P	P	P	P	P	P	P	P
19	Feature	Line from side to side	P	P	P	P	P	P	P	P	P	P
20	Feature	Movable support	P	P	P	P	P	P	P	P	P	P
21	Feature	Bar from the side	P	P	P	P	P	P	P	P	P	P
22	Feature	Compartments	P	P	P	P	P	P	P	P	P	P
23	Main structure	Hatch and support	P	P	P	P	P	P	P	P	P	P
24	Feature	Shelves	P	P	P	P	P	P	P	P	P	P
25	Feature	Foam floor	P	P	P	P	P	P	P	P	P	P
26	Feature	Custom bags/boxes	P	F								F
27	Feature	Integrated cooling	P	P	P	P	P	P	P	P	P	P
28	Main structure	Tetris	P	P	P	P	P	P	P	P	P	P
29	Feature	Roof lifting	P	P	P	P	P	P	P	P	P	P
30	Main structure	Height adjustable floor	P	P	P	P	P	P	P	P	P	P
31	Main structure	Folding rear bumper	P	P	P	P	P	F				F
32	Main structure	Air-balloon	P	P	P	P	P	P	P	P	P	P
33	Main structure	Elastic beams	P	P	P	P	P	P	P	P	P	P
34	Main structure	Beanbag	F									F
35	Main structure	Rolling cylinder	F									F
36	Main structure	Multi-leveled floor	P	P	P	P	P	P	P	P	P	P
37	Safety	Airbag	P	P	P	P	P	P	P	P	P	P
38	Safety	Seat-back beams	P	F								F
39	Safety	Curtain	P	P	P	P	P	P	P	P	P	P
40	Main structure	Low floor	P	P	P	P	P	P	P	P	P	P
41	Safety	MC-protection seat-back	P	F								F
42	Feature	Elastic bag	P	P	P	P	P	P	F			F
43	Main structure	Tilting floor	P	P	F							F
44	Feature	Trunk-opening net	F									F
45	Main structure	Removed wheelhouses	P	P	P	P	P	P	P	F		F
46	Feature	Car adapted baby strollers	P	F								F
47	Feature	In-car delivery cooling box	P	P	P	P	P	P	P	P	P	P
48	Feature	Active suspension	P	F								F
49	Main structure	Under the car compartment	P	F								F
50	Feature	Camper van bed	P	P	P	P	P	P	P	P	P	P
51	Feature	E-scooters	P	P	P	P	P	P	P	P	P	P
52	Feature	E-bike/bike	P	P	P	P	P	P	P	P	P	P
53	Main structure	Hatch and cooling	P	P	P	P	P	P	P	P	P	P
54	Feature	Integrated bike rack	P	P	P	P	P	P	P	F		F

Table 10: First elimination of concepts that do not meet all the marginal values for the different metrics from Table 9, is irrelevant or is out of the scope for the project. Pass: P and Fail: F. The concepts are also categorized into three concept groups: "Main structure", "Feature" and "Safety".

17 out of 54 concepts are eliminated after the first elimination of concepts. Of the remaining concepts are 11 "Main structure", 21 "Feature" and 5 "Safety".

4.2.2 Elimination criteria for second and third elimination

In the next part of the concept elimination phase, concepts are removed based on a number of elimination criteria, which correlates with the customer needs discussed in section 3.4. The elimination criteria and how they relate to the customer needs are shown in Table 11.

Nr.	Customer needs	Selection criteria						
		1	2	3	4	5	6	7
		Standard items	Groceries	Bulky items	Adaptability and flexibility	Security	Overall ease of use	Crash safety
1	Effective transportation of standard items	■	■					
2	Effective transportation of bulky items			■				
3	Cooling of groceries		■					
4	Charging of e-bikes/e-scooters				■			
5	Possible to divide the trunk space				■			
6	In-car delivery					■		
7	Secure storage compartment					■		
8	Users stays clean when (un)loading						■	
9	Fit a hectic everyday living						■	
10	Be safe in a crash							■
11	Suited for all different kind of transportation needs				■			
12	Easy to clean						■	
13	Possible to organize the luggage				■			
14	Easy to slide luggage in and out of the trunk				■		■	
15	Flat load floor which is leveled with the opening						■	
16	Flexible				■			
17	Securing equipment is easy and fast to use						■	■

Table 11: List of the customer needs for the trunk and correlating elimination criteria.

How the different criteria are going to be weighted and rated is described in Table 12. The table is the foundation for the final part of the elimination phase.

Nr.	Criteria	Comment
1.	Standard cargo capacity	How effective the trunk is for transporting standard items (excl. groceries).
2.	Grocery bags	How effective the trunk is for transporting groceries.
3.	Bulky items capacity	How effective the trunk is for transporting bulky items.
4.	Adaptability and flexibility	Usability for different purposes and/or possible to modify the trunk.
5.	Security	How secure the trunk is against theft.
6.	Overall ease of use	User-friendliness, simplicity and intuitiveness.
7.	Crash safety	How the trunk effects the safety for the passengers.

Table 12: The elimination criteria for the concept elimination phase.

4.2.3 Elimination 2

The concepts that are left after the first elimination solve vastly different problems. Some of them are overall solutions for the design of the trunk while other are functions and features that serves more specific purposes. The most essential part of the trunk design is the overall structure and how the available space is used. The concepts relevant for this are labeled "Main structure" in Table 10. All of the other concepts left after the first elimination can be used independently of the main structure of the trunk and are labeled "Feature" and "Safety". The second elimination exclusively focus on the concepts labeled "Main structure".

Before the second elimination, the concepts labeled "Main structure" are analyzed, combined and improved. A morphological matrix is not used, since it relies on a functional decomposition of the product, which was not made (see Chapter 2). Instead, each concept is looked at separately and if it benefits from being combined with one or many of the other concepts, this is done. This leads to nine different concepts for the overall design, these are presented in Table 13.

Concept	Name	Combined concepts	Description
A	Hatches in the floor	1, 23, 53	Two or more hatches. One hatch to the front space and one hatch to the deep space closest to the opening. Possibly hatches to compartments on the sides.
B	Two level floor with hatch	3, 23, 53	The Skoda solution. Level 1: in level with the trunk opening. Level 2: as deep as possible but still flat. Hatch to the deepest part of the trunk.
C	Sliding floor & large hatch	9, 23, 53	Floor that can be slid out. One large hatch to reach the compartments under the main floor.
D	Tetris	1, 28	Multiple small storage compartments under the main floor that maximizes the volume.
E	Height adjustable floor with hatch	23, 30, 53	One or two areas in the trunk that can automatically higher and lowered. One for the deep part and possibly on for the front part as well. Combined with hatch.
F	Air-balloon and hatch	1, 23, 32, 53	Air-balloon that is inflated and deflated to adjust the floor height.
G	Elastic beams	33	Beams which are elastic in the y or x -dimension so it is possible to reach the lower compartments through the beams.
H	Multi-level floor with hatch	1, 23, 36, 53	The floor can be placed on multiple levels both below and above the standard floor height.
I	Low flat floor	23, 40, 53	Floor that is not in level with the trunk-opening. Hatch to the deep part of the trunk.

Table 13: Concepts for the overall design of the trunk.

For the second elimination, it is the nine concepts in Table 13 that are analyzed and compared. The second elimination is done by a team at AFRY using a Pugh matrix, that have a solid understanding of the project and many years of experience from the automotive industry. Concept A is chosen as reference since it is a simple solution that is also an improvement of the existing solution. It is similar to the solution in the BMW 3-series, see Figure 8, but with bigger compartments under the floor. The elimination criteria are derived from the customer needs, see Table 11, and explained in Table 12. Two new elimination criteria are also added after a discussion with the supervisors at AFRY, these are "Mass" and "Attraction". They were not included in the original elimination criteria since they were not emphasized in any of the literature studied or in the interviews. Mass and attraction are according to the team at AFRY important parameters when developing parts of a car in general and should therefore be included among the elimination criteria. The concepts are given a "+" if it is better, "0" if it is equal or "-" if it is worse than the reference concept, for all criterion. The reference concept, is concept A. The "+", "0" and "-" are summed up which result in a score. The concepts are then ranked based on their score. The result of the second elimination is presented in Table 14.

Selection criteria	A Hatches in the floor (Reference)	B Two level floor with hatch	C Sliding floor & large hatch	D Tetris	E Height adjustable floor with hatch	F Air-balloon and hatch	G Elastic beams	H Multi-level floor with hatch	I Low flat floor
Standard cargo	0	0	0	0	0	-	-	0	-
Groceries	0	0	-	0	+	0	-	-	0
Bulky items	0	+	0	0	+	0	-	+	0
Adaptability & flexibility	0	+	-	+	+	0	-	+	-
Security	0	-	0	0	-	-	-	0	0
Overall ease of use	0	0	+	0	+	-	-	-	-
Crash safety	0	+	0	0	+	0	-	-	+
Mass	0	-	-	+	-	-	+	-	+
Attraction	0	+	+	-	+	+	-	-	-
Sum +'s	0	4	2	2	6	1	1	2	2
Sum 0's	9	3	4	5	1	4	0	2	3
Sum -'s	0	2	3	2	2	4	8	5	4
Net Score	0	2	-1	0	4	-3	-7	-3	-2
Rank	3	2	5	3	1	7	9	7	6

Table 14: Second elimination using a Pugh matrix.

Concept C, F, G, H and I scored worse than the reference concept, while concept B and E stood out from the reference concept and scored higher. Concept D scored equal to the reference. The Pugh matrix was iterated ones, with concept I as reference, see Appendix D. The concepts that had a low rating in the first iteration had also a low score in the second iteration. Concept C, F, G, H and I are eliminated since they scored the lowest in the first iteration and all have obvious drawbacks. Concept A and D are in many ways similar concepts and also score the same in in the first iteration. However, both these concepts score worse than concept B and E. Concept A and D also lack innovation, the importance of which was emphasized in the purpose of this project. The ranking in the Pugh matrices and the low innovation eliminates concept A and D for further development. This leaves B and E as the two remaining concepts.

4.2.4 Elimination 3

The two remaining concepts, B and E are both effective solutions that fulfill the purpose of the project. To make a well-founded final elimination, the two concepts were also compared using a concept scoring matrix. The result can be seen in Table 15. The weights in the concept scoring matrix are based on the findings in Chapter 3 and were decided in collaboration with a team at AFRY. The ratings were discussed and decided together with the same people at AFRY, who did the second elimination. The solution in the BMW 3-Series with two large hatches, one at the front and one at the back, were set as reference. The ratings were set in the following way: 1. significantly worse, 2. worse, 3. equal, 4. better and 5. significantly better.

Elimination criteria	Weight	B Two level floor with hatch		E Height adjustable floor with hatch	
		Rating	Score	Rating	Score
Standard cargo	15%	3	0,45	3	0,45
Groceries	15%	3	0,45	4	0,6
Bulky items	15%	5	0,75	4	0,6
Adaptability and flexibility	5%	4	0,2	4	0,2
Security	5%	2	0,1	2	0,1
Overall ease of use	20%	3	0,6	4	0,8
Crash safety	15%	4	0,6	4	0,6
Mass	5%	2	0,1	1	0,05
Attraction	5%	4	0,2	5	0,25
Total score		3,45		3,65	
Rank		2		1	

Table 15: Third elimination using concept scoring

Concept B performs worse than concept E also in the concept scoring. When analyzing the details of the concept scoring, concept B has a higher rating than concept E on two criteria, "Bulky items" and "Weight", while concept E has a higher rating on three criteria "Groceries", "Overall ease of use" and

"Attraction". To further evaluate the outcome from the concept scoring, a number of sensitive analysis were made, these are presented below:

- The weights were removed, this resulted in concept B scoring worse than concept E by 0,11.
- Lower the ratings by one, at least two of the ratings must be lowered by one for concept E to score worse than concept B.
- Removing elimination criteria, at least two of the criteria must be removed for concept E to score worse than concept B.

When comparing the two concepts on innovation rate, concept B is less innovative since it is a modification of a solution that is already out on the market. The importance of innovation was emphasized as a foundation for this project. The outcome from the two Pugh matrices, the concept scoring with associated sensitivity analysis and the low innovation rate, together form a basis for an elimination of concept B. The remaining solution, concept E, will therefore be used in the development of the trunk and it will form the main structure of the trunk design.

4.2.5 Features

The concepts categorized as features and that passed the first elimination are all concepts that could potentially be a part of a final solution. To make an informed decision, if the concept should be a part of the final design or not, most of the concepts must be further analyzed. This is outside of the scope for this project and is something for future projects to investigate. However, some of the concept can be eliminated since they have a similar function as the main structure.

The following concepts can be eliminated since the function of the feature is already in the main structure.

- 4. Support walls
- 15. Bar with hooks
- 17. Dividing net
- 18. Line from roof
- 19. Line from side to side
- 20. Movable support
- 21. Bar from side to side
- 22. Compartments
- 25. Foam floor

Some of the remaining concepts cannot be eliminated at this stage and need further investigation. What more information that is needed to make a decision for the remaining concepts are presented below.

2. Friction/none-friction ledges: it is used in cars today, however the system takes up space and the effectiveness of the feature must be analyzed further.

8. Mesh pockets: it is used in cars today and makes storing of small items easy. They might however make it more difficult to load and unload the trunk since luggage might get stuck in the mesh.

24. Shelves, 29. Roof lifting and 50. Camper van bed are all new solutions which need to be analyzed further, to understand the customer value of the feature and how the design impacts the rest of the trunk.

51. E-scooter and 52. E-bike/bike are concepts that would make it possible to not use the car for last kilometer transportation, but instead park the car outside the city center and use an e-scooter or a bike for the last part of the journey. However, to have an E-scooter or a bike in the trunk would decrease the loading capacity and if it is not something that always is in the trunk, the attachments for it might have a negative impact on the rest of the trunk. To make an informed decision, the prerequisites for this trade-off must be analyzed further.

The following concepts should be in the final design, since they all add substantial customer value without having any major drawbacks.

5. Hooks: for hanging small items on the side of the trunk.

7. Straps: for items to the sides of the trunk.

27. Integrated cooling and 47. In-car delivery cooling box will make it possible for user to transport groceries, food and beverages in need of cooling for long times. It will also enable in-car delivery of groceries.

4.2.6 Safety

The five safety solutions left after the first elimination could all potentially improve the safety for the passengers. To eliminate the concepts that should not be a part of the final solution, each concept is analyzed separately to see if it is an effective concept or not.

Cargo hooks

Cargo hooks for securing the load could be found in most of studied cars in chapter 3 and is something that allows the user to transport heavy cargo in a safe way by using for example tie down straps. None of the other concepts are as effective for this purpose as the cargo hooks.

Safety net and cargo net

A safety net or a traditional cargo net serve a similar purpose as the cargo hooks. It is likely to be less effective for large and heavy items. On the other hand, it will stop smaller items from moving

and is more user friendly than the cargo hooks. Especially, a safety net on a roll at the bottom of the seatbacks is easy to use, except that the user must lean into the trunk to reach the net and pull it over the cargo.

Airbag

An airbag for the cargo is a safety solution that could be used together with the other solutions. If it is effective it would increase the safety without any effort from the user. To investigate if a cargo airbag is a feasible solution safety solution an interview was held with a system engineer at the airbag company Autoliv. The engineer has more than twenty years of experience of car safety and airbags. When he was asked if it is possible to increase the safety by using an airbag to prevent the cargo from entering the passenger compartment in a collision, he was skeptical. The main problem according to the engineer is the lack of support for the airbag in the x-direction of the car. He says that the only way an airbag possibly can improve the safety is, if it is located in the roof and pushes the cargo downwards and thereby decreasing the movement of the cargo in a collision. A problem the engineer emphasized is the variation in cargo and how the trunk is loaded, this would make it difficult to develop an effective airbag. He also highlighted the car manufacturers lack of business interest to develop a solution like this. He says that it is far from self-evident that a cargo airbag would significantly improve the safety and that there has to be some sort of verification of the solution, for the OEMs to be interested. Based on the interview the airbag concept is eliminated and will not be developed any further.

Curtain

The curtain has similarities with the airbag when it comes to the need for support in the x-direction. The lack of support in the x-direction eliminates also the concept with a curtain. Based on the sections above the trunk should include cargo hooks and a cargo net.

4.2.7 Resulting concepts

There is one concept left for the main structure of the trunk. This is concept E "Height adjustable floor with hatch". This will be the focus for the next part of the development. There are four feature concepts left, 5. Hooks, 7. Straps, 27 Integrated cooling and 47 In-car delivery cooling box. These will be considered during the design of the main structure and be presented as a part of the solution, but they will not be designed any further than the current concept phase. The same approach will also be used for the remaining safety concepts, cargo hooks and cargo net.

5 Part 3: Design an innovative and viable trunk solution

The design phase of the project is divided into two step, system-level design and detailed design. The system-level design set the overall architecture and functionality of the trunk. In the detailed design part, each component is designed in detail.

5.1 System-level design

The trunk has two load floors that can be automatically adjusted in height independently from each other. To use the space behind the wheelhouses two hatches are used, one on each side. When the two load floors are at the highest point, they will be in level with the trunk opening and the hatches on the sides. This creates a flat loading floor without any ledges that make it difficult to load and unload heavy items. It is also possible to close the compartment at the back of the trunk, which has integrated cooling and a locking mechanism to avoid theft. The final solution also includes hooks, straps, cargo hooks and a cargo net.

To set the outer boundaries of the trunk, a CAD-model of the body in white was created. The purpose of the model was to replicate the rear part of a midsize station wagon. The measurements are based on BMW 3-Series Touring 2020. The specific car was used since it has one of the smallest trunks for the segment, which means that any solution that fits the BMW also fits most other car trunks in the segment. Easy accessibility was also important for the selection. The model of the rear part of the car is presented in Figure 37 and 38.

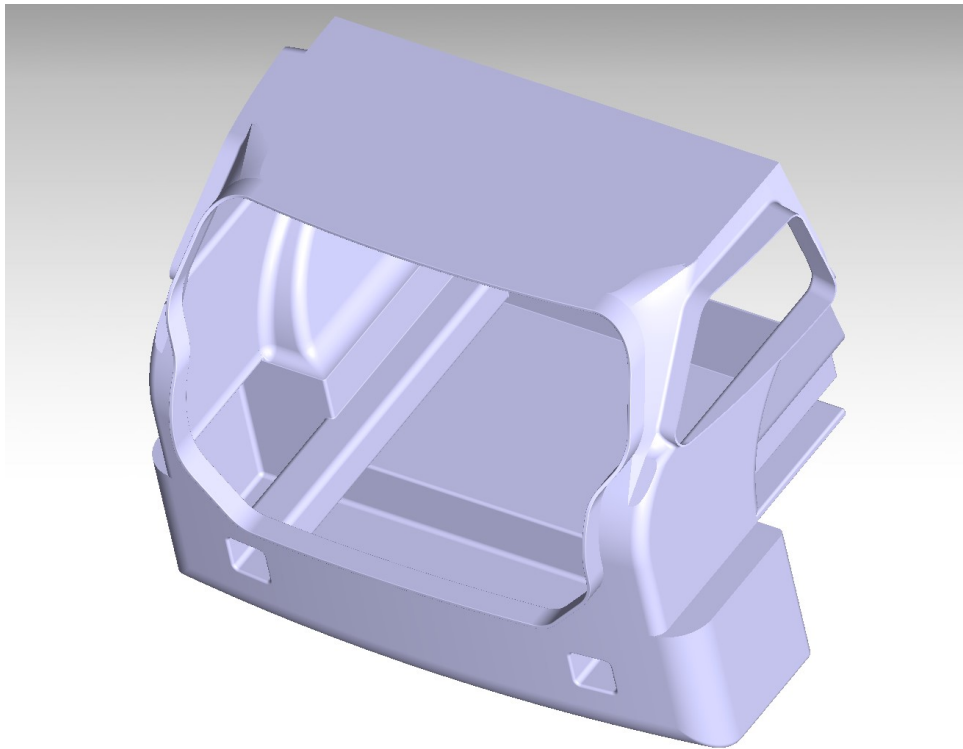


Figure 37: Body in white from the back.

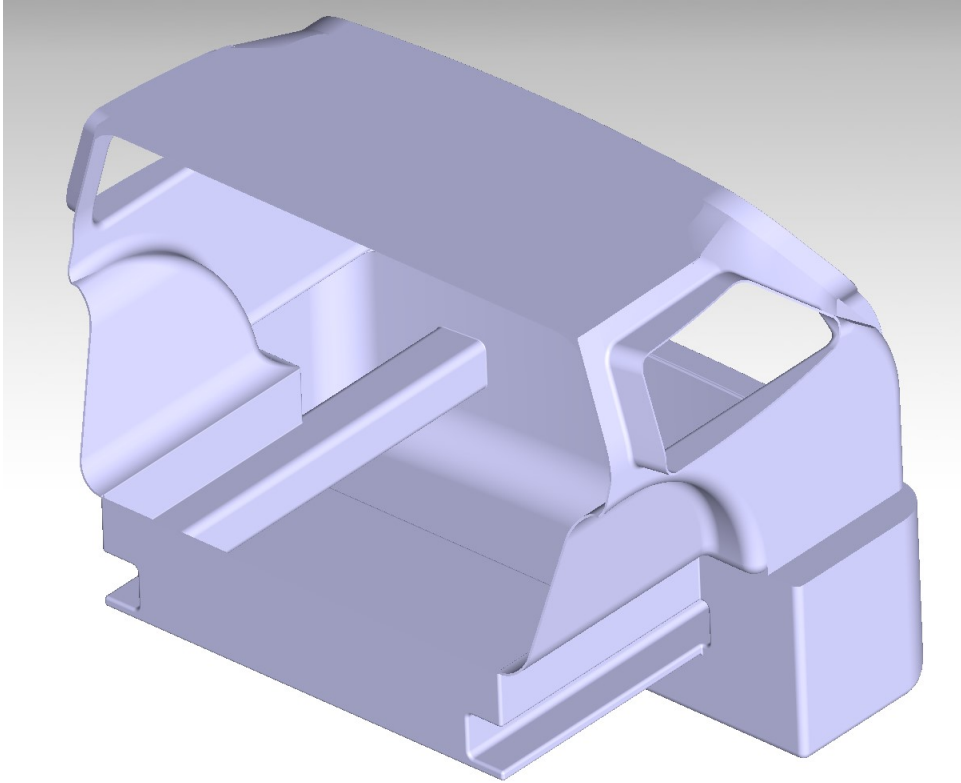


Figure 38: Body in white from the front.

5.2 Detailed design

The detailed design is made based around the different components in the trunk. Most effort is put in the design of the height adjustable floor, since it constitutes the major part of the solution.

5.2.1 Height adjustable load floor

The automatically height adjustable floors provides much of the functionality emphasized in the customer needs. The floor consists of two separate load floors that automatically and independently of each other can be adjusted in height.

Prerequisites

The available space for the height adjustable floor is limited by the lower part of the chassis, the wheel suspension, the rear engine and the two beams in the back of the car. In the CAD-model these are represented by flat surfaces and they set the boundaries for the solution. The available space can be seen in Figure 37 and 38. The solution must fit in this compartment and allow for as much storage space as possible. It is also important that the solution can be operated smoothly and carry the necessary loads.

Lifting mechanism

Two main solutions were considered based for the lifting mechanism. The two options were vertical placed linear actuators in the corners of the load floor and a scissor lift. These solutions were found

in other products with similar technical demands. The vertical linear actuators were eliminated since it would take up more of the loading volume and would have a shorter vertical moving distance. The scissor lift is a proven solution in products similar to this application, for example lifting tables and car lifts. When using the scissor lift it is also possible to use many of the same components for the two load floors, even though the start height and the lifting height is different for the two floors. A CAD-model of the lifting device can be seen in Figure 39 and 40.

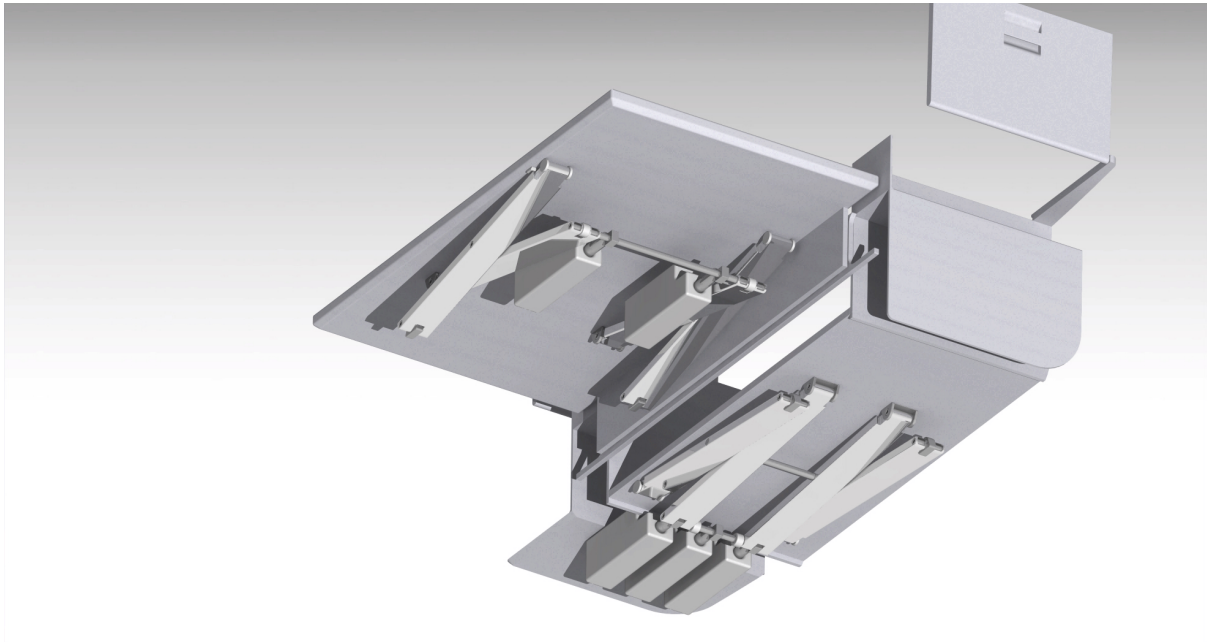


Figure 39: Scissor lifts when both load floors are at its lowest.

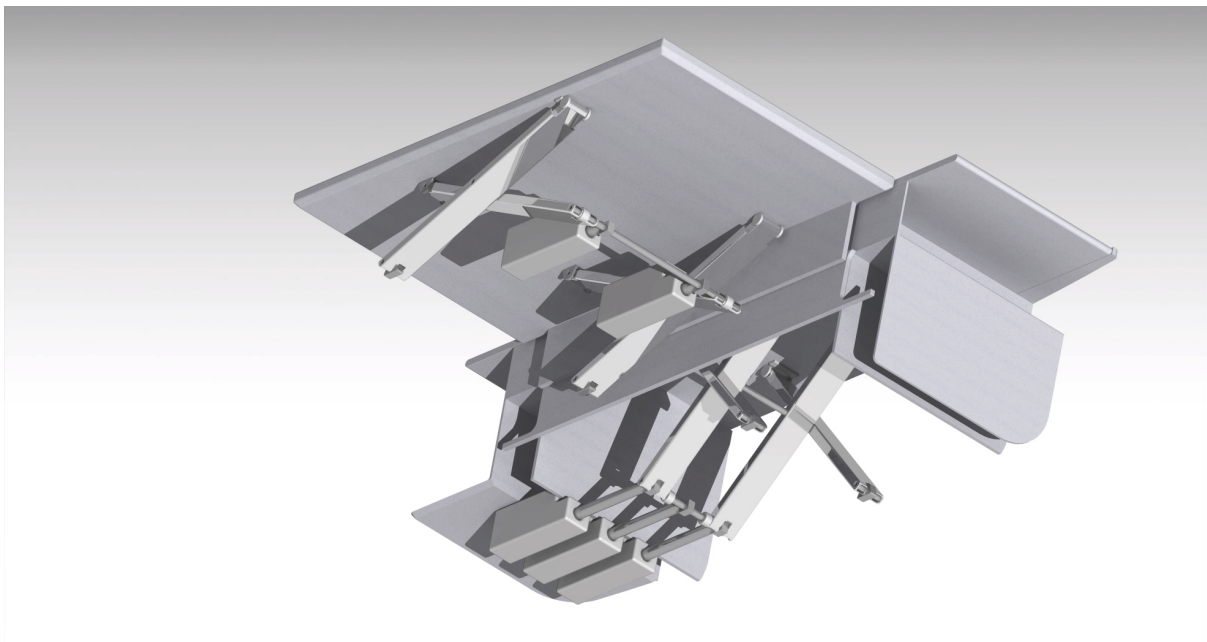


Figure 40: Scissor lifts when both load floors are at its highest.

The two lifting mechanism consist of two "scissors". They are powered by linear actuators, two for the front floor and three for the back floor. One extra actuator is used for the back floor since the angle between the scissor "arms" are smaller for the back floor, when it is at its lowest point compared to the front floor. The two scissors on each floor is connected by two axles, one between the two joints and one where the linear actuators are attached. This adds stability to the design.

Load floors

The two loads floors are made out of a composite material since it is strong and light. The exact material specification is something that must be analyzed further. It is important that that the load floor can withstand both a spread force and a point force. The spread force can for example be if the user transports heavy things from a hardware store, while a point force can for example be if the user puts its knee on the load floor to reach an object in the trunk.

Sliding floor

In the original concept, there were a traditional hatch that had its rotating axis on one side and a handle on the other side. However, when looking at the concept in detail, the solution would cause multiple problems. For example would it be difficult for the user to reach the handle, since the handle would be close to the seatbacks. To see if it was possible to find another solution that could create a closed storage compartment together with the height adjustable floor, relevant concepts that had been eliminated were looked through again. If modified, concept 9. Sliding floor offers a solution that solves the issue of reaching the handle and it also makes the loading and unloading of the front part of the trunk easier. The sliding floor is described in detail in the section below:

The front floor contains a sliding part which can create a closed compartment at the back of the trunk if the back floor is lowered and the front floor sliding part is pulled back, see Figure 41. This compartment can be locked to avoid theft, which might be extra valuable for in-car deliveries and when the owner shares its car with others. The sliding floor can also be used when loading and unloading cargo from the front of the trunk. It is possible to place items close to the trunk opening where it is easy to reach and then push the sliding floor back to its starting position with cargo on it. The opposite can be done when unloading the trunk.

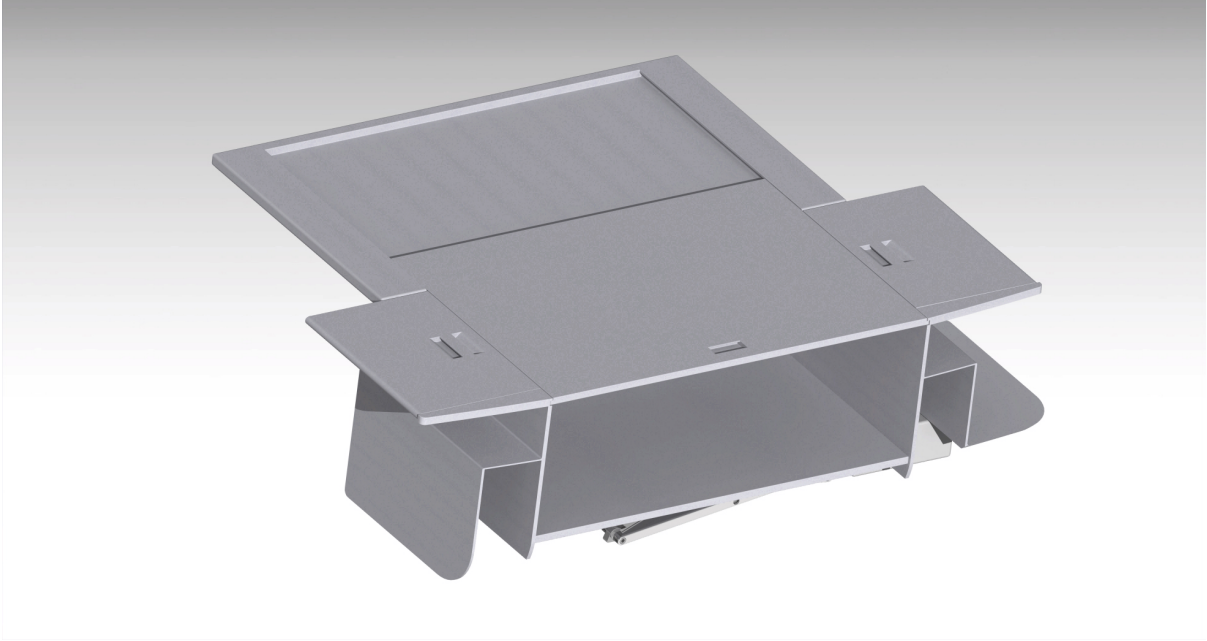


Figure 41: Sliding floor and closed compartment.

Lifting force calculation

To understand what forces the linear actuators have to manage for a certain lifting capacity the lifting mechanism is analyzed in detail. Figure 42 shows a mechanics model of the lifting mechanism.

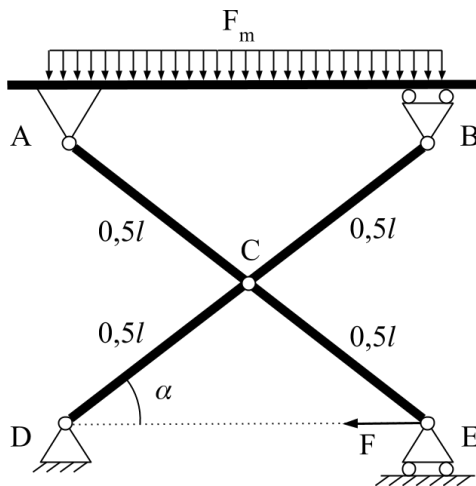


Figure 42: Mechanics model of the scissor lift.

Figure 43 shows the external forces that act on the system.

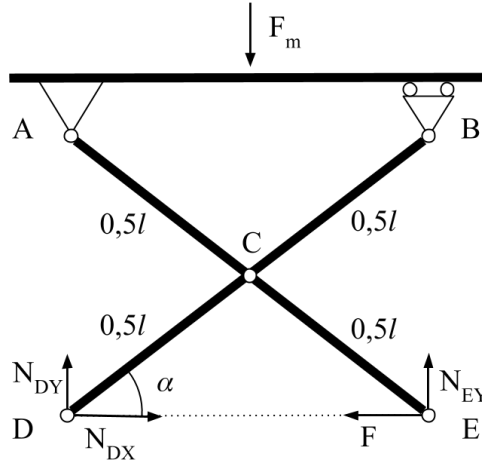


Figure 43: Mechanics model of the scissor lift with external forces.

From Figure 43, the following equilibrium equations derived:

$$\Rightarrow: N_{DX} - F = 0 \quad (1)$$

$$\uparrow: N_{DY} + N_{EY} - F_m = 0 \quad (2)$$

$$M_D : N_{EY}l\cos(\alpha) - F_m 0,5l\cos(\alpha) = 0 \rightarrow N_{EY}\cos(\alpha) - F_m 0,5\cos(\alpha) = 0 \quad (3)$$

To calculate the force F as a function of α and F_m the two legs of the lifting mechanism is isolated, see Figure 44 and 45.

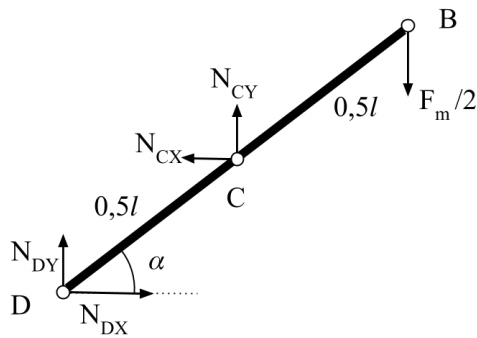


Figure 44: Mechanics model of leg BD in the scissor lift.

From Figure 44, the following equilibrium equations derived:

$$\Rightarrow: N_{DX} - N_{CX} = 0 \quad (4)$$

$$\uparrow: N_{DY} + N_{CY} - F_m/2 = 0 \quad (5)$$

$$\begin{aligned}
 M_C : N_{DX}0,5l\sin(\alpha) - N_{DY}0,5l\cos(\alpha) - F_m/2 * 0,5l\cos(\alpha) &= 0 \\
 \rightarrow N_{DX}\sin(\alpha) - N_{DY}\cos(\alpha) - F_m/2 * \cos(\alpha) &= 0
 \end{aligned} \tag{6}$$

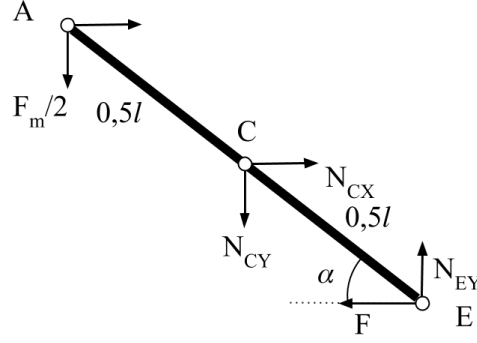


Figure 45: Mechanics model of leg AE in the scissor lift.

From Figure 45, the following equilibrium equations derived:

$$\Rightarrow: N_{AX} + N_{CX} - F = 0 \tag{7}$$

$$\uparrow: N_{EY} - N_{CY} - F_m/2 = 0 \tag{8}$$

$$\begin{aligned}
 M_C : F_m/2 * 0,5l\cos(\alpha) - N_{AX}0,5l\sin(\alpha) + N_{EY}0,5l\cos(\alpha) - F/2 * 0,5l\sin(\alpha) &= 0 \\
 \rightarrow F_m/2 * \cos(\alpha) - N_{AX}\sin(\alpha) + N_{EY}\cos(\alpha) - F/2 * \sin(\alpha) &= 0
 \end{aligned} \tag{9}$$

Equation 3 gives equation 10:

$$N_{EY} = F_m/2 \tag{10}$$

Equation 2 and 10 give equation 11:

$$N_{EY} = N_{DY} = F_m/2 \tag{11}$$

Equation 2 and 4 give equation 12:

$$N_{DX} = N_{EX} = F \tag{12}$$

Equation 6, 11 and 12 give 13:

$$\begin{aligned}
 F\sin(\alpha) - F_m/2\cos(\alpha) - F_m/2\cos(\alpha) &= 0 \\
 \rightarrow F\sin(\alpha) &= F_m\cos(\alpha) \\
 \rightarrow F_m &= F\tan(\alpha)
 \end{aligned} \tag{13}$$

Finally, equation 13 gives the function: $F_m(\alpha) = F \tan(\alpha)$, which makes it possible to decide the needed force F in the actuators and what the smallest angle α can be. In Figure 46 the lifting force F_m is displayed as a function of the angle α for five different actuator forces F .

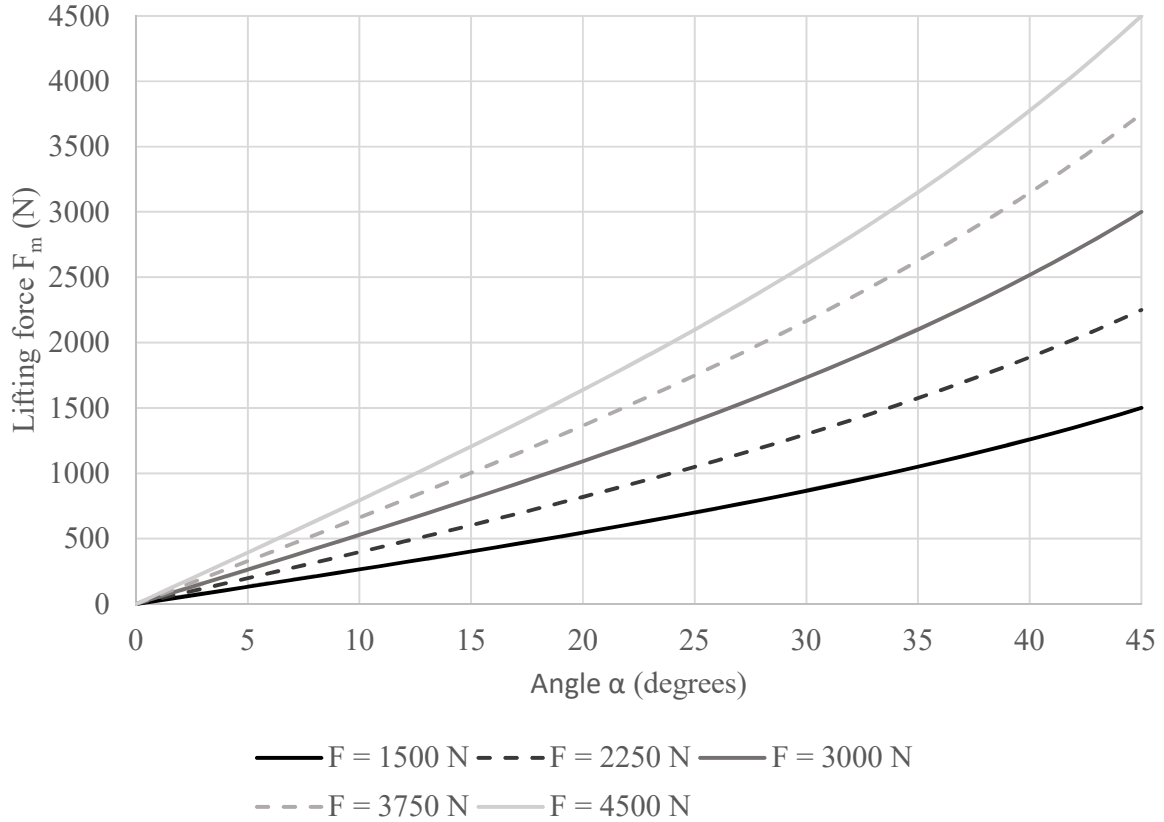


Figure 46: Lifting force as a function of the angle for different actuator forces.

Figure 46 shows that the lifting force is sensitive to the angle and it is when the floor is at its lowest point the lifting capacity is the lowest. Therefore, it becomes important to have as big α as possible at the lowest point. The smallest angle for the front floor is 11,4 degrees and for the back floor it is 4,9 degree. This together with the actuators which each can generate a force of 750 N gives the following lifting forces:

Front floor lifting capacity:

$$F_m(11,4 \text{ deg}) = 2 * 750 \text{ N} * \tan(11,4 \text{ deg}) \approx 302 \text{ N}$$

$$F_m = mg, \rightarrow \frac{F_m}{g} = m : \frac{302 \text{ N}}{9,81 \text{ m/s}^2} \approx 30,8 \text{ kg}$$

Back floor lifting capacity:

$$F_m(4,9 \text{ deg}) = 3 * 750 \text{ N} * \tan(4,9 \text{ deg}) \approx 193 \text{ N}$$

$$F_m = mg, \rightarrow \frac{F_m}{g} = m : \frac{193 \text{ N}}{9,81 \text{ m/s}^2} \approx 19,7 \text{ kg}$$

The calculation of the lifting forces contains the following three simplifications: (1) the system has no mass, (2) there is no friction in the system and (3) the calculations are made when the system is static. Taking all this into consideration it is uncertain if any of the systems can move at all from its lowest position. There are a number of solutions to this problem. From the lifting force function and Figure 46 it is possible to see that increasing the angle and/or the force from the actuators would increase the lifting force. Another possibility is to add an extra lifting mechanism that supports the system when the load floor is at its lowest point. This is something for future development.

5.2.2 Side-hatches

There are two hatches on each side of the trunk behind the wheelhouses. This allows the user to access the compartment underneath the main floor and a flat load floor. The hatches were not a part of the original concept. The two beams in the rear part of the trunk made it impossible to use the full width of the trunk for the height adjustable floor. Regular hatches are used since it provides a simple solution to the problem.

5.2.3 Features and safety solutions

The features and the safety solution that are a part of the solution were not included in the CAD-models since the design of the solutions need more work. Below follow a description of the solution and parameters to consider when making the final design.

Hooks on the sides enable the users to hang small items such as bags. It is important that the hooks are easy to use and strong. The hooks should be integrated in the side walls, so nothing get stuck in them when loading and unloading thing from the trunk. Similar to the hooks, elastic straps on the sides, behind the wheelhouses, make it possible for the user to secure small things. For example, bottles or other things that otherwise are likely to move around in the trunk during transport. The straps should be made in a strong and elastic material.

The compartment at the back of the trunk has integrated cooling. The cooling can either be placed in the floor or at the sides of the lower compartment. This allows for closed cooling compartment when the sliding floor is pulled back. A setup like this is useful for in-car delivery of groceries. The cooling can also be used during transportation from the grocery store. If the grocery bags are too high the cooling can also be used as an open back compartment. This is though less energy efficient. The cooling system can either be a separate system or possibly a part of the car's battery cooling system. This is something that must be investigated further.

The trunk also includes a cargo net to protect the passengers from objects entering the passenger area in a collision or during a hard braking. There are also possibilities for the user to secure the luggage with straps, which the user can attach to the cargo hook. There is one cargo hook in each corner of the load floor. The cargo hooks prevent the luggage from moving in a collision or during a hard braking.

5.2.4 Bill of material (BOM)

The components needed for the height adjustable floor, the sliding floor and the hatches are presented in Table 16. Also, the fixed walls needed to separate the different compartments are included in the BOM.

Number	Item	Mass (g)	Pieces	Total weight (g)	Description
1	Linear actuator LA14	1400	5	7000	130mm stroke. 24-16mm/s + 750 N. 24V. From Linak.
2	Arm1	n/a	8	n/a	Aluminum. 60x20x780mm 3mm thick. See CAD file for
3	Hold1	n/a	4	n/a	Steel. See CAD-file for details
4	Hold2	n/a	4	n/a	Steel. See CAD-file for details
5	Wheel1	n/a	4	n/a	Plastic. Diameter: 25 mm. Width: 5mm
6	Wheel2	n/a	4	n/a	Plastic. Diameter: 25 mm. Width: 15mm
7	Axle1	n/a	1	n/a	Aluminum. Diameter: 12,5mm. Length: 340 mm. Thickness: 3mm.
8	Axle2	n/a	4	n/a	Aluminum. Diameter: 12,5mm. Length: 60 mm. Thickness: 3mm.
9	Axle4	n/a	4	n/a	Aluminum. Diameter: 12,5mm. Length: 55 mm. Thickness: 3mm.
10	Axle5	n/a	1	n/a	Aluminum. Diameter: 12,5mm. Length: 412,9 mm. Thickness: 3mm.
11	Axle7	n/a	2	n/a	Aluminum. Diameter: 12,5mm. Length: 120 mm. Thickness: 3mm.
12	Axle8	n/a	1	n/a	Aluminum. Diameter: 12,5mm. Length: 226 mm. Thickness: 3mm.
13	Floor1	n/a	1	n/a	Composite. Width: 800 mm. Length: 414 mm. Thickness: 15mm
14	Floor2	n/a	1	n/a	Composite. Width: 994 mm. Length: 570 mm. Thickness: 30-15 mm.
15	Sliding floor	n/a	1	n/a	Composite. Width: 808 mm. Length: 545 mm. Thickness: 15 mm.
16	Hatch	n/a	2	n/a	Composite. Width: 380 mm. Length: 261 mm. Thickness: 15 mm.
17	Moving wall	n/a	1	n/a	Composite. Width: 816 mm. Height: 120 mm. Thickness: 10 mm.
18	Fixed internal walls	n/a	1	n/a	Composite. See CAD-file for details.

Table 16: BOM for the height adjustable floor, sliding floor, side-hatches and walls between the compartments.

5.3 Design feedback

The solution described above were presented to six automotive engineers working at NEVS. They thought that the solution served a clear purpose and that it was user-friendly. Their main concern was the cost and if a customer would be willing to pay extra for the functionality the solution provides. Another negative aspect which they pointed out, is that the solution uses volume, which otherwise could be used for transporting things. The total volume is an important selling point according to them. The problem with the lifting capacity, did they see as something that can be solved with an extra lifting mechanism when the lift is at its lowest point.

6 Discussion

The discussion is divided in five parts: "Method", "Customers needs, technological and legal aspects", "Concept generation and elimination" and "Implications". The aim is to give a nuanced view of the methods used, the outcomes from the different parts of the project and what impact the findings might have in the future.

6.1 Method

The methodologies used during the project have a foundation in established product development literature. The methods have been modified to better suit the product that is being developed. The main parameters that have caused the need for these modifications are complexity and uncertainty. This is related to the usage of the product and the fact that the trunk is not a product in itself, it is a part of another product, the car. Some of the methods suggested in the literature would have limited possibilities to explore the design space already at an early stage of the development. For example, making a functional decomposition would have limit the design space for this project, but it is however likely to be useful in an upcoming design iteration, when the main structure and functionalities are already set. This would make it possible to also use tools like the morphological matrix to explore more possible concepts.

One of the main problems in a product development project is uncertainty. Many of the decisions made during the project were based on imperfect data, but the decisions had to be made for the development to progress. It was therefore important to make decisions as systematically as possible, the different decision matrices in the concept elimination phase is one example of this. Another important aspect was also to eliminate inferior concepts, instead of selecting the "best" concept. By doing this, the resulting solution is the one with the least drawbacks.

6.2 Customers needs, technological and legal aspects

The market for BEVs is growing quickly at the moment. The reasons behind the development are many, but key aspects are the technological development, new legislation, increasing competition and the customers' desire for sustainable transportation. All these things point in the same direction, which is towards a society with more BEVs and fewer ICE cars.

How the car is used in general and specifically how the trunk is used, is difficult to pinpoint. It is clear that the car is used for many different purposes today and it is likely that the need for flexibility will remain in the upcoming years. It might even increase, since trends like car sharing, in-car delivery and new views on last kilometer transportation might create new demands on a trunk.

Throughout the interviews, the importance of user-friendliness and simplicity became obvious. The functionalities in the trunk must be easy and fast to use, otherwise it will only be used by a few customers. According to the car dealers, the trunk seemed to be of less importance than other parts of

the car. This included customers who bought station wagons. A bit contradictory, since one important reason of buying a station wagon, is to have a spacious and effective trunk. The only thing that the customer seemed to care about was that they could fit specific items, such as baby strollers and golf bags. The need for an improved trunk, might be limited based on this, since the customers seems to be satisfied with existing solutions. It is however likely that this is a latent need. The customers are not aware of their need for an improved trunk. The unawareness can have many explanations, one is that the OEMs are not focusing their marketing on the trunk, instead the focus is on things like driving experience or safety. However, by having an improved trunk it might be possible to change the marketing and show the possibilities an improved trunk generates.

How car sharing will develop in the future is rather uncertain, some believe that little will change from today, while other believe that no one will have their own car. The impact car sharing will have on the design of the trunk depends on how the car sharing evolves. The way Lynk and Co presents, where the user can share its car to others will create a need for secure storage. In other scenarios, the need for flexibility in the trunk might decrease. For example, the users might have access to a variety of different vehicles which all match different transportation purposes. The customers might for example use different cars for grocery shopping, picking up kids at school, going on vacation etc.

The longtime storage of items in the car varied between the customers. The possibility to place these items in the trunk, enables a better solution for the trunk. Although it is likely to believe that the trunks will become more user-friendly and therefore be more important in the everyday use. The trends for the future which were found during the project will impact how trunks are used. For example, in-car delivery goes hand in hand with increasing e-commerce of both retail products and groceries. Having a trunk that meets these new demands can make the car to a more integrated part of people's lives.

The technological aspects of BEVs is the foundation for this project. It became clear that new opportunities for the trunk appear, but it is difficult to know exactly to which extent there will be for example more space in the rear of the car. In this project the new technological structure of the BEV was used to optimize the trunk. When designing the complete car, it might though be other things that also could benefit from the new structure, but thereby impact the trunk negatively. This would lead to a number of trade-offs for the OEMs. It is however clear that there will be more room for the trunk in a modern BEV compared to an ICE car.

The legal requirements relevant for the trunk turned out to be only three, where only one impacts the interior of the trunk. This gave a big design freedom for the following parts of the project. The legal requirements UNECE R17 and R32 are both related to safety for the passengers. Except for these requirements there is in general a lack of safety when designing the trunk, even though the cargo in the trunk can cause injuries in a collision. If it is possible for an OEM to create a safer trunk and show the benefits of it, the safety of the trunk might be something that customers take into consideration when buying a car.

6.3 Concept generation and elimination

The generated concepts display much of the complexity in the product. It is for example possible to find ways to support grocery bags during transport, both in concepts that have a major impact on the overall design of the trunk, but also in a small feature, that could be added to any overall trunk solution. The same goes for much of the other functionalities as well. One reason to the variety of concepts is probably the focus on the different customer needs and how to solve these, instead of having a functional decomposition to base the ideas on. This approach likely increased the searched design space. Many of the concepts that were generated, were ideas that have not been applied in cars before. This was important since one of the cornerstones for the project was to find not only an effective solution, but also an innovative solution.

The resulting concept for the main structure offers a solution that is easy to use, flexible and innovative. The concept is though rather complicated and there were some question marks when it came to the technical design of the concept. The overall analysis was however that all these potential issues are solvable. Some features and safety solutions were also left after the concept elimination. Most of the resulting feature and safety concepts were all solutions that exist in cars today, this meant that it was of little value to make a detailed design for these items. When it comes to the integrated cooling in the trunk, this was also not prioritized in the design phase, since the cooling is a minor functionality. Instead all efforts were put on the main structure of the trunk.

6.4 Designing the trunk

The focus in the design phase was on the mechanical solutions for the trunk and it was therefore important to have a body in white structure to base the design on. This structure is however an approximation of how a potential body in white of the rear part of a BEV could look like. If an OEM decides to use the design presented in this project, their body in white will be different, which will impact details in the design of the trunk. The design in this project is tailored to the presented body in white structure.

The problems related to the lifting capacity of the load floors are likely to be solvable by having stronger actuators and adding a lifting mechanism for the lowest part of the lifting. The main drawbacks with the design are that it is heavy and costly, compared to the trunk solutions in today's cars. There are also many moving parts in the design which might be a source of problems. The compartments behind the wheelhouses are narrow and might not be optimal from an ease of use point of view, but the compartments increase the total volume of the trunk.

6.5 Implications

The trunk design has the potential to change the way people use their cars and their trunks. It can also make BEVs more competitive compared to ICE cars. This means that, if the solution is implemented, it will have a positive impact on the transition to a fossil fuel free transportation system. Also, the improved in-car delivery possibilities might decrease the total negative CO₂ footprint for the user. This

assumes that the in-car delivery can benefit from increased sustainability of consolidated transports. If the solution enables easier car sharing and thereby increases utilization of each vehicle, fewer cars and fewer parking places would be needed. The integration of last kilometer transportation means is something that is not included in the final design, but it has potential to change the way people travel. It is therefore something that is recommended to be analyzed further in future projects.

7 Conclusion

People use their cars for a variety of different purposes, and this is something that should be reflected in the design of the trunk. The trunk seems however to be under-prioritized by both the customers and OEMs, even though it is one of the main reasons to buy a station wagon. BEVs offer new possibilities for the trunk, in terms of volume and access to a strong and reliable electric energy source. Future trends like in-car delivery, car sharing and last kilometers transportation in cities put new demands on the trunk. The trunk developed in this project offers an innovative solution that has been developed to meet the needs of tomorrow's customers. It benefits from the new possibilities and increased space the architecture of a BEV offers. Flexibility and ease of use are the main strengths of the design. The product has potential to change the way people use their cars and to make the car into a more integrated part of people's lives. However, the product needs further development and refinements in future design iterations. More features should also be added and developed, to make it into a complete trunk solution.

8 Future work

The solution needs refinements before it is implemented. That the product operates smoothly is vital and the control units must be intuitive and simple. These are things that will make the customers actually using and benefiting from the product. The OEMs of BEVs are the stakeholders that must see a business potential in the product, for it to reach the market. To create such business potential, it is important to communicate all the advantages with the product and why it fits the lifestyle of the customer. The OEMs must also see what trade-offs they have to make in the complete design of the car, to include the presented solution in the trunk. It is though possible to implement the solution to different extent, see the different alternatives below:

Alternative 1: implement the solution as it is presented in this report.

Alternative 2: remove the compartments on the sides, behind the wheelhouses.

Alternative 3: only have height adjustable floor at the back of the trunk.

Alternative 4: remove the compartments on the sides, behind the wheelhouses and only have a height adjustable load floor at the back of the trunk.

It is also possible to remove the sliding floor in any of the alternatives presented above. Alternative 2-4 and/or removing the sliding floor will decrease the functionality compared to alternative 1, but it might be advantageous from a cost and weight point of view. It might also be the result of trade-offs when designing the complete vehicle.

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Appendices

A Customer interviews from previous studies

A summary of the user interviews made by Kandukoori & Pinnamaneni (2018) is presented on the following pages.

Interviewee	Age	Gender	Family	Car(s)	Permanent storage	Weekly use	Rare use	Positive experiences	Negative experiences	Other user behaviors	Preferences
X1	48	Male	Married, 3 kids		Snow shovel	Transport groceries	Fishing equipment	Loaded a dishwasher in the trunk	Misses the possibility to hold the trunk floor in place when reaching the things underneath	Secure groceries	Wants the trunk to be flexible for different needs
					Umbrella	Luggage for short trips	Mountain hiking equipment	Baby stroller takes up much of the space	Uses nets/pouches on the side of the trunk to secure fragile goods		
					Towing rope		Baby stroller	Rarely extends the trunk by folding the rear seats			
X2	26	Male	Married, 2 kids	Volvo V50 2015	Washer fluid	Transport groceries	Camping equipment		Curved side walls hindered him from fit luggage (when fully packed)		Flat walls makes it easier to organize the luggage
					Blanket	Luggage for family trips	BQ coal		Pockets in the trunk hindered him from fit luggage (when fully packed)		Flat walls makes it easier to fit more luggage
					Umbrella	Baby stroller	Coolbox				Wants a solution to secure grocery bags.
X3	39	Male	Single	BMW 3-series Touring	Washing equipment	Commuting	Coolbox		To difficult to secure luggage		Easy way to secure luggage
					Oil	Groceries	Skies (by folding rear seats)				Easy system for organizing luggage
					Tools	Fragile bottles					Dedicated tool storage
X4	54	Male	Single	Mazda 3	Starting cables						Flat access in and out of the trunk
					Football shoes						Do not want to transport his pet in the trunk, prefers to have the cage in the passenger area
											Protect the car from being scratched when loading/unloading
X5	22	Male	Single	Chrysler 1991 convertible							Reachability in the trunk is important
											Easy to load and unload heavy goods
X6	29	Male	Girlfriend	Saab 9-3	Oil	Commuting	Skies		Misses cargo securing options	Regular stores laptop in trunk or on the floor behind the front seats	Wants warning triangle and light to be easily accessible
					Wrench	Travel to gym	Camping equipment		Misses organizing walls		
					Start cables	Shopping			Portable solution to carry luggage with him		
X7	28	Male	Girlfriend	BMW 330	Rope	Visiting friends					
					De-icing spray	Groceries					
					Napkins	Commuting	Longer trips visiting friends/family	Possible to only open the rear windshield			Has customer made a foldable bed for his car for sleeping purposes
					Tools	Groceries	Sleeping in the car	Electrically operated trunk-lid	Has an extra battery that powers the heater/cooler when needed	Wants cooling of beverages	
					Rubber mat		Skies				
							Hardware				

Interviewee	Age	Gender	Family	Car(s)	Permanent storage	Weekly use	Rare use	Positive experiences	Negative experiences	Other user behaviors	Preferences
X8	26	Male	Married, 3 kids		Vacuum cleaner	Commuting			Lack of good lights in the trunk		Wants an organized way to place luggage
					Pressure pump	Bags					
X9	54	Male	Married, 3 kids		Snow chains	Laptop bag			Lacks good grocery storage solutions	Do not use the hooks in the trunk	Wants warning triangle to be easily accessible
					Washer fluid	Groceries					
X10	52	Male	Married, 2 kids		Gloves	Leave and pick-up kids at school	Luggage			Secures bottles using existing nets	Wants easy access when he gets older
					Reflective vest	Commuting	Wine and beer bottles				
X11	41	Male	Single		Umbrella	Groceries					Wants more space when shopping at mega stores
					Start cables						
X12	29	Male	Single		Pressure kit	Commuting	Long distance traveling		Luggage hinders visibility in rear mirror		
					Light bulb	Suitcase			Difficult to reach things from the rear seats		
X13	54	Male	Married, 2 kids	Mini Clubman 2008	Bike holder	Commuting	Pet cage			Secures the grocery bags carefully because of safety reasons	
					Roof rails	Groceries			Keeps cargo secure and hidden by using existing trunk cover		
X14	46	Male	Married, 2 kids		Start cables	Commuting	Coolbox		Rubber mat that makes it difficult to load/unload heavy luggage		Does not use trunk cover, since he means that it is an indication that something valuable being stored
					Reflective vest				Existing hooks are not good for storing bags		Wants something else than the trunk cover so he can place valuable items in the trunk

B Trunk data

	BMW 3-series kombi	VW Passat kombi	Skoda Superb	Mercedes C-class
Room for spare wheel	Yes	Yes	Yes	No
Spare wheel	No	No	No	No
Tire repair kit	No (puncture free tires)	Yes, under the floor	Yes, under the floor in the room for the spare wheels.	Yes, under the floor
Lower floor	Yes, two parts with separate lids. One wide between the behind the wheelhouses and one more narrow between the wheelhouses	Yes, two levels. The first level is adjustable, so you can lower the main floor approximately 7 cm. Underneath there is room for a spare wheel or other equipment.	Yes, two levels. The first level is adjustable, so you can lower the main floor approximately 11 cm. Underneath there is room for a spare wheel or other equipment, there is much space under the second floor.	Yes, one storage compartment under the main floor, quite small.
Materials	Felt	Felt	Felt	Felt
Hooks and other features	4 cargo hooks in the corners. 1 hook on the right hand side. 2 mesh pockets. 1 elastic band on the right hand side. 12V.	4 cargo hooks in the corners. 2 folding hooks (1 on each side). 2 fixed hooks (1 on each side). Plastic boards behind the wheelhouses. 12V	4 cargo hooks in the corners. 4 folding hooks (2 on each side). 12V	4 cargo hooks int the corners. 2 hooks (1 on each side). 1 mesh pocket on the left-hand side. 12V
Loading height	63 cm. Flat floor.	66 cm (Alltrack)	66 cm (Superb)	59 cm
Height on lower floor	- 7 cm	-13 to -33 cm	-11 cm and deeper for the lowest floor.	-5 to - 26 cm
Trunk opening size (w x h)	114 x 71 cm	107 x 71 cm	106 x 72 cm	96 x 69 cm
Max w x d x h	134 x 99 x 71 cm	147 x 114 x 71 cm	108 x 115 x 72 cm	123 x 98 x 69 cm
Min w x d x h	95 x 89 x 71 cm	100 x 85 x 71 cm	101 x 90 x 72 cm	95 x 89 x 69 cm
Warning triangle	In the trunk lid	In the trunk lid	Under the floor, in the very rear of the trunk.	Under the floor
Safety equipment	Firs aid kit	First aid kit	First aid kit	First aid kit. Reflective vests.
Trunk lid opening height	180 cm	195 cm	196 cm (adjustable but max is 196 cm)	179 cm
Other features	Metal rails with rubber insert which. The metal makes it easy to slide in luggage and when driving the rubber insert rises and gets in contact with the luggage to keep it in place.	Adjustable floor height.	Adjustable floor,	
Comments				

Kia Optima (PHEV)	Opel Insignia	Ford Mondeo	Audi A4	Volvo V60
No	-		No	Yes
No	-	No	No	No
Yes, in the trunk.	-	Yes, under the main floor	No	No
No	-	Yes, with a lot of small storage compartments. About 6 cm deep.	No, (the space is filled with a 12V battery and only room for some smaller things around the battery).	Yes, but the height is varying
Felt	Felt	Felt	Felt	Felt
4 cargo hooks in the corners. 2 hooks (1 on each side) 72 cm (75 cm is the height of the main part of the floor)	4 cargo hooks in the corners. 2 hooks (1 on each side) 63 cm	4 cargo hooks. 2 hooks (1 on each side). 12V. 58 cm	4 cargo hooks. 2 hooks (1 on each side). Mesh pocket on the left hand side. 12V.	4 cargo hooks. 4 hooks (2 on each side). 12V.
-	-	- 6 cm	-	-
104 x 65 cm	104 x 71 cm	112 x 70 cm	-	-
103 x 107 x 65 cm	139 x 113 x 71 cm	132 x 112 x 70 cm	-	-
100 x 88 x 65 cm	104 x 100 x 71 cm	113 x 80 x 70	-	-
In the trunk.	-	Under the main floor	?	In the trunk lid
-	-	No	First aid kit	First aid kit and cargo net
183 cm	188 cm	180 cm		
Kia Optima is only available as PHEV in Sweden and the battery takes up much space in the rear of the car.	-		Trunk floor 4 cm lower than trunklid opening.	
	The trunk was partly filled with luggage, some data is therefore missing.			

	Renault Talisman	Kia e-Niro	Nissan Leaf	Tesla Model 3	Tesla Model X
	No	Yes	No	No	No
	Yes	No	No	No	no
	Yes, under the main floor.	Yes, under the floor. In the space for the spare wheel	Yes, in the main trunk.	No, optional.	No, optional.
	Yes, room for spare wheel.	Yes, space adapted for spare wheel.	No	Yes. A large storage compartment under the main floor.	Yes. A large storage compartment under the main floor.
	Felt	Hard plastic on the sides. Felt on the other parts.	Hard plastic on the sides. Felt on the other parts.	Felt. Body in white in the roof of the trunk.	Felt
	4 cargo hooks. 1 hook on the right hand side. 12V. Cargo divider.	4 cargo hooks in the corners	2 mesh pockets (1 on each side)	No.	4 cargo hooks in the corners (thin design that could be weak). 12V.
	-	85 cm	74 cm	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	-	-	-	-	-
	In the trunk lid	Under the floor	Yes, in one of the mesh pockets.	In the trunk.	In the trunk.
	No	Under the floor	-	First aid kit and reflective vests in the frunk.	First aid kit and reflective vests in the frunk.
		184 cm		184 -	-
			It had an extra sound system which takes space in the trunk.	-	Folding extra seats in the trunk.
	Not relevant to measure the trunk space since it is not a station wagon.	Not relevant to measure the trunk space since it is not a station wagon.	Not relevant to measure the trunk space since it is not a station wagon.	Not relevant to measure the trunk space since it is not a station wagon.	Not relevant to measure the trunk space since it is not a station wagon.

Audie E-tron

Yes

No

No

Yes room for spare wheel and some extra storage

Felt

4 cargo hooks. 2 hooks (one hook on each side). 12V.

First aid kit and cargo net under the main floor

C Interviews with car dealers

BMW

"Everyone buy stations wagons!" Most families with kids though. Many people buy a bigger car than they need, because they are use to have a big car. Some customers that previously bought station wagons now buy SUVs. Many customers buy a station wagon so they can use it for vacations. The customers use it also for, commuting, transporting their dog, golf equipment and transporting goods for recycling. It should be able to carry golf bag, dog cage, luggage on vacations and storage of permanent equipment.

The customers want felt but many buys a rubber/plastic mat to put on the trunk floor.

"No one cares about the volume". The customers look and make a judgement if it is big enough. Vanity is more important than trunk volume.

Yes.

Not much focus on safety or security. No one stores valuable items in the car.

Customers want a deeper space underneath the main floor.

The customers appreciate that it is possible to place the cargo net and visibility cover underneath the main floor. The possibility to fold all three seats separately do some customers like.

BMW convertibles have a storage between the rear seats and the trunk.

Who buys a mid-size station wagon?

What are the main usage areas?

What do the customer request regarding the trunk?

What materials do the customers want?

How important is the trunk volume for the customer?

Is it important for the customers to have a flat floor?

Do the customer focus on safety and security in the trunk?

Are there any problems or possibilities for improvement of the trunk on the cars you sell?

Do the customers give any comments on features in the trunk? Do you know any trunk solutions that are particularly good out on the market?

Have you discovered any customer needs that today's trunk do not fulfill?

Do you have any ideas for trunk storage solutions?

Other

Volkswagen

Skoda

Families with kids and company cars.

Families with kids and company cars.

Everyday use and going on vacations.

Vacations, pick-up and leaving kids at trainings, everyday life.

It should be able to transport a stroller, dog cage. It is important that is deep and wide, and have a rectangular shapes.

The cargo capacity. It should be able to carry strollers and luggage for skiing holidays.

The customers want felt but many buys a rubber/plastic mat to put on the trunk floor. "10 out of 10 buys a rubber/plastic mat". The back of the rear seat can be in rubber which is requested by some customers.

The customers want felt, most customers also want a rubber/plastic mat, with edges stopping water and dirt from the felt.

Very few people talk about volume, some take measurements on wide and depth etc.

No one talks about the volume. People measure so they can fit specific equipment.

Yes.

Yes.

Not much focus on safety except the cargo net. Some company customers request extra alarm.

Customers only want a cargo net.

"The trunk is to deep"

-

-

Some OEM have vehicles where it is possible to limit the depth, example for grocery shopping.

-

-

-

-

"95 % buy the car without a spare wheel."

Mercedes

Families with kids and company cars.

- The customer buys a station wagon to get big storage space. Customers want to be able to carry a stroller.

The customers want felt but many buys a rubber/plastic mat to put on the trunk floor.

Some customers care about the volume.

Yes.

No.

No.

No.

No.

No.

It would be good if you could carry skis inside the car.

-

Kia

Family with kids and company customers.

Commuting private use, everyday family use.

The space is important. It should be able to carry a stroller.

The customers want felt but many buys a rubber/plastic mat to put on the trunk floor.

Not much focus on the volume. People care about width and length.

Yes.

No.

The floor in the Optima is not completely flat which is something that many customers point out.

See above. Some customers want to have a sensor for opening the trunk with their foot.

-

-

-

-

Audi

Families and company cars

Families: use in daily life and use for vacations. Company cars: sales men who use it to transport sales items.

People want to make sure different items can be fitted. Baby strollers and golf bags are common. They want a large cargo space.

Felt, but many customer buys a rubber/plastic mat.

The exact numbers are not important. Many customers compare with their current car.

No one cares about the edge. (Audi A4 has a difference in height of 4 cm between the trunk opening and the trunk floor).

No, no one mentions crash safety issues connected to the trunk.

Not what he has seen.

The Audi A4 has a large and wide trunk.

No

No

No

60-70% of the customers really consider the trunk when buying a Audi A4

Renault

Every one buys station wagons. Companies, families with kids and older people. It is only younger people that tend to not buy a station wagon.

Families: be able to bring all items related to everyday life and hobbies. Golf bags are important for some customer segments.

They want to transport: baby strollers, golf bags and other items related to their hobbies.

Felt, but most customers also buy a rubber/plastic mat

Few customers care about the volume. Most customer look and test to fit specific items.

Yes it is important and something that a station wagon should have

No more than the cargo net.

No.

No most customer do not care about the trunk particularly much.

No.

No.

The storage compartment underneath the main floor could be improved in most cars.

The storage of charging cable is a problem for electric vehicles since it often is dirty.

D Elimination 2, second iteration

Selection criteria	A Hatches in the floor	B Two level floor with hatch	C Sliding floor & large hatch	D Tetris	E Height adjustable floor with hatch	F Air-balloon and hatch	G Elastic beams	H Multi-level floor with hatch	I Low flat floor (Reference)
Standard cargo	+	+	+	+	+	-	-	+	0
Groceries	0	0	-	0	+	0	-	-	0
Bulky items	0	+	0	0	+	0	-	+	0
Adaptability & flexibility	+	+	0	+	+	+	-	+	0
Security	0	-	0	0	0	-	-	0	0
Overall ease of use	+	+	+	-	+	0	-	0	0
Crash safety	-	0	-	-	0	-	-	-	0
Mass	-	-	-	0	-	-	0	-	0
Attraction	+	+	+	0	+	+	-	0	0
Sum +'s	4	5	3	2	6	2	0	3	0
Sum 0's	3	2	3	5	2	3	1	3	9
Sum -'s	2	2	3	2	1	4	8	3	0
Net Score	2	3	0	0	5	-2	-8	0	0
Rank	3	2	4	4	1	8	9	4	4

Table 17: Second elimination using Pugh-matrix, second iteration.