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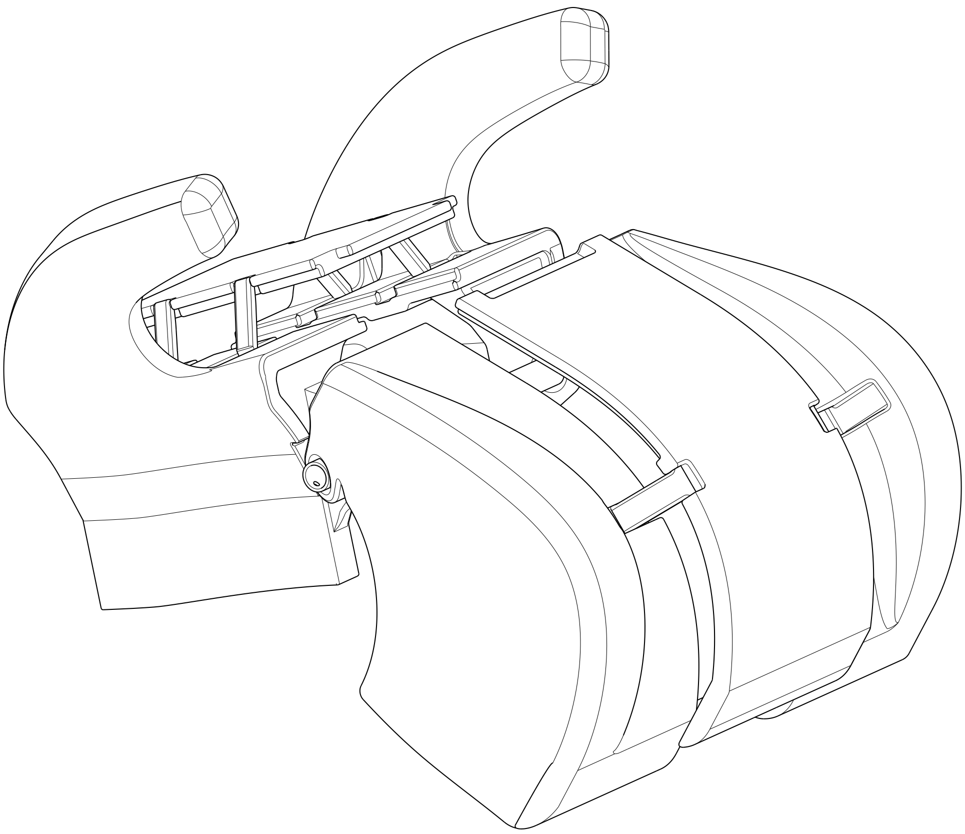

Booster Cushion for Shared Mobility

The development of two new portable booster cushions

A master's thesis in Product Development

Charlie Johansson
Sebastian Simmons

Department of Industrial and Materials Science
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Gothenburg, Sweden 2020

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Supervisor: Katarina Bohman, Volvo Cars
Examiner: Anna-Lisa Osvalder, Chalmers University of Technology

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Department of Industrial and Materials Science
Division of Design & Human Factors
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover (front): The SaFE booster cushion in a semi-folded state
Cover (back): The SaFE in its compact state (top) and deployed state (bottom)

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Chalmers University of Technology

Abstract

The aim of this report was to develop one or several booster cushions suited for a future use in shared mobility. This meant the product would have to be easy to carry, easy to use, adds user and customer value and still makes the cars protective systems available for the child. A rising need for this type of booster cushion can be seen as car sharing and carpooling is becoming more and more common in everyday society.

Several topics were researched to get an understanding of what value the product would imbue. By performing several interviews, a survey and several benchmarks, an understanding of the booster cushion and its usage was obtained. After this 26 concepts were created and evaluated through several elimination matrices with criteria built from a requirement specification and a customer needs list. The final concept were evaluated further through static FEM analyses and prototype observations.

The primary factor for affecting portability was deemed to be the carrying feature followed by the volume, and in third place weight. Two booster cushion concepts were conceived which were capable of changing size, the AID and the SaFE. The AID is an automatically inflatable booster cushion which utilizes a drop stitch construction for increased durability and an automatic pump to increase ease of use while the inflation aspect makes it portable. The SaFE is able to compress in two dimensions, reducing in width using a sliding mechanism and in depth by a folding itself in half. A more robust and easy to use revision of the SaFE was made which also conformed to the new UN R129 regulations. Several additional features were also presented and briefly evaluated together with future recommendations which could increase the products potential further for both the AID and the SaFE.

In the discussion the products and processes are discussed in detail with regards to time constraints and how different priorities could have led to different outcomes. Possible sources of errors are discussed, how they were dealt with and what could have been done differently. How the project was affected by the CoVID-19 virus pandemic is also taken into account. Finally, future development and recommendations for the SaFE and AID is discussed.

In the conclusion the aims are compared to the achieved results with the AID and SaFE. While some of the aims such as 'easy to carry' and 'easy to use' can be considered more developed than others, all of the aims have been fulfilled in some way. However, all of the aims similarly shows potential to become more fulfilled and the report have recommendations for how to continue development.

Keywords: booster, cushion, foldable, inflatable, automatic, safety, R129, shared, mobility, future

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Charlie Johansson, Sebastian Simmons

Gothenburg, June 2020

Contents

1

Introduction

This chapter serves as an introduction to the master thesis “Booster Cushion for Shared Mobility”. The project was carried out during the spring semester of Chalmers University of Technology at Safety Centre at Volvo Car Group in Gothenburg with an aim of developing a concept of a more portable booster cushion.

1.1 Background to problem

New technological breakthroughs have altered the prerequisites of urban mobility and thus enabled new solutions that does not require owning a car. Car sharing and carpooling are becoming more commonplace, which in turn poses questions when it comes to children’s safety. The booster cushion is usually used by children at around the age of four to around the age of twelve years in order to reduce the risk of injury. The booster cushion raises the child up so the seat belt is properly positioned. When the lap belt is properly positioned, the risk of the lap belt slipping off the pelvis bones is reduced, which could otherwise lead to abdominal injury should an accident occur.

The available booster cushion products have relatively low weight but are cumbersome due to their volume which makes them unable to fit common bags and rucksacks and as a result usually must be carried around by hand. In a plausible future where users only have access to the car during the trip, the transporting of the booster cushions will increase. This combination of temporal cars and unwieldy booster cushions may result in more people taking shortcuts and avoiding using the cushion all together, putting the child at a greater risk while in the car. As thus there exists a need to develop a more portable booster cushion to fit this future market segment.

1.2 Aim

The aim of the project was to design one or several concepts of a booster cushion that is especially suitable for shared mobility, meaning a booster cushion that is easy to carry, easy to use, adds user value, adds customer value and still protects the child in an accident.

1.3 Limitations

The thesis had a set of limitations in that it will only investigate child restraint systems aimed at the designated age group and a specific subset of booster seats, referred to as booster cushions. This means that infants and children requiring other solutions are not within the scope of this project, and the design will thus not be a rear-facing booster seat or a booster seat with backrest.

- The designs would only be aimed towards children within the age range of four to twelve years old and within the height range 125-150cm.
- The designs would not feature a backrest.
- The designs would not consider the use of the design in other vehicles than a car.
- The designs would not require the usage of top tether or ISOFIX attachment points to be functional.

1.4 Research Questions

The following questions will be answered during the project duration as they are essential to fulfilling the aim.

- What are the values associated with the current day booster cushion?
  - From a customer perspective.
  - From a user perspective.
- What is the potential future value that can be associated with the booster cushion?
- How can the booster cushion be designed so that mobility becomes vastly improved?
- What loads should the booster cushion handle in order to fulfil its function?
- How can features be combined in a way that enhances mobility, safety and value?

2

Methodology

The methodology applied in this thesis report is based on a typical product development process as described by Ulrich and Eppinger [1] and can thus be divided into five distinct main phases: The pre-study phase, the requirement specification phase, the concept generation phase, the validation phase and a finalization phase. As these phases occur chronologically with some overlap between them, it was chosen to present the content of the report in a similar manner as opposed to a traditional report which divides its content into method-, result- and conclusion-chapters. Methods used and results obtained during a phase will be presented together in the order in which they were performed chronologically throughout the report. The penultimate chapter also discusses some of these results and methods.

The first phase, the pre-study, included writing a planning report, scheduling and conducting a literature study in order to get a knowledge base to work from. Areas that were investigated included the following: booster cushions, user behavior and utilization of the booster seats, anthropometry and anatomy of children, protection principles, car sharing and carpooling, traffic accidents and safety data. The result of this phase is presented in Chapter 3.

The second phase was the requirement specification phase. Here, a market analysis was carried out which included an evaluation of the current state of the market through a P.E.S.T.-analysis. An analysis and categorization of the current products available on the market was done by benchmarking current and similar solutions, as well as a patent search. The benchmark was performed in order to get some insight into already known portable solutions that could act as inspiration or references. In parallel to the market analysis, a user study was done which began with a stakeholder identification and then continued with semi-structured quality interviews. These interviews were performed with different stakeholders such as parents, children and car safety organization NTF. Personas were also utilized in order to get an image of the users. To complement the interviews an online survey was also performed which was shared on several relevant forums. The interview and survey were done in order to get an idea of what the customer and user valued in a booster cushion. When done, the result and relevant legislations were compiled in a requirement specification and customer needs list. The result and methods of this phase are presented in Chapter 3, 4 and 5.

After this phase, the concept generation took place, which was aimed to generate and evaluate different ideas and concepts. The methods used in this phase included a function analysis, brainstorming, elimination matrices, Pugh matrices and Kesselring matrices. When a few final concepts had been chosen, they were further modeled in CATIA V5 in order to enable further evaluation. The result of this phase is presented in Chapter 7 and 8.

The validation phase began when the concepts had been fully modeled. The 3D-model of the most developed concept was sent to be manufactured through SLS printing. At the same time, a finite element model was created from the CAD data and static structural analysis was made in the Generative Structural Analysis workbench available in CATIA V5. The CAD model was later redesigned to accommodate changes driven by evaluation of the structural analysis and prototype. A simple cost analysis of the products was performed. Future additions, changes and features were also presented and evaluated. This phase is presented in Chapter 9.

The final phase included planning eventual further development, discussing potential sources of errors and reasoning around other circumstances that have affected the project. This phase is presented in Chapter 10.

3

Background

This chapter presents a basic summary of what a booster cushion is, how it works and studies on how it is used. It also presents some theory regarding the anatomy of a child, and how some of these aspects may differ to an adult, an anthropometry study was also made and can also be found in Appendix A. Lastly, the intended users' stances and behaviors regarding car sharing and taxis are briefly presented. This is presented together with theories on how that industry will change in the coming year, and how booster cushions are used in taxis today.

3.1 Anthropometry and anatomy

Younger people are shorter than adults until they reach puberty and their bodies start to develop more rapidly. This is one of the main reasons why a booster seat or booster cushion is necessary for young children as the belt is developed after an adult's anthropometry and anatomy.

Since children are constantly growing until adulthood their anatomy is different than that of an adult. The bones in the neck for example, the cervical vertebra, are not fully ossified until the age of seven, making them more fragile until then [2]. This in combination with their larger head results in a greater number of neck injuries and injuries overall pertaining to children in collisions that did not use any child restraint system [3, 4]. Similarly, a difference between children and adults can be seen in the pelvic bones. In adults the iliac wings, illustrated in Figure 3.1, is of a squarish shape which helps the lap belt catch the hip during a collision. This bone in children is more circular which results in the lap belt being less prone to restrain the pelvis [2]. If this happens the subject slides under the lap belt and the lap belt loads the abdomen, this phenomenon is referred to as "submarining" and is further explained in Chapter 3.3.3.

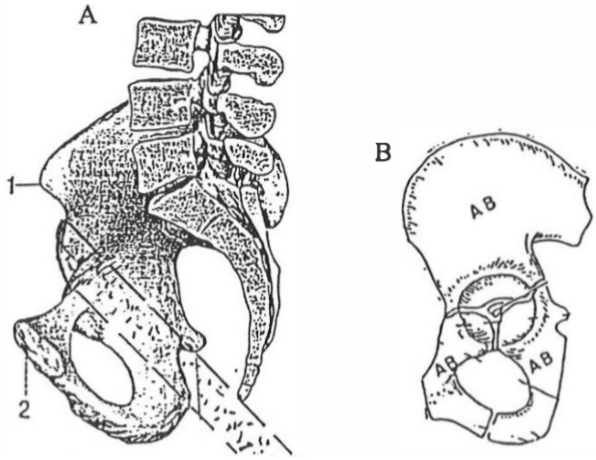

Figure 3.1: *Comparison of the pelvis bone between an adult (A) and a child (B), note the more squarish shape of the iliac wings denoted with a (1). [2]*

3.2 The booster cushion

To properly protect children in a car seat, adjustments needs to be made so that full protection is guaranteed. Children are generally small and the larger geometry and space in passenger cars are fitted, tested and constructed for measurements fitting the range from small to larger adults. It is necessary to adapt the seat belt geometry and vehicle geometry, to fit the children's size and special needs. This is done with different types of child restraint systems.

According to Swedish law, every child under the length of 135cm must use some sort of child restraint system. These different types of child restraint systems can be divided into three sets of seats depending on the age and length of the occupant according to The National Society for Road Safety (NTF) [5]. The first type of child restraint system protects an infant up to the age of nine months, until they have enough stability in their neck while sitting. This type of infant seat is placed rear facing in a car seat and is secured to the vehicle with either the seat belt or the ISOFIX attachment points. From nine months up to four to five years of age a different type of seat is used that is similar in shape and usage. This one is similarly rearward facing but is more suitable for children older than infants. Both seats can be seen in Figure 3.2.

Figure 3.2: *Illustration of a child restraint system most commonly used for infants up to the age of 9 months (left). Children are then placed in a rearward facing child seat (right) until they have grown big enough to not fit anymore. [5]*

After reaching the age of four to six years old depending on size of the child, a third type of seat, the booster seat is introduced when the child becomes unable to sit in a backwards facing position anymore due to their length. The booster seat, also called belt positioning booster seat, is a forward-facing seat used up to the age of ten to twelve years old when the child starts to reach either puberty or a height of at least 135cm and is fully able to take advantage of the vehicle seat and seat belt safety functions [5].

The main function of the booster seat is to elevate or "boost" the child so that the belt becomes properly placed. Properly placing the shoulder belt means that it goes diagonally over the torso from the pelvis to the middle of the opposite shoulder, not too close to the neck or too close to the edge of the shoulder. Lap belt is properly placed when fitted tightly over the upper legs close to pelvis. When boosted, the child's legs need to have a proper angle to prevent slouching. This is regulated by the depth of the cushion as it allows the knees to bend, without slouching the pelvis forward. If a collision was to occur, it is important that the booster seat has a limited deformation in the sitting area and that the cushion is also able to slide on the car seat in a balanced manner.

The booster seats can come with a high back support or no support at all, with just the cushion, and sometimes a modular variation of the two, see Figure 3.3. The backless booster seat is from here on onwards referred to as a "booster cushion" to clearly distinguish the two. There also exists integrated booster seats in some modern cars which provides similar support and functions as the standalone versions.

Figure 3.3: *Illustration of a booster seat (top left) and a booster cushion (bottom right). [5]*

Most traditional booster cushions are similar in function and appearance. They elevate the child up by some height and are slightly sloped rearwards for comfortable sitting and to prevent slouching. There are often supporting and guiding surfaces at the sides, most notably close towards the rear were the seats often form two symmetrical “handles”, “horns” or "guides". These horns help guide the lap and shoulder belt towards a more correct position over pelvis and torso. The horns also helps anchor the cushion to the vehicle seat and may double as a handle when transporting the seat outside the vehicle. Some booster cushions opt to use belt guides in the form of "clips" instead of horns to reduce the height and in turn the overall volume it occupies. Such a belt clip can be observed in some of the booster cushions such as BubbleBum presented in Chapter 5.2.

3.3 Behavior, misuse and risks

The booster cushion can safely secure a child, when used appropriately. While non-usage is known to increase the risk of consequences associated with a collision. The behavior and misuse while in the booster cushion may reduce the safety functions effect.

3.3.1 Reason for non-usage

There are several reasons why both children and adults might neglect using the cushion or neglect enforcing usage. The most prominent reason among adults is thinking that the child is old enough to sit without a booster seat, which is due to a lack of knowledge when it comes to legislation, injuries, risks or safety. Many children see the booster cushion as something childish and their desire to grow up can cause them to prematurely stop using the cushion [6, 7], and this can also be observed in the decreasing usage with age [4, 6, 7, 8]. It was also observed that usage percentage decreased the more passengers the car occupied, meaning that people may avoid using the booster in order to have more room when occupying multiple people in the back seat. There are also possible scenarios where there are not enough booster cushions in a car resulting in younger children being prioritized [7, 8].

Other reasons for non-usage includes the child thinking the booster cushion is too uncomfortable resulting in he or she not wanting to sit on it or just a general refusal to use it [9]. Other reasons for parents to neglect usage included a wide range of reasons including: believing them to be a hassle, believing them not to be safe enough and while some reportedly forgot them when they were in a hurry [9, 10].

3.3.2 Usage behavior

When using the booster cushion there were also several noted mistakes that may occur. The belt can be incorrectly routed against the manufacturer's recommendations. Sometimes the shoulder belt needs to be routed under the horns and sometimes over the horns, depending on the size of the child and the design of the booster cushion. If the user is not vigilant, the wrong path may be used, and the shoulder belt is not properly placed over the torso [11, 12]. Depending on which problem occur the belt may be positioned either too close to the neck or to the far out on the shoulder causing it to cause discomfort or potentially slip off.

The discomfort, of a belt too close to the neck, may be solved by changes in the posture, leaning inboards or pulling the belt away from the neck. Other observations include putting the belt under their arm or even behind their back in order to get away from the discomfort [13]. These behaviors can also occur when the child tries to adjust for discomfort that appear when having the same sitting posture for a longer period of time. They may also drag and pull on the belt to rectify this discomfort which causes it to sit loosely [11] and thus be less effective.

3.3.3 Submarining

Submarining is a phenomenon that may occur when the seat belt is not properly used together with child restraint systems. Submarining is commonly observed in children when the lap belt is not properly fitted over the pelvis. Due to deacceleration and the lap belt not properly catching the hip bones the lower part of the body is sliding forward while the lap belt travels into the abdomen which might result in internal injuries. Submarining is more commonly observed when the child is not using a child restraint system, or have a slouching sitting posture [3, 14].

3.4 Car sharing, car pools and taxi

Car sharing is a growing trend that aims to better utilize motor vehicles, mainly in in cities and surrounding areas. With more people living in urban areas, maintaining a high amount of motor vehicles while having less available parking space and increased traffic congestion, it becomes generally less attractive to own a car. If the city and urban area has buses, trams, trains and similar infrastructure available to use, commuting becomes a more viable option than owning a car. The total need for cars becomes a lot more situational, often appearing when a person needs to get somewhere more remote not reachable by commuting.

There is also a need for cars when users need to transport objects that are not possible or preferable to carry a longer distance, either due to their weight, volume or number of objects to transport. This situational need together with the rise of smarter vehicles lead to a popular increase in car sharing and car pools, where people rent a car for usage and only pays for the rental period. This leads to an increase in the cars' uptime and variety of customers which potentially requires more maintenance, service systems and adaptable features. Experts in several countries expects the trend of car sharing to continue to grow throughout the 2020's or stabilize sometimes during it [15].

Taxis can also be utilized if a car sharing service is not preferable. They similarly operate in urban areas and the customer only pay a fee for the distance traveled and time used. Taxi services usually offers child restraint options in some cars if the user request it. However, a study found that child restraint usage in taxi is significantly lower than in private cars. Several reasons were given as too why the people utilizing the taxi service did not bring a child restraint seat with them including: being too expensive, being too difficult to understand and being too difficult to carry around [9].

4

Stakeholder analysis and interviews

This section identifies the different stakeholders at a high level, who in some way is involved in this project by interacting with the finished product. What type of person they are, what their motivations are, and if they have any potential wishes and goals, are all essential questions to understand the associated value of the product. To concretize the stakeholders, two personas were utilized to create stereotypical stakeholder description of people who may be affected by this project, these can be found in Appendix B. Afterwards a user study was done by conducting several interviews with said stakeholders as well as performing an internet survey which tasked different forum groups to answer demographic, behavioral and opinion-related questions regarding booster cushions and other child restraint systems.

4.1 Identification of stakeholders

A project stakeholder is someone who stands to gain or lose something from the end goal, be that in the form of a product, a service or other relevant goal. Since they have something to gain, they usually have a vested interest and valuable input that can later be transcribed to requirements for the product. To get there, it was first important to identify what stakeholders the booster cushion might attract.

4.1.1 The customer

The customer is usually the one who buy, rent or otherwise acquire the product. The most apparent customer segment is the parents of the children as it is their responsibility to ensure usage of child restraint systems until the appropriate age or height. What they judge a booster cushion on might speculatively be things like price, comfort of use, safety ratings and appearance. Other customer segments might include taxi-services that buy booster cushions in batches for their companies' taxi-fleet. When buying a booster cushion, the price, portability and size is thought to be prioritized.

4.1.2 The user

The user is the one using, handling or interacting with the booster cushion. This mainly includes children between 4 and 12 years old that fit the length requirements. They utilize the booster cushion by sitting on it, handling it by carrying it around and interact with it by correctly positioning the belt. Adults does not use it by sitting on it, but they handle and interact with it in a similar manner. These adults are most likely the parents but might also be relatives or others that transport the children, such as taxi drivers. Other users that interact with the seat might include passengers helping with fastening the belt, such as siblings.

4.1.3 Other stakeholders

A stakeholder may also be different in that they are interested in the result that stems from widespread adoption of the product. In this case, organizations interested in increased traffic safety would count as stakeholders given that the new product is just as safe as the current products on the market but with the addition of being more appealing, which would increase adoption and in turn increase passenger safety. The most prominent such organization is Volvo Car Group as they commissioned this project and NTF (the Swedish National Society for Road Safety) is a stakeholder since they research road safety and rent out booster cushions and other child restraint systems.

4.2 Interviews

Five interview sessions were carried out with a diverse set of eleven people, 7 adults and 4 children. The criteria for interviews were that they have children or have had them, or where otherwise experienced in the usage of booster cushions. The base-set of questions used was mostly the same but additional questions where added as more interviews were performed and an area of focus started to emerge, a list of these questions used can be found in Appendix C.

Most of the questions were qualitative in nature meaning that the questions were open ended and the respondents could not just answer with a ‘yes’ or ‘no’, but had to formulate an answer. This type of questions were chosen as the aim was to understand what the customers and user thought were the most important in their own word and later interpret this as customer values. A semi structured flow was also followed to allow the interviewer to intertwine with follow-up questions [16]. This interview set-up allowed for a discussion surrounding certain topics and for a deeper probing into what value surrounds the booster cushion.

4.2.1 Interview 1 - NTF

The first interview was conducted with two employees from The National Society for Road Safety, shortened NTF. The NTF is an independent organization that works with Swedish road safety. One part of this work is to support and educate parents regarding questions surrounding child restraint systems. The interview had some structured questions but was mostly an open conversation with the employees about their experience working with children, parents and child restraint systems.

One of the first topics broached was about what parents are looking for when buying safety equipment. The employees explained that “parents want big and bombastic equipment”, things that look like they provide maximum protection for their children. They also mentioned that most parents that contacted NTF had made prior research and read consumer tests in order to make an informed decision regarding their purchase. The parents usually ask NTF what seats are the safest and best prior to their purchase.

When asked about what the most common use errors regarding child restraint systems are and when they occur, the two employees replied that many parents omit tensioning the belt, which means that there is belt slack which results in sub-optimal safety for the passenger. Some parents let their children fasten their own seatbelts, which often results in the same use error. Other parents sometimes also route the shoulder belt above the booster seat horns in cases where it is not intended, which positions the belt even higher up. The employees also mentioned that the children car seat manufacturer BeSafe has launched designs without horns which eliminates that particular use error.

Not all parents are fully aware of the core functions of the booster cushions. Some believe that the sole purpose is to move the seatbelt away from the children's necks and are thus unaware of the importance of correctly positioning the lap belt.

When asked about what value the booster seats may hold if seen from a buyer's perspective, the employees replied that the customers or parents usually want their children to be safe and sit comfortably while in the seat. Generally, the customers want the seat to be soft, cushy and not too warm for the child since they believe comfort is very important.

Based on interactions with parents, the two employees explained that the color and shape of the seat is important, and that some parents aim to match the booster seat with the car interior. Black seats are always popular, and parents generally prefer a more worn out black seat over a colored seat which in a better condition. They also repeated the statement that parents spend a lot of energy on making sure that their children are comfortable.

The two NTF employees mentioned that parents seemed to remove the booster cushion at 7-8 years of age, which in most cases is too early. Their theory regarding why the transition is done that early is that the children wants to appear more as adults and thus do not want the booster seat, especially if they are brightly colored or have popular children figures on them, which may be seen as childish.

4.2.2 Interview 2

A pilot interview was conducted with a 4-year-old, an 8-year-old and their two parents. They live in a rural area and have two cars that they use for transport. The children were interviewed first in order to not be affected by their parents' answers, but the parents were assisting with reformulating the questions if the children struggled to understand or answer. The 4-year-old old opted out of most of the interview but the 8-year-old participated in the entirety of it.

The children rode cars almost every day while using both booster cushions and booster seats. The 8-year-old mostly used a booster cushion while the 4-year old used a booster seat. The rides usually consisted of trips to school, the store or sports practice. Their mother drove them the most, followed by their father and lastly their grandparents. While the seats mostly stayed in the vehicles, the children could carry the backless booster cushions by themselves. They were also fastening their seatbelts by themselves, but the parents always checked that they were correctly fitted before driving off.

The 8-year-old opinions towards the booster cushions were somewhat neutral. She expressed that not being able to see out of the car without the booster cushion was a downside. An upside to not using the cushion was that it became easier to put in the belt buckle into the latch. When asked to choose between using and not using the booster cushion, they chose to use it, but the 8-year-old also mentioned later in the interview that they intended to stop using it when they turn 10. When asked to choose between using a booster seat and a booster cushion, they responded that it did not matter. The only feature the children wished for was a cup holder in their boosters. Worth noting is that the booster seat which the 4-year-old used had retractable cup holders in the back, but they were hardly useful since they interfered with the foam cushioning in the back of the car seat when deployed.

The parents were interviewed after the children and had nothing to add to the questions previously asked. At the time of the interview, they owned booster seats from Axkid, and a booster cushion purchased at Jula. The purchase decisions were influenced by recommendations from store sales assistants and that they trusted the Axkid brand from prior ownership of other Axkid products.

They occasionally moved the boosters to and from their cars and they did not find it too cumbersome to do so. The noted downside with the booster seats was that the shoulder belt occasionally would not enter the belt guide and get too close to the 8-year old's neck. It also tended to occasionally snag or catch the shoulder belt and thus introduce slack in the belt. The noted upside was that the booster seats were easy to move around, and that the height of the backrest was adjustable.

Since the parents never had used a taxi or car sharing service to ride together with their children, they were asked what the possible downsides with their current booster seats and booster cushions would be in such a scenario. They did not explicitly mention any downsides but instead said that they probably would remove the backrests of the Axkid seats and thus convert them into booster cushions in order to make them easier to move between cars. At the time of the interview, the seats were stored in the garage when not in use, and thus storage was not an issue for them.

When asked about other methods of acquiring booster seats than buying brand new, the parents were skeptical. They would never rent booster seats or cushions due to the fear that previous users would have misused them and thus compromised the safety. They would not borrow any seat either, unless it was from someone they really trusted. When it came to trust in the product, the brand had the biggest influence, and thus they trusted the Axkid booster seats more than the Jula booster cushions.

4.2.3 Interview 3

An interview was performed with two parents and a 5-year old boy. The family lives in a big city and the parents are studying at university level. They also have relatives in Norway and Russia. The child was very shy and opted out from the interview most of the time but occasionally whispered some things to his parents, some of which were relevant to the interview.

The family have not owned their own car for two years and mainly commuted with train and buses. When they did have a car, they traveled for up towards half an hour at most and used a BeSafe iZi rear facing child seat that was fastened with ISOFIX attachments. They bought it second hand since it was cheaper than buying new. They chose that brand because a relative had the same model and recommended it. The parents liked it because it gave a feeling of robustness when it was in place, it did not wiggle or sway in any way. They also owned a booster seat located in a relative's home in Norway, and they noted that it was difficult to transport by train. Because of this difficulty, they only used that booster seat when they visited in Norway and borrowed their relative's car.

The parents travel by bus most of the time when in their home city, and it usually exists a booster cushion on the bus that they can use. They remarked that it was a problem when they traveled in Russia as the taxis there did not have booster cushions that they could utilize. When asked about what qualities or properties a booster cushion would need for them to carry one around, they noted that it had to be light or foldable since they already had a lot of baggage when traveling. They had no issue with buying used, renting or borrowing a booster.

When traveling in any way the child noted that he liked to watch out the windows. He also liked playing with Lego a lot and would not mind a motive printed on the upholstery of said Lego. His favorite colors were black and grey and felt that the Volvo booster cushion brought along for the interview was comfortable when sitting on it.

4.2.4 Interview 4

The next interviewee was a mom to two children, a 4-year old boy that had started using a booster cushion and an older sister who had stopped using it. In total the family owned three seats which they used, one in each of their three cars. Two were booster cushions and one was a booster seat. The booster seat was a KidsEmbrace and modeled after the superhero Batman, which the son was a huge fan of. While it was his favorite, the son had no problem with the other booster cushions as he associated the colors of them to other superheroes. When driving longer distances the son usually watched kids-shows on a tablet, played with Lego or made drawings.

The parent noted that there had been situations where the booster cushion had not been present in any of the cars due to a miscommunication or other reasons. One of these cases they used a package of toilet paper as a makeshift booster cushion instead, but usually a booster cushion was always present in any of the cars, since the children would ride with the father to school and be picked up by the mother in the afternoon. The booster cushion was only moved if the son was going to use it in another car, for example in their grandparents' car. The boosters were mainly stored in the car but if space was needed, they were stored inside near the outer door in order to not forget about it when coming home later. When abroad, they were not as cautious as it was harder to find a booster cushion. When renting a car, one could usually get a booster cushion as well, but taxis seldom had it available. She saw no problem with renting or lending a booster cushion in case they would not have one with them.

The cushions they currently owned felt secure and safe since they did not glide around when in the car seat, they were robust when handled and felt quite solid. One of the booster cushions was a Biltema booster cushion variant which they thought were easy to use, fit properly in their car and held the belt properly in place. The booster seat was more difficult to handle seeing as they had to enter the belt through a loop. When asked about how an ideal booster cushion would look, the mom said that it would need to be portable, comfortable to carry around and not take up too much space.

When inquired about what was preferred between weight or volume, she said that volume is more of a detrimental factor seeing as you might have to carry something else around as well. She also noted that it had to be easy to install or assemble and that it should take no more than 20 to 30 seconds. However, if assembly was required it was not important that it is obvious the first time around, just that it becomes easy to assemble with time. When inquired about a method of carrying the cushion around she said that backpack straps or a proper handle would probably be the best option. Finally, she thought it was very important with removable upholstery, seeing as their cushions get dirty all the time.

4.2.5 Interview 5

The final person person interviewed was a mother of two children, a 5-year old girl and 7-year old boy, living on the west coast of Sweden, and her family had no car but rented one when needed. They used a car two to three times a month on average and it was usually not for long distance travels. The furthest they traveled by car was to a small village located in the northernmost part of Sweden, and this trip happened semi-regularly. When they traveled there, they usually rented a car, and get an offer to rent booster cushions along with it. She noted that the only reason that her family was not actively using a car pool was due to the issue with booster cushions. She found them hard to carry around, that they take up a lot of storage space and feel bulky.

They had booster cushions for their children which they had gotten a hold of one way or another. She noted that she really liked their Britax booster cushion since it had a very functional and practical textile handle which made transporting very easy. She expressed that the market segments regarding booster cushions aimed at families without cars was lacking and felt underdeveloped. They thought about buying a combined booster cushion and backpack but found the alternatives to be too clumsy to use as a daily backpack to bring to school and that they were generally too expensive. She said she could consider buying a used one however.

When asked about her ideal booster cushion it had to be easy to transport like their current one that used a handle. One suggestion was that the cushion could be attached to an ordinary backpack through hooks or loops that could be fixed on the back of the booster cushion. Another wish was that it could be flexible to fit most cars, she told that they often had problems when they were trying to fasten the belt since the cushion blocked the belt-buckle. It was also hard to fit in the backseat as an adult between two booster cushions. She thought an inflatable cushion would be the best solution. When asked about what would be a reasonable time to inflate and if she would consider an automatic pump she said that it would not matter if it took a long time to deploy since they usually knew a few days in advance when they are going to use a car, as thus, there were never spontaneous trips planned involving booster cushions. When asked about weight she thought the ones today had a reasonable weight to them as anyone could carry it around. It was more important to find a transport solution or deal with the volume she thought.

4.3 Survey

To gain more insight and get complementing data to the interviews an online survey was made. This survey followed the same approach as the interviews did with a structured semi qualitative interview approach, meaning that many of the questions required a written answer to complete [16]. This approach is harder to sort through than a quantitative approach but gave the respondent the possibility to give a more nuanced answer. The survey also contained some quantitative multi choice questions, mainly aimed to collect data about the answering demographic. The survey was advertised in several Facebook groups that were thought to be relevant to the project. These group included groups focused on sustainability, traveling with children, electric cars and child restraint systems. The questions used on the survey can be found in Appendix app:survey.

The posts in the four Facebook groups generated 88 answers in total. 51 of these were from the group concerning child restraint systems, 19 from the sustainability-group, 16 from the ‘traveling with children’-group and only 2 answers from the electric cars group. 2 of the answers stated that they had no children and was thus not allowed to continue the survey. The survey took between 10 to 15 minutes on average to complete depending on group and demographic.

4.3.1 Demographic of the survey

The answers were almost entirely from a female demographic which is important to note as men might have differing opinions and preferences when it comes to dealing with child restraint systems. In total, 81 women, 4 men and 1 non-binary person answered the survey. 31 people stated that they lived in apartments, while 55 lived in a house. 51 people in total was living in a city with 50 000 people or more. Those living in houses often had more access to two or more cars compared to those who lived in apartments. The two largest demographics presented were families who lived in houses which had two cars (35) and people who lived in apartments who had one car (23). Of the six people stating they had no car, only one expressed that they utilized a car sharing service.

There was also an observable increase in the number of cars the family owned that increased with the number of children, as can be seen in Figure 4.1. The number of children differed, 12 just had one child, 47 of them had two children, 24 had three and 3 people stated having more than three children. Counting all the children, it encompasses 193 in total which averages out to 2.24 child per family. When looking at the age of the children, over half (103) were in the targeted age group of 5-11 years old, while 57 children were also in the 1-4 years range and some would perhaps make the shift to booster cushion usage shortly after the survey.

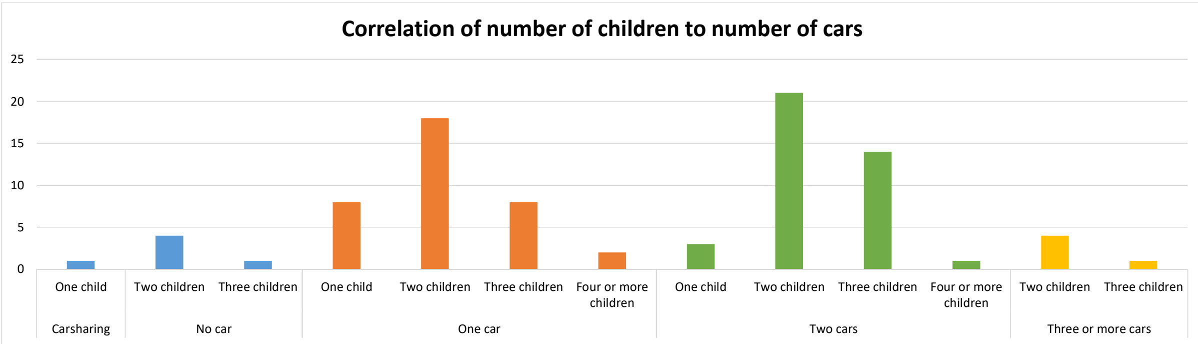

Figure 4.1: *A visual representation of the survey demographic that showcase the correlation between the number of children and number of owned cars.*

What followed these initial questions was some queries regarding what child restraint systems the family had access to, how they come to choose it and whenever or not any of their children used a booster cushion currently. The greatest number of child restraint systems was rearwards facing child seats which had 53 responses, followed by booster seats at 46 responses and booster cushions at third place with 39 responses. It is worth noting that 43 people answered that their child currently use a booster cushion, which is 4 more than those who reported to use booster cushions. The underlying reason may be due to a misunderstanding of the previous question. When looking at the answers relating to booster cushions, people said that they were not as thorough as they were with previous child restraint systems. They looked at what had gotten the best reviews, what fit their car, if their child liked it and if it was a good price.

4.3.2 Opinions about the booster cushion

The following part of the survey was for those 43 people that answered that their child is currently using a booster cushion. The first question asked them to identify themselves with some listed problematic situation, they could choose multiple answers. About a third (16) noted that they had no current problem with the booster cushion. 14 agreed that it was uncomfortable to carry around since it lacked a proper way to grasp. 10 identified that their cushion was too big to fit in their car. The statements regarding taking up too much space outside the car, being heavy and being uncomfortable for the child, all attracted 5 votes per situation. When asked if there where something they wanted to elaborate on many noted the problem with the booster cushion being too big, they said they could not fit three child restraint systems beside each other in the back seat and that it was difficult to sit as an adult in the middle seat when one or more child restraint systems was placed in the back seat. They also noted that the booster cushion sometimes covered the seatbelt buckle, making it harder to properly adjust and fasten the belt.

The next question probed if the respondents could see any potential problems that would occur if they would sell their current cars and switch to car sharing. Most of the answers centered around it being hard to carry. Some people that had younger children thought those corresponding child restraint systems would cause a bigger problem and were not too worried regarding the booster cushion. Some were worried about bringing it along, especially when they had two or three children which made bringing one for each more worrisome. One person mentioned that they wanted to use car sharing, but child seats were one of the main reasons they did not. Many people also advocated that car pools should have integrated booster cushions or that there should be a separate booster cushion present in all cars.

The next set of questions asked if the correspondent could imagine themselves renting a booster cushion, lending one or buying one second hand. 14 people said no to renting, 4 said no to buying used and one person was opposed to lending a cushion, this person also said no to the previous two. 18 people were positive to all three situations unconditionally, 29 were positive to all three if the lending or buying second hand can be done from family and friends.

The next questions regarding booster cushion covered when and if the child had traveled without one, and the underlying reasons for it. Of the alternatives presented, 19 said that when they traveled by taxi, they could not get hold of one. Another commonplace occurrence noted by 15 respondents was that it occurred when the children traveled in another car that did not have a booster seat available. 14 also responded that when they transported several children, for example friends to their children, they did not have enough booster seats for all of them. A small amount of people (8) said they skipped it during very short trips. 6 respondents also stated that the booster cushion sometimes gets misplaced in another car which makes it unavailable for the child during that journey. Just one person stated that they had forgotten it one time. In a follow-up question they were asked how they would go about to solve the previous issue. Most then said that taxis always should have a booster cushion available, some wanted integrated booster cushions in their car while some wanted a more portable booster cushion which they could bring.

4.3.3 Behavior and Activities

This next section covers behavior that the children or parents conduct with their child restraint system, note that all questions forward is once again answered by all 86 respondents. The first question was a free-text answer over behavior or activities that the child does during traveling, both short and long trips. After decoding and classifying different answers it was concluded that the most common activity done by children is to converse (48) with others in the car. The following three activities are to interact with a tablet (33), a phone (28) or watch a movie (20). It is important to note that many parents expressed that they only get to do this during longer trips, so the real numbers are probably lower for the average trip. Other common activities were listening to music (19), singing (14), playing with toys (14), reading a book (11) or listening to an audiobook (11). Playing, gaming, drawing, sleeping, comics and looking out the window all also got between 10 and 5 votes.

The next question asked how often the boosters are removed from the car if at all. 52 families said they never move their boosters, with rare exceptions being when the children must ride in another car that does not have a booster or when they get a new car. 24 persons says it happens very few times a month stating the same reasons as previous in addition of transporting goods, changing cars, carpools and transporting adults. Many of the people who removes the boosters between one time a week to one time per day, states that they do not always have access to their car or that the cushion is moved between several cars. The most common places to store the cushion was the car, garage, house, apartment or other storage location.

The next set of questions touched on the respondents' experience with car sharing and taxis. Most of the users had not tried a car sharing service or carpool before. A majority of those that had however, stated they had trouble with child restraint systems, note that this include all types of systems and not only booster cushions. Some were of different opinions however as they drove the car home first and thus did not have to carry the child restraint systems for any longer time. On the question of taxi experience, the opinions seem to be divided evenly. Some said they brought their own booster cushion, some said the taxi provided it while other had the experience that the taxi did not provide it.

4.3.4 Scenarios

The next set of questions asked the user to imagine themselves in certain scenarios. The first scenario asked the user to imagine that they were going to buy a booster cushion for their car. Putting aside such aspects as safety, comfort and usability, they were asked to choose what quality between weight and volume would be the most important attribute when buying a booster cushion. The answers to the question, which focused on only understanding this divide, were vague or seem to have been misinterpreted. Many answers that mentioned volume also attributed it to being able to fit in the backseat with an adult placed on either side of the cushion. This misconception appeared frequently. Regarding weight there was some vague answers, many people said they want a "lätt", "lättanvänd" or "lätt att använda" booster cushion. The Swedish word "lätt" in this case can refer to either weight or by ease-of-use. Meaning that depending on the wording some answers may be interpreted as "light in weight" or "easy to use". The motivations for weight being the most important was so that the elderly and children can carry it around. Motivation for volume was quite diverse with people stating many reasons, like the aforementioned point about being able to fit in the backseat with several adults or several booster cushions between each other. Other points in favor of volume mentioned storage space, it being easier to carry if it is smaller, that the weight of current products is quite light, and that volume is the critical factor when considering bulkiness. Some outliers also argued that neither weight nor volume matters and that the possibilities for carrying is what is important.

The next scenario asked them to consider the same as the last scenario but for use in a car sharing service instead of their own car, that is, what would they consider between weight and volume if they were to buy a booster cushion for a car sharing purpose. Once again, the same interpretation of volume and vagueness regarding "lätthet" appeared, but the motivations were more focused on portability this time around. Many answers mentioned some sort of carrying support such as a handle, shoulder strap or a bag for the booster cushion. Many advocates of volume also said that it should be possible to fit it inside of a bag. Others wanted it to be light as they would have to carry it around a lot, while some specifically said that the weight would not be a problem since a booster cushion cannot be unreasonably heavy.

The third scenario was focused on wherever or not the user would prefer to use their own booster cushion while utilizing a car sharing service, or if they would like to use an existing booster cushion in the car. The answers were split since around 23 people refused to use a booster cushion which they did not know the history of and would use their own as it was not too difficult to carry around. Others were lenient and said that if the company could guarantee the safety of the cushion, they would use it. A majority were very positive to the idea and embraced it, saying that they would not have to carry around their booster cushions anymore.

The final scenario posed the question of what possibilities the user would like when it comes to carrying the booster cushion. The user could choose from several existing alternatives as well as come with their own suggestion afterwards. There were four alternatives, with two variants to each alternative asking if they would like this opportunity for their child and for themselves. The alternatives were if they would like a double backpack straps on their cushion, a single shoulder strap, a hook that could fasten on their current backpack or if they would like the option to put it in their bag. Around 50 people would consider having a double backpack strap for their children or for themselves. 44 people would be okay with a single shoulder strap for themselves but only 13 were okay with their children having it, making it the largest difference in any of the alternatives. 36 people would consider using a hook in their own bag but only 11 would like to hook it onto their children's bag. Finally, the option of having the booster cushion in their own bag was met with 37 agreements and 20 people said it would be okay for their child to have the option as well.

In the free text answer to the final scenario, the user was asked to provide any input. One option that the respondents came up with was an ordinary handle that one could use to grab and carry the cushion with. Many people opted for several alternatives as different situations require different possibilities to carry the cushion on. Another user raised the idea of hooking or storing several booster cushions together making it easier to handle in general.

4.3.5 Notes about survey

The main part worth noting about the survey is that it does not distinguish between the opinions of people owning a booster cushion and people that do not own a booster cushion but who are using some other form of child restraint system. These people may not have noted that some questions, like the scenarios, are for booster cushions and might have applied their own experiences with other child restraint systems. These are generally much more heavy than ordinary booster cushions making some of the opinions of the surveys skewed where there is not specifically stated what kind of child restraint system is used.

4.3.6 Comments surrounding the survey

When the survey was posted an inquiry was made in order to further discuss booster cushions in the comments to the main post, which a handful of people replied to. It was a more free-flowing structure in which direct replies and comments allowed for deeper probing into some of the opinions presented in the survey.

A user that was well-versed in the child restraint group and who run a blog that reviews child seats commented how she really adores the SitSac, a booster cushion and backpack hybrid, since it has such an abundance of features she likes. Her child was able to carry it around on his back when only three years old if it was not too fully stacked. She noted this was possible due to the removable backpack and extra straps over torso which makes the shoulder straps stay in place. It is also fully possible for adults to carry it since the straps are long enough. She also preferred the removable backpack in contrast to a fully integrated backpack with booster seat as it would be hard to pick up something you want, for example a headrest, if the child sits on the backpack itself. The horns were very robust, and it could be used as a chair booster when they were away from home. The backpack itself was not that appreciated since it felt like it was of lower quality and shifted the center of gravity making it less pleasant to carry around.

Two other user had similar opinions regarding the BoostApak, another backpack booster cushion hybrid. One liked that the horns felt robust, correctly placed the belt over the child and that an adult also could carry it without too much trouble. The other noted that it was practical that the child could bring their toys and use it to get a boost when eating at an ordinary table. It was easy to transform and comfortable to sit on.

In the sustainable Facebook group several users also shared their experience regarding traveling with booster cushions. While most of the comments devolved to discussion regarding rearward facing child seats and integrated booster cushions, a user noted that she often travels and still have need for a booster cushion. However, she would rather rent or lend a booster cushion when she arrived at the destination if possible, instead of carrying it the entire trip. They had one booster cushion in her parents' home since they sometimes use their car. Another user noted that they usually rent a booster cushion from the car renting company, that it usually exists in taxis and that it would be best if it also would exist in car sharing cars.

4.4 Conclusions of the interviews and survey

The main takeaway from the survey is that most people that are confronted with the issues regarding car sharing want a booster cushion that is portable and easy to carry around. Another takeaway is that there are a number of current users who find car sharing and car pooling to be unavailable to them due to the hassle around moving child restraint systems. The easiest way to fix this for most booster cushions would be to attach a carrying feature that makes it easier to carry such as a handle, strap or similar.

The portability aspect also included an argument of weight versus volume and what the most important thing is. While both sides had valid arguments the one which stood out the most is that some people mentioned that a booster cushion cannot be too heavy. That would mean that even if it weighs around 3kg, which is around what the maximum booster cushion weight is, it could still be considered "light".

Other features the participants argued for was a width-adjustable feature to be able to fit in the car better, that the child should be able to carry the booster cushion around and that the cushion should be easy to clean due to the wear and tear that children expose it to.

5

Market and technology analysis

In this chapter the different factors surrounding the booster cushion is explored by examining the current market and surrounding elements. This is done by looking at the trends through a political, economical, societal and technological lens (P.E.S.T) [17] and several different benchmarks. The current product and its variations are assessed and benchmarked by taking inventory on what is sold in various stores, both physical and digital [1]. The inventory is taken on existing child restraint systems, patents in the belt-positioning booster cushion category or patents and products that fulfills a similar value in portability or enable better protection in a car. A perspective over the relevant technology is gained by analyzing features in other products that generate a similar value, for example, mechanisms that allows the product to become more compact, to minimize the volume and structures that allows for high dynamic and static loads.

5.1 Market trends, P.E.S.T.-analysis

Market trends can be defined as the direction the market is heading towards during a certain period of time. This direction can be influenced by a wide variety of factors such as: political, economic, societal and technological. These factors are considered in a P.E.S.T.-analysis, which in this application look at child restraint system manufacturers, the current market and surrounding landscape through these four lenses. [17]

5.1.1 Political trends

The political landscape surrounding child safety systems can be largely summarized in the new UN R129 [18] regulations introduced by the EU in 2013. The regulation aims to replace and update the old system of ECE R44.04 [19] and deals with an updated standard for tests, safety and features regarding child safety systems. One thing to note is the inclusion of test standards that require the system to protect the child's body and head area. This makes it more difficult to get a booster seat approved under the first version of this regulation unless it includes some form of head protection in the case of side collisions. Another notable update in UN R129 compared to ECE R44.04 includes a switch from weight requirement to length requirement. It also adds a requirement of accommodating for the hip breadth of the 95th percentile user of the maximum intended stature. Another addition that R129 will enforce is that booster seats and booster cushions can only have one assigned belt route, meaning that the cushion can no longer have different shoulder belt routing configurations suited for different user heights. The old standard of ECE R44.04 is still under effect but is planned to eventually be phased out and fully replaced by R129. However, new child restraint systems can still be approved under ECE R44.04 until then.

There have been approved proposals to alter the UN R129 regulations, such as the Proposal for Supplement 3 to the 03 series of amendments to UN Regulation No.129. Proposal for supplement 3 adds a definition for booster seats without backrest, named booster cushions. The supplement thus made it possible to certify booster cushions under UN R129 since the requirement for lateral protection only applies to booster seats. The supplement also added a limitation in which the shortest intended user must have the top of their head 770mm above the car seat when seated on the booster cushion in order to partake in the car's built in protection. This requirement coupled with that a booster cushion may not be declared for use by children under a stature of 125cm, results in that the cushion needs to increase the users sitting height more than 10.8cm in order to accommodate the largest range of users as possible. The booster height is deducted by subtracting the minimum measured sitting height of 66.2cm on children that with 125cm stature, stated in supplement 3 to the 03 series of amendments.

5.1.2 Economic trends

While economic data for different child restraint system companies are not publicly available, a speculative economic trend can still be argued for. A study from WHO concludes that child restraint systems drastically reduces the total risk of fatalities and that the high-income countries in North America, Western Europe and Japan have managed to significantly reduce the road traffic fatalities [20]. Traffic fatalities however remains high and continues to rise in low-income countries. It thus stands to reason as more countries rise from poverty, more nations will seek to make their traffic systems safe, leading to a wider adoption of child restraint systems. However, the market growth for child restraint systems will probably stagnate as reality catches up to the zero vision of no fatalities in traffic coupled with the fact that the customer base is saturated. The market for booster cushions might also decrease if more car manufacturers aim to include integrated booster seat cushions.

5.1.3 Social trends

The social and cultural trends are very closely connected to what was discussed in the economic perspective. Development in a country is closely connected to safety on roads because of infrastructure, funds and common goals in a society. Sweden has had a constant goal of working towards having no fatalities or serious injuries in road accidents since 1997 by working with infrastructure, laws and safety. Recently the European Union adopted a similar new strategy of "Vision Zero" with the aim of having "no deaths and serious injuries on European roads by 2050" [21]. Developing nations can be expected to also take a more firm stance towards road safety and improve it when more resources becomes available. Since integrated booster seats still is a rarity in produced cars it is expected that people will continue to buy booster cushions for a foreseeable future.

5.1.4 Technological trends

While technology used in booster cushions has had limited development since the first commercial product, the technology surrounding and affecting it is developing rapidly, and one of the biggest areas is smart cars and self-driving cars. While the technology is currently emulating ordinary cars regarding layout and seat placements, it is currently unknown how the layout of seats will change when there is no need for a forward-facing driver. It is possible that the current form of booster cushion is not optimally designed to be placed in such a future car seat if it, for example were to be placed sideward or rearwards. Smart cars and self-driving cars both enable different forms of ride sharing and other forms of mobility than traditional car ownership. This change in ownership make the portability and storage of booster cushions more important.

Another technology area that affects the booster cushion is the integrated booster seat. These child restraint systems are built into the car and is currently offered by a small number of car manufacturers. The future of child restraint systems may be to have integrated booster seats in all cars but until such a decision is made by the car manufacturers and either chosen as an add-on by customers or implemented as a standard feature, portable child restraint systems will still be utilized and needed.

5.2 Benchmarking of booster cushions

The benchmark was performed by gathering data of popular and unique booster cushions listed on the web store Amazon, the prize-comparison website Prisjakt and the web store Jollyroom that specializes in products for children. Searches using Google image search was also conducted with variations and combinations of the search terms: booster seat, booster cushion, child restraint system, belt-positioning, foldable, compact, small, inflatable, portable and mobile and other synonyms thereof. The search terms were also coupled with previously identified products combined with minus signs, for example “-mifold”, “-bubblebum” and “-boostapak” in order to filter them out of the search results. When identified, a list was compiled that compared dimensions (height, width, depth), weight, safety rating, price, features, manufacturer, recommended weight for child and pictures of normal state and alternate transformed folded compact state, if any. Dimensions and weight were documented as they were thought to be features that contributed greatly to portability and could later act as a frame of reference. The other aspects were documented as they were deemed to be potentially relevant.

The list was divided into three categories of booster cushions, presented in Chapter 5.2.1, 5.2.2 and 5.2.3, the full benchmark can be found in Appendix E. The cushions presented are all approved under some rating, either ECE R44.04 in Europe or FMVSS 213 [22] in the US, note that the products are only described with regards to their features and no judgments regarding their safety as no tests have been conducted. Also note that the listed height does not specify if it is the height of the seating area or the height between the lowest and highest point, for example between the bottom of the cushion and the top of the horn.

5.2.1 Category 1: Traditional booster cushions

This category encompasses traditionally formed booster cushions whose sole purpose is to provide the safety benefit of raising the user’s sitting height and properly routing the seat belt. All the booster cushions in this category have horns that can position the belt over torso and lap, and they all feature a washable and removable upholstery. The dimensions vary between the cushions, but stays relatively consistent and bulky. The height varies between 190mm to 255mm, the width between 370mm to 430mm, the depth between 355mm to 470 mm and the weight between 0.9kg to 2kg. An example of a traditional booster cushion can be seen in Figure 5.1 which depicts Axkid Mate made by Axkid.

Figure 5.1: *The Axkid Mate is designed like a traditional booster cushion. [23]*

An outlier in this category is the Turbo GO™ Folding Backless Booster Car Seat made by Graco, see Figure 5.2. This seat is more shaped like a square and has nontraditional horns which can rotate to be hidden by following the contour of the cushion, when not used. It also features a belt-clip that can be attached to the shoulder belt to keep it lowered. This booster can also belong in category 2 but was placed here due to its form and narrow focus on portability.

Figure 5.2: *Graco Turbo GO™ Folding Backless Booster Car Seat with rotational horns. [24]*

5.2.2 Category 2: Portable booster cushions

The second category is about booster cushions that promotes themselves with being more portable and smaller than traditional booster cushions. This is done with different methods depending on manufacturer, but all aims to be more portable by either being less bulky when not in use or less bulky overall. The most compact booster cushion found are the ones produced by Mifold, these booster cushions have a limited height to them, around 40 mm, see Figure 5.3. Instead of using the height and horns to adjust the belt position on the child, it is featuring three clips for positioning of the lap and shoulder belt, whereas the two clips on the side are extendable in order to both accommodate different widths and to become more compact. The foldable version can also be folded, making it easy to bring along when traveling.

Figure 5.3: *The Mifold is a flat booster cushion that utilizes clips to position the belt. [25]*

There are also inflatable booster cushions made by Uberboost and BubbleBum, see Figure 5.4. These are more portable due to the ability to deflate when not in use thus allowing them to take up less space. The user inflates the cushions when they intend to use it by blowing air into them. The BubbleBum in deflated form is around half its ordinary volume and is also composed of memory foam. Both seats use belt clips instead of horns for the lap belt. BubbleBum also includes a belt clip that is used for the shoulder similarly to the Mifold seats.

Figure 5.4: *The inflatable booster cushions Uberboost (left) [26] and BubbleBum (right) [27].*

The third seat in this category is the Graco TurboBooster TakeAlong Backless Booster, see Figure 5.5. This one is similar to the category 1 boosters in shape, bulkiness and weight. It has horns that positions the lap belt and is the heaviest booster cushion in the benchmark, weighing in at 2.7 kg. It also has two cup holders which can be hidden by rotation. The booster cushion can become more compact by folding down the middle which halves its width, which can also be seen in Figure 5.5. This seat showcase that a traditional design can still be portable.

Figure 5.5: *The Graco TurboBooster TakeAlong Backless Booster in its deployed state (left) [28] and in its compact portable state (right) [29].*

5.2.3 Category 3: Multi-functional booster cushions

This category encompasses booster cushions that have another function besides being a child restraint system. By combining or integrating the seat with something else, it increases the customer value by offering more than one function or functionality.

The two products, SitSac by Minno and BoostApak by Trunki, found within this category are both transforming a Category 1 booster cushion into a backpack, see Figure 5.6. The SitSac has a removable backpack-style storage and a hollow storage compartment inside the booster cushion while the BoostApak is the backpack in and of itself. The BoostApak also features a belt clip for the shoulder.

Figure 5.6: *The SitSac (left) [30] and BoostApak (right) [31] both serve as a multipurpose booster cushion.*

5.3 Benchmarking of other portable products

The benchmarking of similar and other portable solutions was conducted in the same manner to the previous benchmark. Similar portable solutions include other child restraint products that is not classified as a booster cushion while other portable solution includes products like, wild-life equipment that is made to be as portable as possible. Products that were deemed relevant but did not classify as a booster cushions were added to the child restraint category and thus uses the same search terms as the benchmark. The wildlife and hobby equipment also use the same terms except for the exclusion of terms related to child and car safety. The product information for the child restraint systems was gathered from the shopping site Amazon, a press release made by Volvo Cars [32] and the respective websites for Bombol, Ridesafer, ClypX and Nachfolger. The product information for the wildlife and hobby equipment was gathered from the shopping site OutNorth and the respective producers' website for Primus, Sitpack and Red Paddle Co products.

5.3.1 Child restraint products

This category focuses on products that have potentially relevant solutions for the project, but either are not made for cars or are not booster cushions nor booster seats. The Bombol Pop-up and the Munchkin GoBoost are solutions aimed at elevating the child when sitting at a normal chair and allow for easy transportation, see Figure 5.7. In addition to this the GoBoost brings customer value by also having an integrated bag which enables storage of things, much like the Trunki BoostApak. The Pop-up aims towards being very compact when not in use by being able to be folded flat. It transforms into a seat via an origami folding solution.

Figure 5.7: *The Bombol Pop-up (left) [33] and Munchkin GoBoost (right) [34] are booster cushions for chairs.*

The RideSafer vest and the ClypX clip, see Figure 5.8, are meant to be used in a car together with the seatbelt but does not elevate the user. It is worth noting that the RideSafer vest is evaluated based on FMVSS 213 and the ClypX is evaluated both under FMVSS 213 and ECE 44.04. The RideSafer vest is a belt guiding harness meant to keep the child fixated in a crash and guiding the seat belt correctly while the ClypX's selling point is to adjust the shoulder belt to fit a child and allow the lap belt to be tensioned across the hips.

Figure 5.8: *The RideSafer vest (left) [35] and ClypX (right) [36] are non-traditional child restraint systems.*

The Volvo Cars Inflatable Child Seat Concept and Nachfolger HY5 TT edition 2020 are both rearward facing child seats that are inflatable in order to suit the user's needs, the products can be seen in Figure 5.9. The Inflatable Child Seat Concept weighs under 5 kg and has an integrated Bluetooth controlled pump that can inflate the seat in less than 40 seconds. It also features a drop stitch fabric construction which can reach high internal pressure. The HY5 TT edition 2020 weighs 4.9kg and inflates in 2 minutes via an external pump, and the seats construction detail is not specified. The HY5 TT edition 2020 is also certified for use in aircraft.

Figure 5.9: *The Volvo Cars Inflatable Child Seat Concept (left) [37] and the Nachfolger HY5 TT edition 2020 (right) [38] are both inflatable rearwards-facing child seats.*

5.3.2 Wildlife and hobby equipment

In order to identify as many possible solutions as possible, products that were not relevant to car safety and children's products, but that had methods of becoming more compact or portable were explored and identified. A selection of products focused on wildlife were deemed to have relevant solutions since much wildlife equipment has a focus on being as light, portable and robust as possible. The Primus Aeril small and the Primus Kamoto are portable firepits that employ different folding mechanisms constructed from sheet metal, which allows for a possibly light, compact, robust and cheap construction, see Figure 5.10. The SitPack 2.0 is a sit support that utilize a telescopic mechanism made from plastic segments with a locking function in order to expand or become compact depending on the users need, this can also be seen in Figure 5.10.

Figure 5.10: *The Primus Aeril small (left) [39] and Primus Kamoto (middle) [40] utilize sheet metal parts that fold to become small and portable. The SitPack 2.0 (right) [41]becomes smaller by retracting telescopic arms.*

The Urberg Airmat Nova is an inflatable mattress with small cells that can be inflated in order elevate the user from the ground when they sleep. The Red Paddle Co 9'6" COMPACT standing paddle board is also inflatable but takes advantage of high internal pressure and a drop-stitch fabric construction combined with horizontal slats in order to become very stiff and robust when used for paddle boarding, but very compact and light weight when deflated and folded, see Figure 5.11.

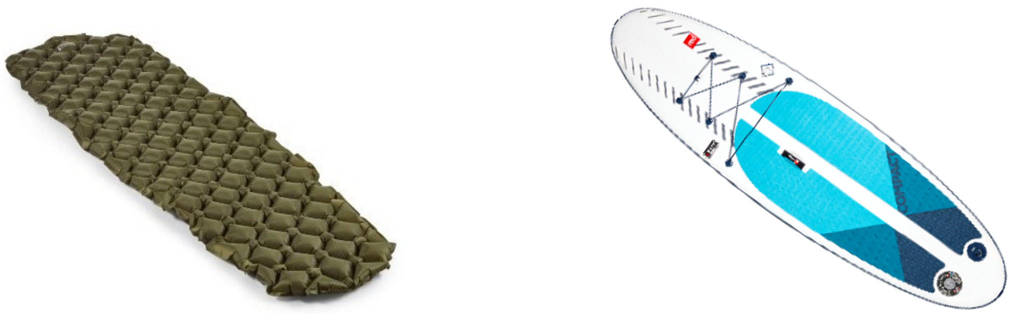

Figure 5.11: *The Urberg Airmat Nova (left) [42] handles inflation using small individual cells while Red Paddle Co (right) [43] handles it by utilizing drop-stitch fabric. [40][41]*

5.4 Patent search

In order to further explore possible solutions, multiple patent searches and reviews were conducted using the Derwent innovations index and Espacenet patent search databases. The search terms used for the Derwent innovations index database were "child*" and "booster*" combined with the following terms using OR-statements: "mobil*", "porta*", "fold*", "collaps*", and "inflat*". The * sign denotes wildcard search terms which allows matching of the search query to a larger number of patents. The searches in the Espacenet database used the same queries but were broken down into smaller individual queries, allowing for a level of redundancy and overlap between searches while diminishing the risk of not discovering valuable patents due to use error. The search results were filtered to only display patents with the international patent classification code B60N2/28. The code covers patents involving seats, and thus by extension also booster cushions, with a special purpose and is mountable on existing seats in the vehicle, like for example car seats. In order to filter out patents that were not relevant to the project, patents with the word "airbag" in the abstract were excluded. The search in the Espacenet database with the stated filter and the query "inflat*" yielded 144 results. The terms "fold*" and "expand*" were used in the same search query coupled with an OR statement yielded 70 results. The terms "fold*" and "expand*" were used in the same search query coupled with an OR statement yielding 70 results. The query "collaps*" yielded 70 results, and the search in the Derwent innovations index database with the earlier stated queries yielded 90 results.

All individual search results were analyzed, and 31 patents were selected for further analysis, these can be found in Appendix F. The selected patents were deemed relevant for the project, provided a novelty solution and could possibly contribute to the concept generation process or become relevant later in the project in order to ensure the chosen solution is unique. The selected patents consisted of relevant solutions that were not mapped earlier, but also patents of products identified in the benchmark and relevant products category. These patents were for the Volvo Cars Inflatable Child Seat Concept, Nachfolger HY5, Mifold One, Sitsac, Graco Turbo GO™ Folding Backless Booster Car Seat, Bombol Popup and BubbleBum. A patent which drawings are visually very similar to the Mifold was also selected but it could not be determined if it is the corresponding patent or not.

12 patents used some sort of inflatable component, either by being entirely inflatable, having rigid outer portions and an inflatable cushion or having a rigid frame with an inflatable outer layer. 7 of the patents depicted solutions that was combined booster and storage solutions. These solutions consisted of either having a hollow booster with carrying straps or combining the booster with a suitcase, pull along luggage or rucksack. 9 of the patents depicted various foldable or collapsible solutions. These solutions varied from high backed boosters with foldable back rests to backless boosters with structures that were collapsible width-wise, height-wise or dept-wise. The last 3 patents were the solutions that were similar to the Mifold, flat constructions with either fixed or foldable horns that holds the belt at a level intended for children.

6

Product requirement specification

Before development of new potential concepts could begin, a list with defined requirements was needed that could act as a foundation for the new concepts to be built from and evaluated against. This requirement specification is composed of requirements and wishes explored in Chapters 3, 4 and 5. It is also composed of limits and design choices that was made internally. In addition to this, a customer needs list was also created that ranked features which customers wished for. The ranking was partially in how difficult it was to implement but also in the potential customer value that would be gained by doing so.

6.1 Requirements

As a part of the information gathering, a requirement specification was formulated, which can be found in Appendix G. It acts both as a tool for summarizing legal requirement and as a guide to specify measurable product goals that not only can be used for product validation but also can be used in decision making during concept generation and construction. Several customer needs were interpreted in terms of measurable goals, such as time to expand or time to assemble the product, ease of use, being possible to clean and more goals. It was decided that the new cushion would be designed to have as small of a volume as possible over having low weight. This decision was made due to the user feedback conclusion made in Chapter 4.4. There was also an argument to be made regarding that it is easier to work on reducing the volume first via mechanisms and then trim down the weight than vice versa.

The dominating legal requirements for the booster cushion is mainly UN R129 [18] which is a standard made by the UN and employed within EU. In order to be sold and used in a large scale as possible, American standard FMVSS 213 [22] and Canadian standard SOR/2010-90 [44] has also been taken into consideration but it was decided to follow European regulations first hand. The UN R129 regulations mainly dictate max dimensions, belt routing and minimum height increase in the users posture while using the product. There are also some requirements made in conjunction with the supervisors and expert in order to increase the user safety in the product, such as the maximum deformation in a car crash. The motivation behind the requirement is the insight into the behavior of some other booster cushions on the market, where there is an indicated correlation between deformation and user safety due to the behavior of the belt routing.

Despite the anthropometric data presented in Appendix A, it was decided internally to dimension the cushion foremost to the standards set by the UN R129, which means that a minimum height of 125 cm is to be considered. The sitting height for the 50th percentile for 125 cm is 66.2 cm according to tables provided by proposal for supplement 3 to the 03 series of amendments to UN Regulation No. 129. The lowest declared user stature affects the minimum height of the booster cushion since the top of the shortest user's head must reach 770mm over the surface of the car seat. The method for measuring this height is described in the regulation itself. The highest declared user stature limit affects the minimum width, since UN R129 requires the 95th percentile user's hip breadth to fit between the horns. This means that a booster cushion which allows users with 150cm stature must allow for a hip breadth of 32cm.

6.2 Customer needs

In order to get a simple overview of the customers' needs and priorities, a customer needs list was made, see Appendix H. The entries on the list are needs that either has been clearly stated by current users, interpreted needs based on problems stated by customers or insights provided by stakeholders. The entries are sampled both from qualitative interviews and the conducted semi qualitative survey. Individual entries have been graded on a scale 1-5 where 1 is low and 5 is high. The grading is done in the aspect of perceived priority or interest by users and how feasible it is to develop a solution that fulfils the need within the project time frame. Some needs were not graded and instead were labeled with an asterisk to indicate that the rating varies too much between concepts to be able to grade at this stage in the project. By comparing the perceived level of user need and deemed feasibility, priorities of feature development can be made during the construction phase in order to develop a solution with maximum customer value within the scope of the project. It is also useful regarding concept evaluation since evaluations can be made about what customer needs can be fulfilled by a concept and thus give a rough measure of how much customer value it may provide.

In total, 21 customer needs were formulated, of which 10 were directly related to the booster cushion, 4 were related to the deployment mechanism, 3 were related to act of transporting the product, 3 were related to desirable extra features and one was related to the product and the transportation. The needs that has grade 5 are either features that the customers take for granted from the current products on the market, expressed as a need or otherwise given the indication that they prioritize the feature. The needs regarding tamper proofing, possibility to clean and is comfortable for the child to sit on is taken for granted from the current product, but having adjustable size, taking little space when not used and being easy to carry are features that would bring great amount of customer value. For these customer needs, the importance takes precedence over feasibility since failure to address them may lead to a product that is comparable to what is on the market or even inferior.

For the rest of the customer needs, the priorities are not as clear cut. Despite being possible to rank customer needs regarding relative importance, it is more difficult to evaluate if spending the same amount of time and resources in order to fulfil multiple customer needs with lower rank, but high feasibility will lead to higher customer value compared to fulfilling a single high ranked customer need with low feasibility. Regardless, it is considered wise to prioritize so called low hanging fruit that has favorable rankings in both categories. User needs with low priority and high feasibility is also considered to be low hanging fruit and will also be fulfilled as long it will not impact the realization of another customer need with higher priority.

7

Concept generation

This chapter describes the iterative process of concept creation from idea generation to evaluation. Many concepts were created and eliminated through several matrices with differing criteria based on the requirement specification. The final concepts were thoroughly analyzed until some potential candidates remained which had the potential to become full products.

7.1 Function and feature analysis

Before beginning to generate ideas, it was decided to categorize what area the idea generation would cover. The ideas could be about the functions or the features of the booster cushion and would as thus need to be dealt with in different order depending on what it is. A function was classified as something that would need to be worked into the concept from the beginning while a feature was something that could be added afterwards as an attachment. From the requirement specification and customer needs list some of these categories could be determined.

- Size changing function: The body of the booster cushion should be able to expand and compress in size to accommodate to user need with some sort of mechanism.
- Multipurpose function: The body of the cushion could act as something else if used in a different way. For example, a backpack.
- Height adjusting feature: A feature that can adjust the height of the cushion or adjust the elevation of the belt to get proper belt placement. Could also be function if combined with the size changing function.
- Width adjusting feature: A feature that can adjust the width of the cushion to get a proper seat placement. Could also be function if combined with the size changing function.
- Carrying feature: The cushion should be made easier to carry around with this feature.
- Lock feature: How a mechanism could lock the booster cushion in certain positions.
- Fabric features: How the textiles and foam would be added to the cushion for comfort.

7.2 Idea generation

Ideas were generated that fit into the categories described in Chapter 7.1. The ideas did not necessarily have to be complete, full or logical if it fit that category. For example, if a mechanism could compress or expand in size in some direction it would qualify for an idea in the size changing function category. This of course led to some ideas that could not be applicable in practice but could still inspire other solutions.

Ideas were gathered by inspiration from existing commercial products, both booster cushions, household appliances, things and events that had the function or feature in some capacity. Inspiration and ideas were also gathered from outside participants that were asked about the different functions and features.

It was decided to primarily work on generated ideas that could be classified as functions, as these are more fundamental to the product and harder to change later. The result is presented in Chapter 7.3 and onwards. The features that were idea generated became evaluated later in Chapter 9.5.

7.3 Concepts

In this chapter the initial concepts are presented with little detail. The concepts themselves are ideas of how a booster cushion could work or look like. Some of the concepts were not as realistic, feasible or practical as the concept initially might suggest. Not all concepts are fully detailed and many of them may miss crucial details, such as horns, that would be added later if the concept was deemed to have potential. Note that all the concepts can be placed in the 'size changing' function as no idea was thought up in the 'multipurpose' function.

7.3.1 Claw

The Claw concept, see Figure 7.1, is a concept that utilizes the idea of having the cushion being divided in two parts: the back part and the front part. The front part is meant to be hollow enough for the back part to slide into when a locking mechanism is deactivated. For this to happen the back part needs to be smaller than the front part which would impart that the horns needs to be placed low or be able to be adjusted so they can be lowered to fit into the hollowed-out front.

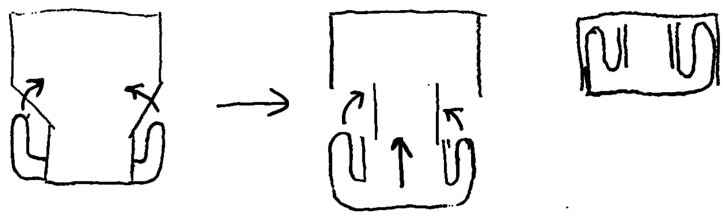

Figure 7.1: *Illustration over how the Claw concept can slide into itself.*

7.3.2 Pyramid

The Pyramid is a concept that could alter the cushions volume by changing the height. There are multiple potential levels that can be used as can be seen in Figure 7.2. The inner part of the cushion is hollowed out to enable that the multiple different squares can be hidden inside each other. In this concept the horns are suggested to be removable to act as a handle if inserted in another place. This also enables the horns to be put at different levels in the pyramid for optimal belt routing.

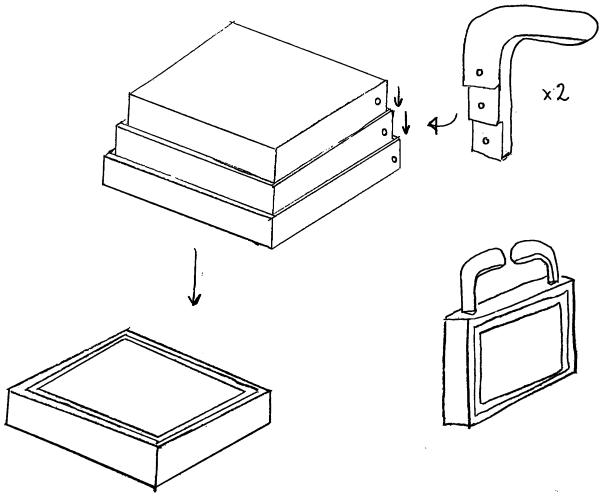

Figure 7.2: *Illustration of the Pyramid concept and how it could reduce in height. Note the removable horns that could double as a handle.*

7.3.3 Hexaflex

The Hexaflex is a concept based on a specific origami folding structure that can take loads vertically and is based on a report discussing the issue [45]. The structure takes the shape of a hexagonal pillar and can be folded flat when twisted. It can take structural loads due to it locking its arms when twisted around its own vertical axis and having vertical pressure applied to it, resulting in the structure self-supporting itself unless rotated the other way. A possible implementation is to connect the upper part of the cushion with the lower one, thus enabling it of becoming flat height-wise, see Figure 7.3.

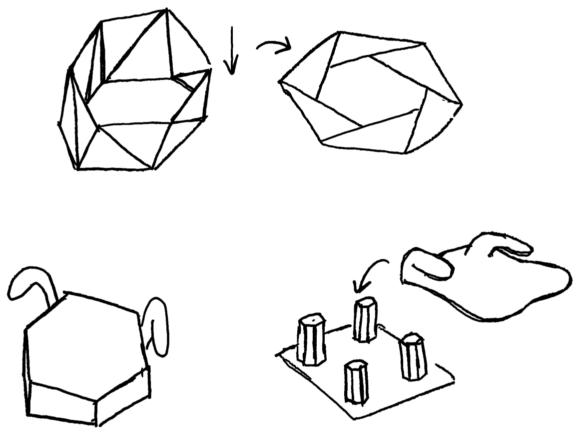

Figure 7.3: *Illustration over how the origami folding structure could be implemented in a booster cushion.*

7.3.4 Matroska

The Matroska is a three-way segmented booster cushion that can, similarly to the pyramid concept, hide inside of itself by folding each part upside down, see Figure 7.4. In contrast to the pyramid concept however it would not require the user to adjust settings or similar and can consist of 3 forms with some sort of strap connecting them and acting as guides.

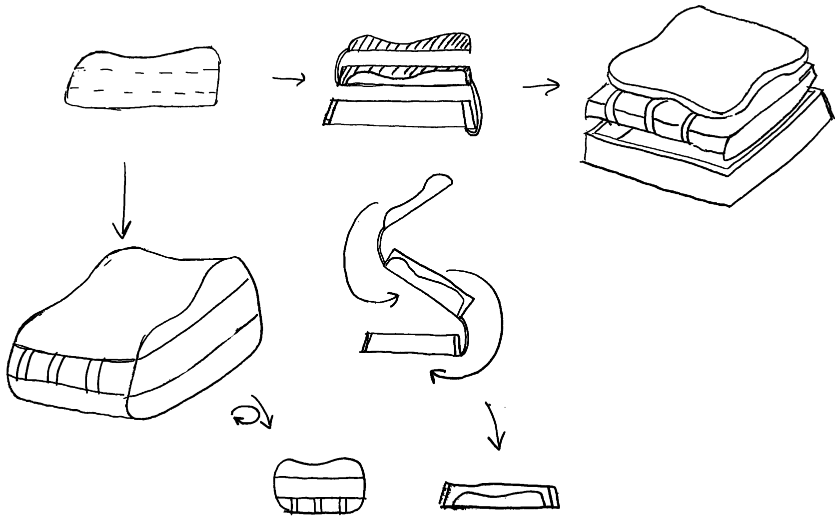

Figure 7.4: *The Matroska concept, a three segmented booster cushion that can stack to create a high enough sitting height for the user.*

7.3.5 Ribs

The Ribs concept take inspiration from park benches and puzzles. The idea is that several separate ribs can interlock when sheared apart from their initial starting position and pushed together, see Figure 7.5. This can potentially give a directional reduction of up to 50% when the ribs and pockets are the maximum length. It would also be able to handle loads very well as the construct would be more solid and have more supporting features compared to more hollow concepts.

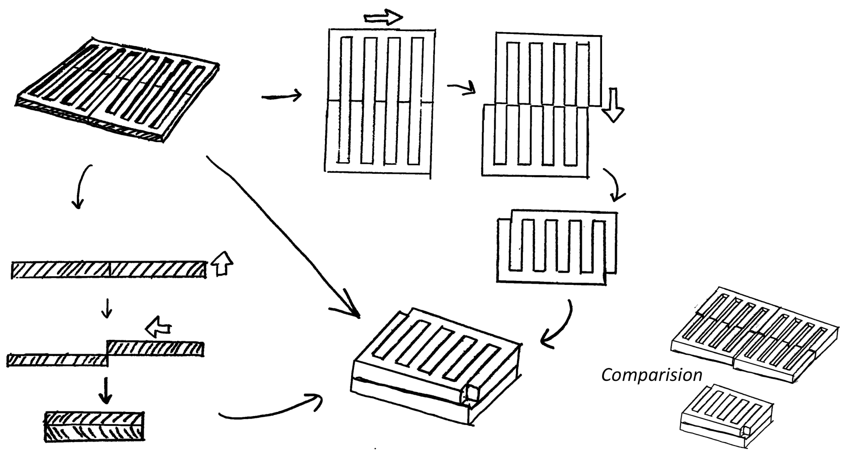

Figure 7.5: *An illustration of the potential volume reduction if multiple ribbed plates are stacked. Given an optimal amount ribs the size can potentially decrease to around 50% of original size given a squarish shape.*

7.3.6 Melon

This concept is very similar to the previous ones as it also utilizes a rib-like structure, see Figure 7.6. It however uses the ribs on the side of the cushion and not in the immediate sitting area as the ribs-concept did. The melon has an axis down the middle in which it can be rotated around after shearing the cushion and thus interlocking the two ribbed sides when fully rotated.

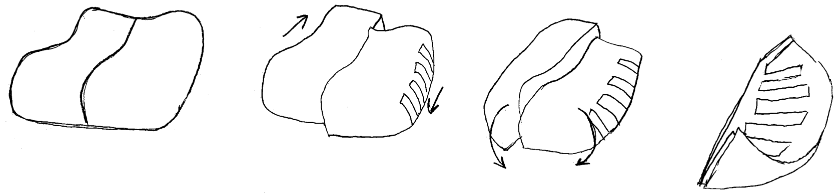

Figure 7.6: *The Melon-concept, two halves of a product that rotates and intersect.*

7.3.7 Cake

The Cake concept also utilized ribs as its size reduction mechanism. This one however is divided into four different parts which all could be separated. The two front parts can interlock with each other and similarly so can the back parts. The two parts that then are created could be stacked inside each other making the final volume reduction quite substantial, see Figure 7.7 for schematics.

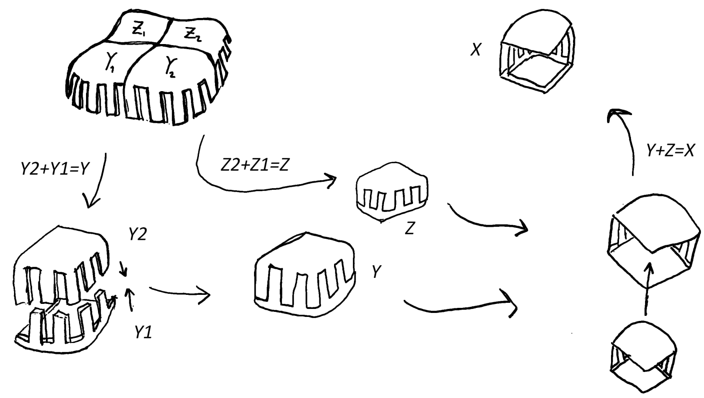

Figure 7.7: *The Cake concept used four different part that could be separated and arranged in a smaller formation. The front parts are denoted as "Y" and the back parts as "Z".*

7.3.8 Turtle

The Turtle concept is a concept that has telescopic tubes along the middle of the cushion acting as the sitting area, see Figure 7.8. These tubes can expand or retract horizontally to make the cushion smaller. Additionally, it is divided into two parts which can be folded into itself in two ways, either by rotating the horns first and then folding or by rotating the whole back part and then folding it. For the evaluations, the first method was considered.

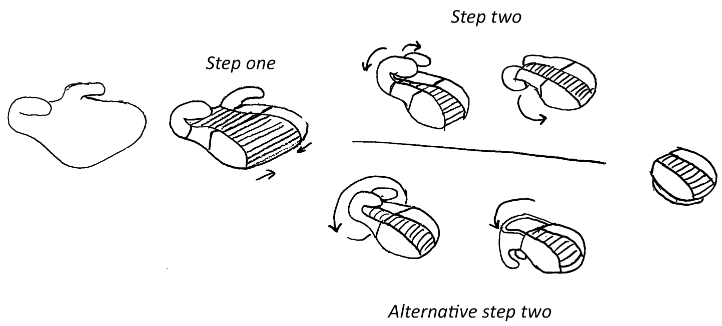

Figure 7.8: *The Turtle concept can compress width-wise by telescopic arms and fold in half.*

7.3.9 Camp

The Camp concept is named after its resemblance to a portable camping chair, see Figure 7.9. The concept can be minimized in height by a folding motion and has an accordion-like upholstery to prevent it from getting pinched and to further prevent misuse from user.

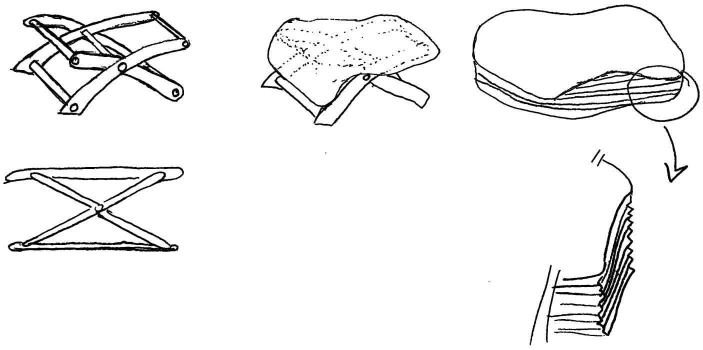

Figure 7.9: *The Camp concept can minimize its height and protect the user from pinching with an accordion-like upholstery.*

7.3.10 Sheet

The Sheet concept is the concept that may minimize in height most effectively. It consists of several sheets of metal that can fold almost as flat as the plates combined thickness when stacked upon each other, see Figure 7.10. When deployed, the plates in the middle acts as a bearing structure as they can only be folded one way. Thus, by sitting on this cushion, it is prevented from folding and eventual misuse is eliminated.

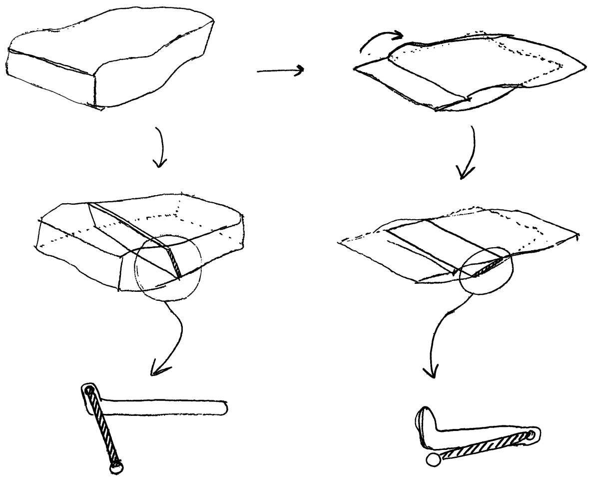

Figure 7.10: *The Sheet concept utilizes sheet metal to fold very flat, to the left it is in deployed state and to the right it is in compressed (folded) state.*

7.3.11 Snake

The Snake concept consists of many blocks linked together, see Figure 7.11. These blocks are supposed to be folded in a certain way to create the booster cushion. It can also be folded to minimize max dimensions or use it in some other way, for example as a small table.

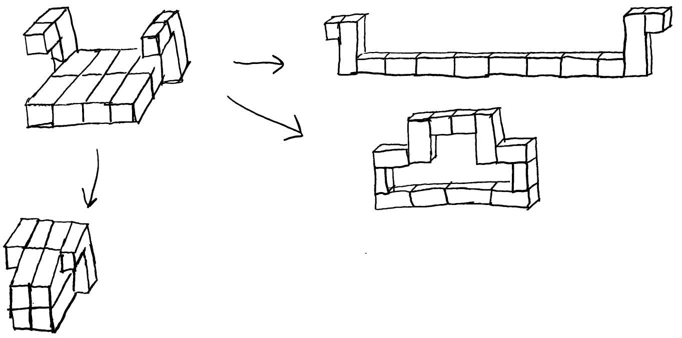

Figure 7.11: *The Snake can assume many forms depending on how it is folded and rotated.*

7.3.12 Hamster

This concept is inspired by DIY-projects (Do it yourself projects) in that the user assemble the cushion themselves. The cushion consists of a skeletal frame and an upholstery that also doubles as a carrying bag for all the loose parts, see Figure 7.12. An alternate design was also conceived which use skeletal plates instead of frames or a combination of the two.

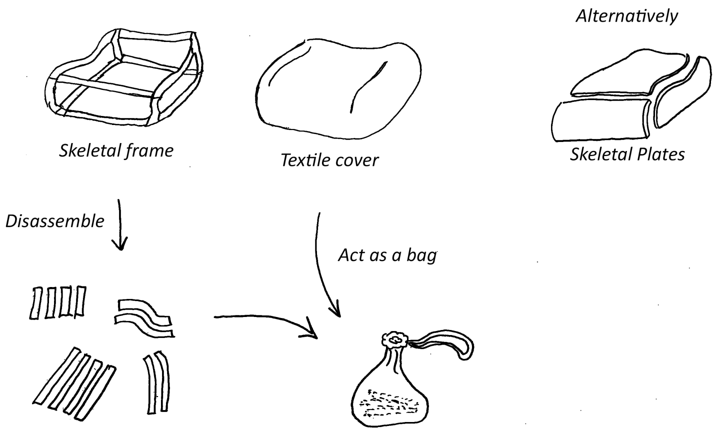

Figure 7.12: *Illustration over how the Hamster concept can be utilized.*

7.3.13 Wave

The Wave concept has a sitting area that consist of several plates. When unlocked, these plates can slide over each other and stack in staples which in turn can be hidden inside the side of the booster cushion, see Figure 7.13.

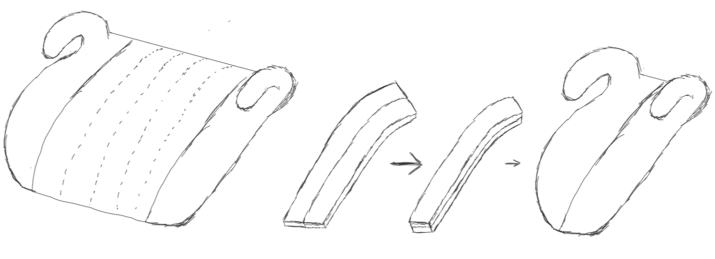

Figure 7.13: *The Wave has a sitting area that consist of many long plates that could stack upon each other.*

7.3.14 Cab

This concept is a booster cushion that can be folded in half. The cab is hollow enough so that the back part of the booster can fit into the front part, see Figure 7.14. The Cab was deemed to have a high potential to crossbreed with other concepts and is already part of the turtle concept.

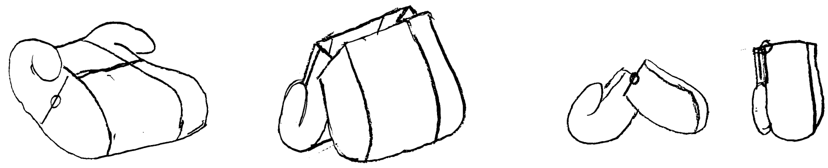

Figure 7.14: *Illustration over how the Cab can be folded in half.*

7.3.15 Tire

Tire is an automatically inflated booster cushion with an included automatic pump, see Figure 7.15. This concept utilizes drop-stitch fabric like the Nachfolger booster seat and Volvo concept booster seat mentioned in Chapter 5.3.1. Drop-stitch can handle great internal pressure and external loads but first needs to be inflated to a high pressure, which is why an automatic pump is included.

Figure 7.15: *Illustration over how an automatically inflatable cushion can look like with a built-in pump and interface on the side.*

7.3.16 Balloon

The Balloon concept is another inflatable booster cushion using drop-stitch just like the Tire concept. The difference here is that this is manually inflated by a pump that exist inside of the booster cushion, see Figure 7.16. By placing the pump sideways, the booster can potentially be rolled up when in a deflated state.

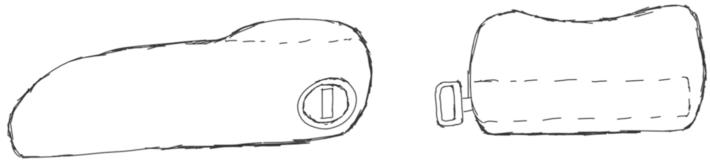

Figure 7.16: *The Balloon is a manual inflatable cushion with a pump integrated in the rear.*

7.3.17 Ostrich

The Ostrich is a booster cushion concept that a hollow middle segment. This part is instead replaced with one or two plates that makes up a part of the sitting area, see Figure 7.17. These plates can be folded down and then hidden inside the front part of the cushion, enabling the cushion to be pushed together. To assist with this, it would also need to have guiding elements on the bottom of the cushion.

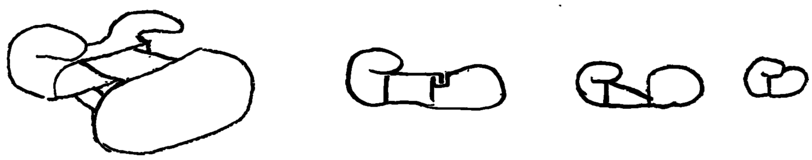

Figure 7.17: *The Ostrich concept. The middle plate can be seen to the left. The images on the right depicts how the plate is folded into the front and the cushion slid together.*

7.3.18 Bridge

A concept that uses load bearing structures similar to the load bearing elements in Leonardo da Vinci's self-supporting bridge, see Figure 7.18. These bridges can deform and compress in height and either width or depth depending on orientation. The concept would need to have outer shell that the bridge element can carry, and the user can sit on.

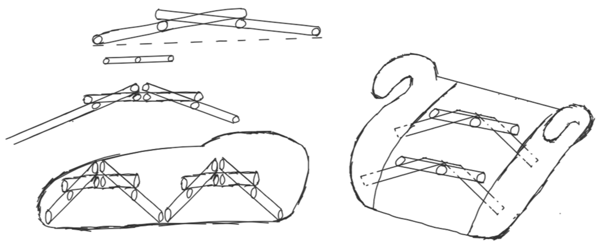

Figure 7.18: *Illustration over how a potential bridge concept could look like with the structure inside the booster cushion.*

7.3.19 Salad

The Salad concept is two separate parts that the user must assemble themselves, see Figure 7.19. One is the side of cushion and the other is the sitting area. Both can be folded in similar way and kept together. To get the whole cushion the user must unfold and then put the sitting area onto the load-bearing walls.

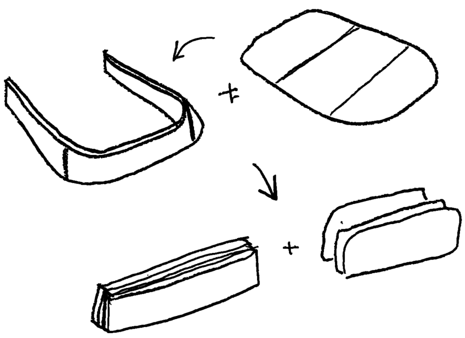

Figure 7.19: *The Salad concept would consist of two parts. Both parts would be able to fold.*

7.3.20 Lasagna

The Lasagna concept utilizes a cross shaped mid-section that can carry most of the loads. The cross-shape also make it possible for it to fold which can be seen in Figure 7.20. Similarly, the sitting area can also be folded down the side of the folded cross-shape making it envelop the final cushion.

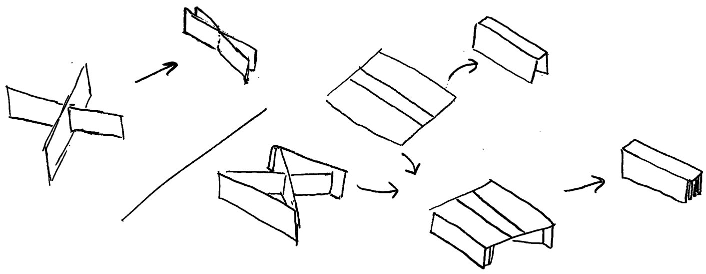

Figure 7.20: *Illustration over how the different parts in the Lasagna concept would interact.*

7.3.21 Cross

The Cross concept utilizes a similar cross shaped mid-section as the lasagna concept. This cross however is folded by rotation instead of direct folding. This give it the advantage of having a smaller stack of plates in the end compared to the Lasagna-concept. This stack of plates can then be hidden inside of the side compartment of the booster cushion, see Figure 7.21.

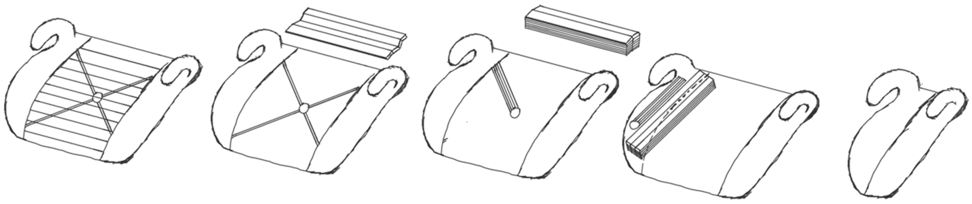

Figure 7.21: *Illustration over how the Cross concepts parts would function.*

7.4 Elimination matrix

The elimination matrix was the first of several evaluation matrices used to evaluate the 21 first concepts. This matrix is useful for eliminating concepts early on for failing to fulfill basic criteria. The concepts are graded with either a plus (+), a minus (-) or a question mark (?) depending on if it passes that particular criterion. If it reasonably fulfills the criterion, the concept passes with a plus. If it is believed to not fulfill a constraint it receives a minus grading. If there is some uncertainty regarding the details and such it receives a question mark. If a concept receives a minus in any category it is deemed unfit for further development. If a concept receives 3 question marks it is eliminated seeing as it has to many uncertainties surrounding it.

The following criteria and constraints were used to evaluate the concepts in the matrix. The idea being that the concepts need to fulfill very basic principles regarding booster cushion design and making it more portable. For the elimination matrix see Table 7.1.

1. Volume reduction: The concepts needed to be able to reduce its volume in some capacity, be it in height, width or depth.

2. Height increase: The concept needed to be able to increase the user's sitting height by a certain amount to comply with R-129 regulations. Flat cushions would thus be eliminated.

3. Load bearing: The concept needed to handle a reasonable amount of load. This was hard to estimate this early, but the most non-durable concepts could be eliminated if their structure was deemed to be unstable.

4. Ergonomic surface: The concepts needed to be able to have an ergonomic surface in some capacity. This eliminated all the blocky solutions with uncomfortable sitting areas and sharp edges and corners.

5. Belt positioning horns: An internal constraint was that the booster had to use traditional horns to ensure the belt is properly positioned. Therefore, the concepts needed to be able to have horns attached to its main body.

6. Being reasonably priced: This constraint existed to make sure the concepts were not relying on unreasonably expensive technology or hard to produce materials.

7. Non-complex deployment: The deployment itself could not be too complex for the user. This meant that it could not take a lot of steps and long duration to deploy as that would increase the risk of misuse and annoyance with the product.

Table 7.1: *The elimination matrix with the 21 first concepts. The seven concepts highlighted in red were eliminated.*

Criteria	Claw	Pyramid	Hexaflex	Matroska	Ribs	Melon	Cake	Turtle	Camp	Sheet	Snake	Hamster	Wave	Cab	Balloon	Tire	Ostrich	Bridge	Salad	Lasagna	Cross
1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2	+	+	+	+	+	+	+	+	+	+	?	+	+	+	+	+	+	+	+	+	+
3	+	+	+	+	+	+	?	?	?	?	+	?	?	+	?	?	+	+	?	+	+
4	+	?	+	+	+	+	+	+	?	-	-	+	+	+	+	+	+	?	+	?	?
5	+	+	+	+	+	-	-	+	?	?	+	-	+	+	?	?	+	?	?	+	+
6	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
7	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+	?	+	+	+

Seven concepts were eliminated in the elimination matrix in total. Melon and Cake were eliminated due to the perceived difficulty of including any form of belt positioning horns that would be compatible with the mechanisms. The Camp concept was eliminated due to three uncertainties making it hard to develop alongside the others. Sheet and Snake both had very flat sitting surfaces which would make it hard to properly construct ergonomic surfaces without intruding on the mechanism drastically. Hamster was eliminated in two categories seeing as it was deemed both too complex to assemble for the average user and difficult to include secure belt positioning horns. Finally, the Bridge was eliminated due to uncertainty over how the mechanism would coexist with an ergonomic sitting surface, belt positioning horns and the assembly method. This left 14 concepts for the next evaluation matrix.

7.5 Pugh matrix

The 14 remaining concepts were inserted into a Pugh matrix with some new criteria. When using the Pugh matrix, a concept is chosen to act as a reference, and all other concepts are compared towards this reference in each category. If the concept is better than the reference it gets one point (+1), if it is worse a point is retracted (-1) and if it is equal in performance it gets no points (0). Afterwards the points are summed up and ranking decided between all the concept and reference. The best ranking concept is then used as the new reference, and the process is repeated until the reference is the best concept compared to all other concepts. This type of matrix is useful for quickly determining the best and worst concepts comparatively by just judging them as ‘better’ or ‘worse’ without thoroughly grading all the products.

The criteria used for the Pugh matrix was reworked since all the concepts passed the previous criteria used in the elimination matrix. These new criteria where aspects and properties that could be used to compare the concepts against each other. The following criteria were used.

1. Height reduction: Examined if the concept could reduce more in height than the base.
2. Width reduction: Examined if the concept could reduce more in width than the base.
3. Depth reduction: Examined if the concept could reduce more in depth than the base.
4. Price: Compared if the concept was cheaper than the base. In this stage of the process this was an uncertain metric and was thus loosely estimated.
5. Mass: Comparison if the concept was deemed to be lighter than the base.
6. Deployment complexity: Examined if the concept takes more steps to deploy than the base.
7. Deployment speed: Evaluated the how fast the concept could be deployed and compared between the concept and base.
8. Mechanism Intuitiveness: Compared which mechanism was more easily understood.

The matrix itself was iterated four times to get an estimate of what concept performed worse than other and to tweak criteria by introducing weighting to the third iteration. In the first iteration a traditional booster cushion was used as the reference to get a comparison and to get a first reference among the concepts. Due to the five last criteria the traditional booster cushion outperformed all the new concepts. The traditional booster cushion is faster, less complex, cheaper and has lower mass most of the time since it has no mechanism to compare with. The first iteration can be seen in Table 7.2. The matroska concept was chosen as the new base for the next iteration.

Table 7.2: *The first Pugh matrix with an ordinary booster cushion as the reference.*

Criteria	Traditional	Claw	Pyramid	Hexaflex	Matroska	Ribs	Turtle	Wave	Cab	Balloon	Tire	Ostrich	Salad	Lasagna	Cross
1	0	0	1	1	1	0	-1	0	-1	1	1	0	0	0	0
2	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1
3	0	1	0	0	0	-1	1	0	1	1	1	1	1	0	0
4	0	-1	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
5	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
6	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
7	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
8	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Tot.	0	-4	-4	-4	-3	-5	-4	-4	-5	-3	-3	-4	-4	-4	-4
Rank	-	4	4	4	1	13	4	4	13	1	1	4	4	4	4

The second iteration, seen in Table 7.3, showed that 11 of the concepts were better than the Matroska concept. In this iteration the Ribs and Cab concepts were the highest ranking and thus the Ribs were chosen as new base.

Table 7.3: *The second Pugh matrix with the Matroska concept as the reference.*

Criteria	Weight	Claw	Pyramid	Hexaflex	Matroska	Ribs	Turtle	Wave	Cab	Balloon	Tire	Ostrich	Salad	Lasagna	Cross
1	0	-1	0	0	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	0	0	0	0	0	1	1	1	0	0	0	0	0	1	1
3	0	0	1	0	0	-1	1	0	1	1	1	1	1	1	1
4	0	0	0	-1	0	0	-1	-1	0	-1	-1	0	0	0	-1
5	0	0	0	0	0	0	-1	-1	0	0	0	0	0	0	-1
6	0	1	0	1	0	1	1	1	1	1	1	1	0	0	0
7	0	1	0	1	0	1	1	1	1	-1	-1	1	-1	0	-1
8	0	0	-1	1	0	1	1	1	1	1	1	0	-1	0	-1
Tot		1	0	2	0	3	2	1	3	0	0	2	-2	1	-3
Rank		6	8	3	8	1	3	6	1	8	8	3	12	6	13

In the third iteration it was chosen to introduce weighting to get a more accurate representation compared to previous iterations. This weighting can be seen in Table 7.4 and is based on the feedback from stakeholders and the customer needs list. It was deemed that width and depth reduction had highest priority since they had the highest impact on the volume, resulting in an assigned weight of 4. Second priority were given to mass and deployment speed with a weight of 3 as it also had high impact on customer value. Next in line was deployment complexity and height reduction with a weight of 2 and lastly both prize and mechanism intuitiveness having a weight of 1. In this new iteration, four concepts perform better than the ribs as reference, with the Wave and Lasagna scoring the best. The Wave was chosen as a new base.

Table 7.4: *The third Pugh matrix with the Ribs concept as the reference. Includes weighting.*

Criteria	Weight	Claw	Pyramid	Hexaflex	Matroska	Ribs	Turtle	Wave	Cab	Balloon	Tire	Ostrich	Salad	Lasagna	Cross
1	2	0	1	1	1	0	-1	0	-1	1	1	0	-1	0	0
2	4	-1	-1	-1	-1	0	0	1	-1	-1	-1	-1	-1	1	1
3	4	1	1	1	1	0	1	1	1	1	1	1	1	1	1
4	1	0	0	-1	0	0	-1	-1	0	-1	-1	0	-1	-1	-1
5	3	0	0	-1	0	0	-1	-1	0	-1	0	0	0	1	-1
6	2	0	-1	1	-1	0	-1	0	0	-1	0	0	-1	-1	-1
7	3	0	-1	1	-1	0	-1	0	0	-1	-1	0	-1	-1	-1
8	1	0	-1	0	-1	0	0	0	0	0	0	-1	-1	-1	-1
Tot		2	2	2	2	0	1	0	2	2	2	2	2	0	0
Rank		1	1	1	1	10	9	10	1	1	1	1	1	10	10

In the final Pugh iteration, see Table 7.5, the Wave concept outperformed all the other concepts based on the used criteria, including the Lasagna which it tied for the first place with in the previous matrix. Cab was a close second followed by Hexaflex and Tire. It was decided to eliminate three concepts, the Pyramid, the Salad and the Cross, due to their poor performances across all the Pugh matrices.

Table 7.5: *The fourth Pugh matrix with the Wave concept as the reference. Includes weighting.*

Criteria	Weight	Claw	Pyramid	Hexaflex	Matroska	Ribs	Turtle	Wave	Cab	Balloon	Tire	Ostrich	Salad	Lasagna	Cross
1	2	0	1	1	1	0	-1	0	-1	1	1	0	-1	0	0
2	4	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1	0	0
3	4	1	0	0	0	-1	1	0	1	1	1	1	1	0	0
4	1	0	0	-1	0	1	0	0	1	-1	-1	0	0	-1	-1
5	3	0	0	0	1	1	0	0	0	-1	-1	0	0	0	0
6	2	0	-1	0	-1	0	-1	0	0	-1	1	-1	-1	-1	-1
7	3	0	-1	0	-1	0	-1	0	0	-1	-1	-1	-1	-1	-1
8	1	-1	-1	0	-1	0	0	0	0	0	0	-1	-1	-1	-1
Tot		3	2	1	2	0	2	0	2	2	2	3	3	1	1
Rank		1	3	9	3	12	3	12	3	3	3	1	1	9	9

7.6 New concepts

At this point in the evaluation, some new concepts were created and included in the evaluation. Most of these new concepts were crossbred from existing concepts to make up for weaknesses of each other but some new mechanisms were also created. The concepts were quickly put through the elimination matrix to make sure they passed the bare minimum requirements. They were not put through the Pugh as the upcoming Kesselring matrix would evaluate the same criteria but more thoroughly.

7.6.1 WaveCab

WaveCab is a combination of the two top ranking concepts. It utilizes both mechanism in the Wave and the Cab by first reducing in width and then in depth by folding itself in half, see Figure 7.22. The width reduction is done by having the sitting area being made up of several plates that can horizontally slide over each other.

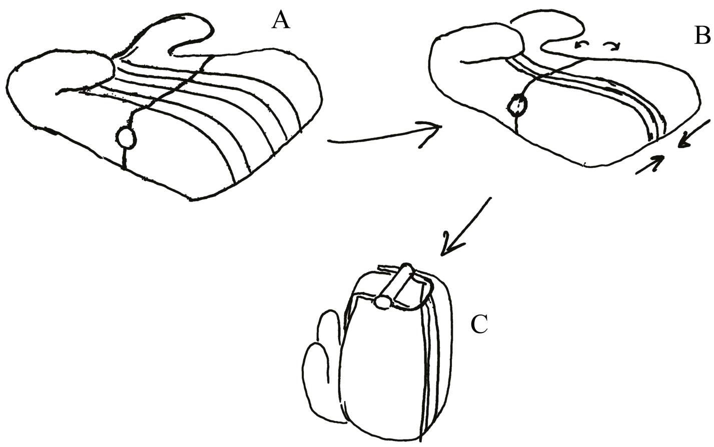

Figure 7.22: *Illustration over how the WaveCab (A) works. It is first compressed sideways (B) and when folds in half around a central axis (C).*

7.6.2 WaveOstrich

The WaveOstrich is also a combination of the Wave but together with the Ostrich-concept instead. It reduces in size width-wise using the Wave mechanism. This is done by having plates first stack upon each other and then in depth-wise with the Ostrich mechanism by angling a plate downward and pushing the back and front parts together. For an illustration of this process and concept see Figure 7.23.

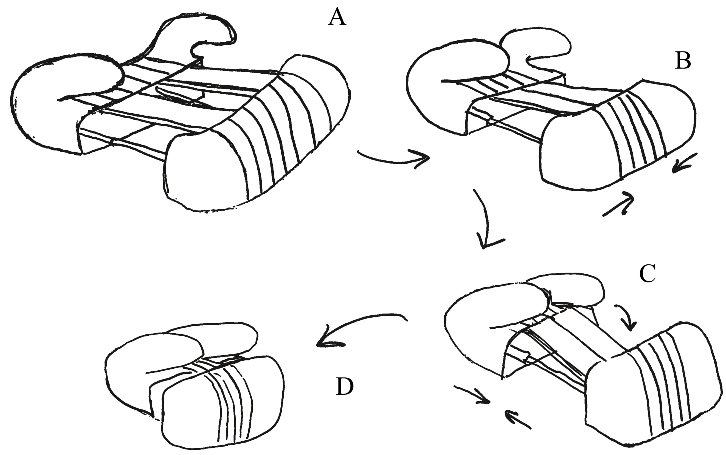

Figure 7.23: *Illustration on the WaveOstrich (A) mechanism. It first compresses sideways (B), followed by angling the plates downwards (C) and pushing the back and front parts together (D).*

7.6.3 RibOstrich

The RibOstrich is a crossbreed by the Rib concept and the Ostrich concept. Similarly, to the WaveOstrich, it reduces in depth with the Ostrich-mechanism and in width with the Rib-mechanism by shearing the both halves and then pushing them together, see Figure 7.24 for illustration. The Rib is only used on the front and back components and not on the plates relating to the Ostrich.

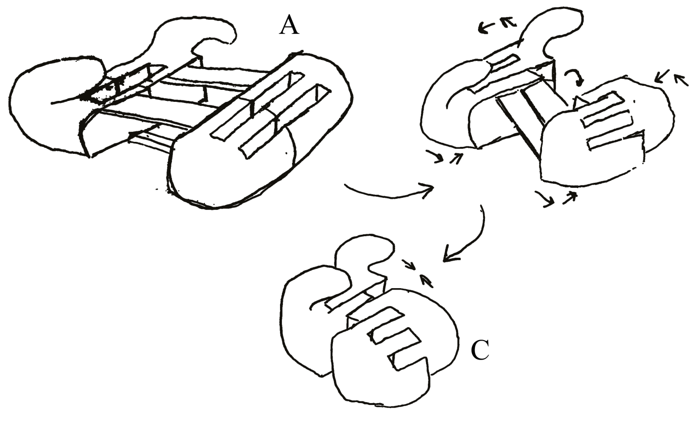

Figure 7.24: *Illustration of the RibOstrich (A). To reduce its dimensions, the sides are sheared and pushed together (B). The Ostrich plates are then angled down (B) and finally the back is pushed into the front parts (C).*

7.6.4 RibCab

RibCab is a combination of the Rib concept and the Cab concept, see Figure 7.25. This concept first utilizes the Rib-mechanism by shearing and then pushing the two halves together. Afterwards, it rotates around a central axis to fold in half. Note that this axis must be separated into two axes that align when the booster cushion is sheared, in order to be able to properly rotate.

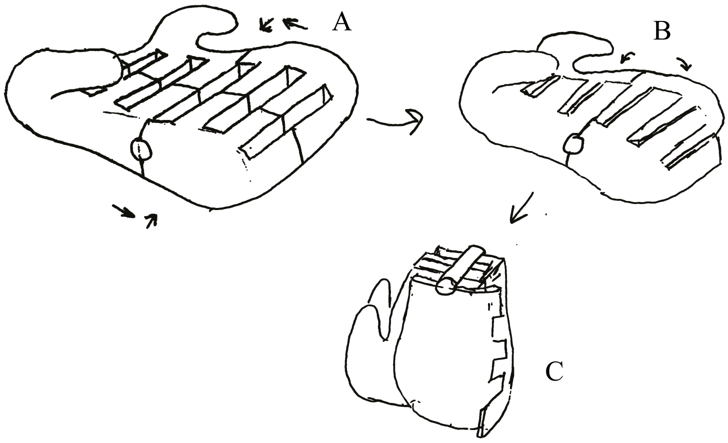

Figure 7.25: *The RibOstrich (A) and its mechanism. It is first sheared and pushed together (B), before being folded in half around a central axis (C).*

7.6.5 Frog

The Frog is a concept similar in design to RibOstrich, but instead of having separate plates that hide inside the front body it has beams that can slide into the front body, see Figure 7.26. This somewhat simplifies the process of deploying the mechanism since there is no need to angle the plates downward. The middle section slides onto the back of the booster cushion when in compressed mode.

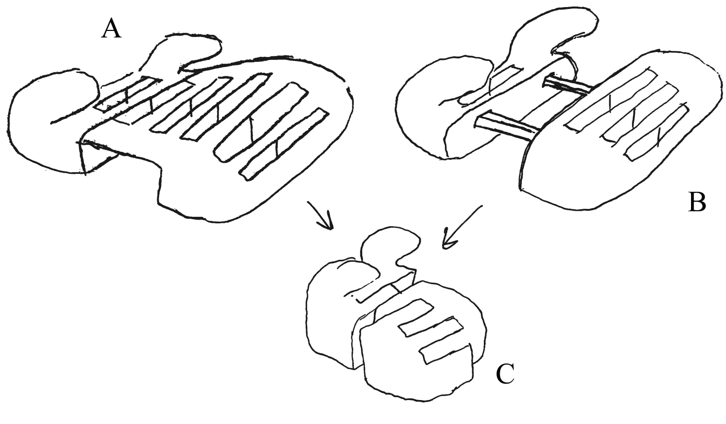

Figure 7.26: *Illustration of the Frog (A). An alternate view illustrating the beams that acts as a load bearing structure underneath the Rib components (B). It becomes smaller by first shearing and pushing together before pushing the back into the front (C).*

7.7 Kesselring matrix

After the new concepts were defined in greater detail, all the concepts were evaluated using a Kesselring matrix. The matrix contained more detailed criteria with varied ratings depending on quantifiable volumes, measurements or actions. The criteria are like that of the Pugh matrices but with more added details and with five distinct levels so that each category can be rated from 1 to 5. While the criteria are explained below the full grading for each criterion can be found in Appendix I.1. One instance of the Kesselring was performed before it was discovered that some criteria needed to be changed and new aspects were considered. The following were used as the first matrix criteria.

1. Height reduction: Rates how much the concept can reduce height-wise when in compact state.

2. Width reduction: Rates how much the concept can reduce in width

3. Depth reduction: Rating over how much the depth measurement is decreased in compact state.

4. Measurement increase: It was observed that some concepts managed to decrease a measurement in a dimension while simultaneously increase in another dimension, for example the Ribs concept. This criterion exists to reward concepts that does not increase in any direction and to penalize concepts that do increase in a dimension. The measurement used for comparison is the bounding box of the product when in deployed state and compact state.

5. Price: This criterion was a rough estimate of what the market price would be for the product when finished. The estimates were based on existing similar products, number of features and complexity of the mechanism.

6. Mass: This was estimated in a way that was similar to the prize. The estimation was based on number of components, their solidity, expected material and reference products already on the market.

7. Deployment complexity: This criterion is a measurement over how many steps needed to fully deploy the booster cushion from its compact state. A simple action such as pulling something out or sliding a component was counted as a step. It was decided that just pushing a button to start an automated deployment process would count as less than one step.

8. Deployment speed: This criterion is a rating of the time taken to fully deploy the cushion from its compact state. It is different from the previous state as the complexity can be simple but still have a long deployment time and vice versa. The speed was divided into a manual speed and an automatic speed as some users provided feedback that they would be okay with longer deployment times if it was fully automatic.

9. Mechanism intuitiveness: This metric was used to get a sense of how easy it would be for an inexperienced person to use the booster cushions deployment mechanism. Contrary to other criteria, this one used a non-quantifiable grading system as it was deemed the most fit for this kind of metric.

It is important to note that all the details surrounding the concept had not been ironed out in this phase of the project, and many metrics will differ from the final product. The metrics most likely to change or vary are mass, price and deployment complexity. This problem was however deemed acceptable as this margin of error would probably be equally applied across all the concepts, so if one concept is lighter than anticipated it is likely that most of the others concept would differ with a similar amount. Concepts that are deemed better than other concepts in a metric would then probably still be better after the correction.

The weighting was the same as in the Pugh matrices. Reduction in volume was deemed the most important as that is what will allow for easier transportation and storage of the final product. The volume reduction was separated into measurement reductions as described above, however the width and depth dimension was deemed the most important of these criteria seeing as those are the largest dimensions and would allow for more customer value in a more compact product. They were thus given a weighting value of 4 each. Height was still deemed important but not as important and thus received a lower weighting at 2. It was deemed acceptable to weigh the dimension aspects so high since most concepts would only be able to capitalize on one of these multipliers. Criterion number 4, the measurement increase, was given a low weighting since the concepts usually had a minimal size increase if any.

The price criterion was also given a low weight multiplier of 1 as it was deemed to be a very low priority during the project to minimize product cost and that it was also the most uncertain metric. The mass-criteria received a high multiplier of 3, it was justified that while volume was prioritized, mass is almost as influential on the portability as well and should be taken into account as such. Deployment complexity and speed were each given a 2 in weighting as it was reasoned they were important but not as important as the mass. Finally, the intuitiveness was given a multiplier of 1 seeing as the user would become familiar with the cushion and know how to use it as long as it was reasonably intuitive. The total weighting multiplier sum was 20 making 100 the maximum possible score. For the full first Kesselring matrix, see Table 7.6.

Table 7.6: *The first Kesselring Matrix, the Tire and WaveCab performed the best.*

Criteria	Weight	Claw	Hexaflex	Matroska	Ribs	Turtle	Wave	Cab	Balloon	Tire	Ostrich	Lasagna	WaveCab	WaveOstrich	RibOstrich	RibCab	Frog
1	2	1	5	4	1	1	1	1	2	2	1	1	1	1	1	1	1
2	4	1	1	1	3	3	4	1	1	1	1	4	4	4	3	3	3
3	4	3	1	1	1	3	1	3	5	5	3	1	3	2	2	2	2
4	1	5	5	5	3	3	5	3	4	4	5	4	3	5	5	5	5
5	1	4	4	5	4	3	4	4	5	1	4	4	3	3	4	3	4
6	3	3	3	4	4	3	3	4	4	4	4	4	3	3	4	4	4
7	2	4	4	3	4	4	3	4	1	5	3	3	4	4	3	3	3
8	2	5	5	4	5	4	4	5	1	3	4	4	4	4	4	4	4
9	1	4	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4
Total		58	58	57	59	61	58	59	57	65	57	60	65	63	61	60	61
Rank		11	11	14	9	4	11	9	14	1	14	7	1	3	4	7	4

In the first Kesselring the best ranking concepts were the Tire and the WaveCab concept, followed by WaveOstrich, Turtle, RibOstrich and Frog. The Matroska, Balloon and Ostrich scored the worst out of all concepts. After further discussion it was decided to redo the Kesselring once more with some changes and addition to the criteria with the following justification. The new Kesselring can be seen in Table 7.7.

6. Mass: All concepts in the previous Kesselring this metric scored either 3 or 4 points which meant that the grading needed to be refined.

8. Deployment speed: A similar reasoning was used here. Most concept received either 5 or 4 points and a separation of these was needed to gain a more beneficial evaluation.

10. Adjustable settings: A new metric that was added. The metric is supposed to award concepts that can be adjusted or have some sort of adjustable height or width settings seeing as that was a highly requested by customer in the survey. It was decided to evaluate this function this early in the project as the mechanism is closely connected to the possibility for adjustable settings.

Table 7.7: *The second Kesselring matrix with revised weighting and criteria. The revised criteria are denoted with an asterisk (*). WaveOstrich was the top-performing concept. Green denotes the top concept scoring over 60 points and receiving further development while red denotes discontinued concepts. Grey concepts mark potential candidates for backup if none of the top scoring concepts would work out.*

Criteria	Weight	Claw	Hexaflex	Matroska	Ribs	Turtle	Wave	Cab	Balloon	Tire	Ostrich	Lasagna	WaveCab	WaveOstrich	RibOstrich	RibCab	Frog
1	2	1	5	4	1	1	1	1	2	2	1	1	1	1	1	1	1
2	4	1	1	1	3	3	4	1	1	1	1	4	4	4	3	3	3
3	4	3	1	1	1	3	1	3	5	5	3	1	3	2	2	2	2
4	1	5	5	5	4	3	5	3	4	4	5	4	3	5	5	5	5
5	1	4	4	5	4	3	4	4	5	1	4	4	3	3	4	4	4
6*	3	3	1	2	3	2	2	3	3	3	4	2	3	4	4	4	4
7	2	4	4	3	4	4	3	4	1	5	3	3	4	4	3	3	3
8*	2	4	4	3	5	4	4	5	2	3	3	3	3	3	3	4	3
9	1	4	4	5	4	4	4	4	4	4	4	4	4	4	4	4	4
10*	1	1	1	1	1	3	3	1	1	1	1	1	3	3	1	1	1
Total		57	51	50	58	61	58	57	57	63	56	53	66	67	60	62	60
Rank		10	15	16	8	5	8	10	10	3	13	14	2	1	6	4	6

This new Kesselring matrix shows the WaveOstrich as the highest-ranking concept closely followed by WaveCab by just one point. The Tire, RibCab, Turtle, RibOstrich and Frog all received 60 points or more. Based on this matrix, it was decided to continue development on these seven highest scoring concepts and to keep Ribs and Wave as potential backup concepts. The remaining concepts were discontinued.

7.8 Detailed development evaluation

It was decided to develop the final seven concepts further by putting them through a more advanced kind of elimination process. Three main categories were created that the concept would have to pass through. In each category the concept would be discussed, and potential issues or uncertainties would be highlighted and addressed.

7.8.1 Comfort, textile and foam

When receiving feedback from technical experts at Volvo Cars, they asked about the plausibility of accommodating for comfortable sitting when being presented some of the concepts. As the concepts already possessed the ability to have ergonomic surfaces it would also need to have foam and textiles in order for the user to sit comfortably. This is important since the user must remain seated during longer periods of time during certain car trips, which children might be unwilling to do if the comfort is lacking.

An upholstery that would be attached to a booster cushion that changes shape would need to compress, wrinkle and deform depending on the concept. Take for example the Tire concept, when deflated it would need to wrinkle and deform together with the drop-stitch fabric. This however is acceptable seeing as the upholstery is not a deal breaker when it comes to comfort, while the foam is. The foam cannot be one solid layer or sheet in most of the concepts seeing as it involves moving parts. For example, with the concepts that involve ribs such as RibOstrich, RibCab and Frog, a solid piece foam would in the best case deform when the cushion compress or in the worst case, become pinched between the moving parts and hinder movement, ultimately ripping the foam. This is similarly also true for the wave concepts. The inflatable Tire concept can handle this the best as it has no moving or separating parts. This problem however is solvable for the concepts if the foam is divided into smaller segments, for example if each rib had a separate rectangular piece of foam on top of it. This is also true for the Wave-based concepts if the different plates are separated enough height-wise so that the foam does not collide with anything.

7.8.2 Mechanism and form of cushion concepts

This section discusses the different mechanisms, how they would work and what potential difficulties might appear when constructing them. It is also discussed what features each mechanism would have to include in order to function correctly. Both the individual mechanisms will be discussed in addition to the different combinations of solutions as well.

The concepts that utilize the Wave mechanism will have plates that stack on top of each other when in a compact state. To achieve optimal ergonomic form of the cushion, while still maintaining an effective mechanism function, all plates must maintain the same shape. The level of compactness that can be achieved with this method does not depend on the number of these plates but on how many layers that can be stacked at once. For example, if there are just two plates in total and they stack upon each other, that would amount to the same compactness as eight plates just stacked on two layers. Additionally, since these plates will be parallel to each other when deployed, they would need to be pulled out or pushed in from its original direction to allow for the horizontal movement, this would in turn require guiding surfaces.

The three concepts that utilize a ribbed body has two ways to benefit from it. The body will be split in two parts and these parts can either be asymmetric or symmetric. In the case of an asymmetric construction, each component that makes up the body will perfectly fit into each other when pushed together. This would however feature an uneven sitting area which might be noticeable depending on the size of the ribs. It would also require some sort of pin that can lock the movement while the cushion is in use, this would have to be disengaged when the user wants to compress it. If the ribs are symmetric it would solve two of these problems, first it would be a more even area to sit on and it would be impossible to compress without first shearing the two parts apart first. However, this additional shearing would require additional guiding surfaces as the user may find it harder to compress. The symmetrical variant is probably the preferred solution as the load will be more evenly distributed and the comfort for the user is more plausible to achieve.

The Ostrich solution removes the middle part of the cushion and replaces it with one or two plates which acts as sitting area. The best option is probably to use two plates instead of one as it could be more optimally placed to take vertical loads, see Figure 7.27 for how the two Ostrich-plates would look like in the RibOstrich. When not in use, these plates can be folded or rotated down to be hidden inside the front body. This would in turn require axial movement where the plate is fastened and can be solved by integrating a simple axis in the back-part. However, this present a challenge when combined with the Rib or the Wave.

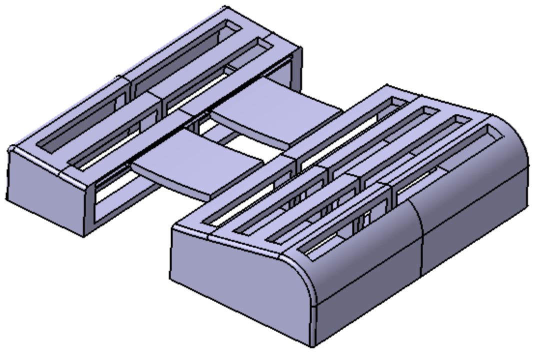

Figure 7.27: *The RibOstrich with two ostrich plates.*

With the Wave concept, the two Ostrich-plates would need to be fasten to one Wave-plate each. This is to hinder an Ostrich-plate from lodging between the wave plates and blocking the movement. By making them exclusive one also ensures that the Ostrich-plates stay in the correct position, which is important. The RibOstrich cannot solve this problem in a similar way as both of the Ostrich-plates would have to be aligned to the same side in order to not interfere. If each of the two Ostrich-plates were aligned on one side each the situation that is illustrated in Figure 7.28 would happen and the concept would get stuck. There is also the potential problem of both Ostrich-plates needing to be too big to fit inside of the front part. Because of all these issues it was decided to discontinue the RibOstrich concept.

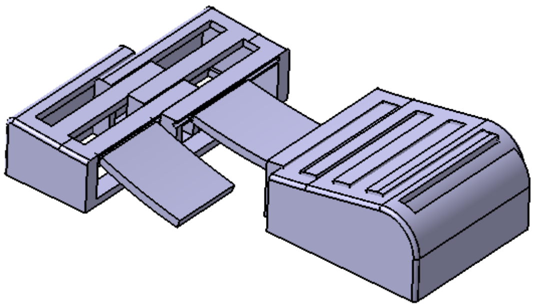

Figure 7.28: *Demonstration over how the RibOstrich would get stuck with two plates.*

The two concepts utilizing a Cab-solution need to be divided into two parts depth-wise. This is because one part is supposed to be rotated around and envelop the other part, this is called the outer part while the enveloped element is called the inner part. For this to be possible there needs to be an axis that the parts can rotate around. The optimal axis placement can be found with simple trial and error when modeling. Another vital detail for the cab to work is that the parts must fit in each other when compressed. Ideally the front part should be the part that house the back part if they are reduced by the same amount. For the front part to fit in the back part it needs to reduce as much or more than the front, which may cause the process to be less robust, more complex and more time consuming. The inner part will also have more options for support structures while the outer part will have limited options since it needs a lot of free space to house the inner part, for an illustration of this see Figure 7.29.

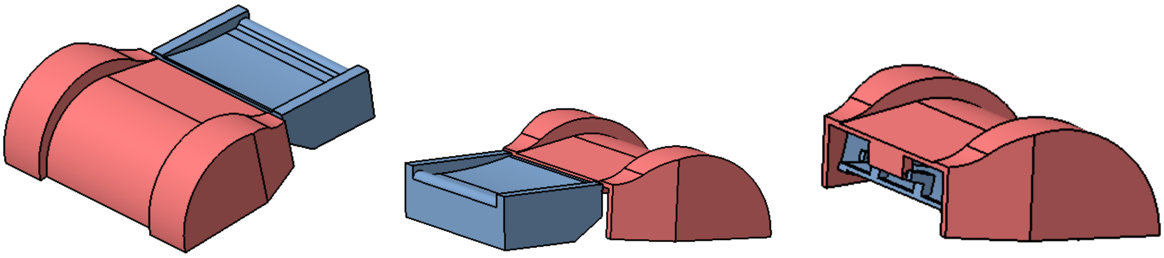

Figure 7.29: *The Cab mechanism requires the back part to be smaller and the front part to be hollow.*

The Turtle, WaveCab and RibCab all implement a cab solution. For the Turtle and WaveCab, the Cab-mechanism can be incorporated without too much issue since they just reduce horizontally without clashing. The RibCab on the other hand, faces a similar problem as discussed with the RibOstrich. Since an initial shearing movement is needed to bring the Rib-parts together, the axis of the Cab that is seated on each half will not be aligned. This is however solvable if the axis is not aligned when the product is deployed but becomes aligned when the rib part is sheared. This would also act as a safety measure since it is not possible to rotate before bringing the rib parts together.

The Turtle concept uses telescopic arms to compress width-wise. As established in the previous paragraph, there should be no problem to combine this with the Cab-solution. The telescopic arms however may be constructed in two ways. The telescopic arms should be constructed by having two distinct parts, a solid rod and a hollow tube that slide over it. Since the booster cushion should be symmetric in the greatest extent possible in order to allow for comfort and equal distribution of applied force there should be three telescope parts in total, two connecting to the side of the cushion and one in the center. The two ways to construct these are either having the hollow tube in the middle or the solid rod in the middle, a comparison can be seen in Figure 7.30. Both provide two small edges in the cushion which may become uncomfortable if not properly rounded and padded. The one comprising of a tube in the middle is preferred since it provides a more natural level increment in the middle that make it feel more ergonomic if the edges are rounded off. The one with the tube in the middle is however more likely to provide better width compression as it can be inserted further into the body than the tubes can.

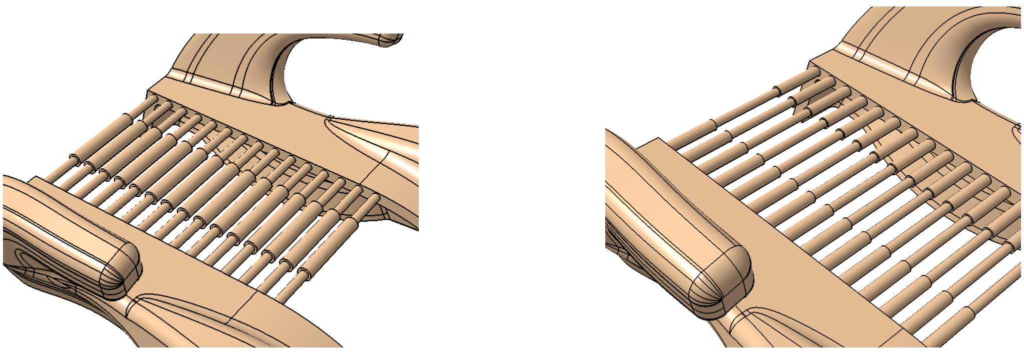

Figure 7.30: *The Turtle concept can have the hollow tube in the middle (left) or at the sides (right).*

The Frog concept, which is very similar to the RibOstrich, does not share the same weakness that got it eliminated. It gives the illusion of having a continuous sitting area when in reality, the middle section of the booster cushion is empty with only two supporting beams as can be seen in Figure 7.31.

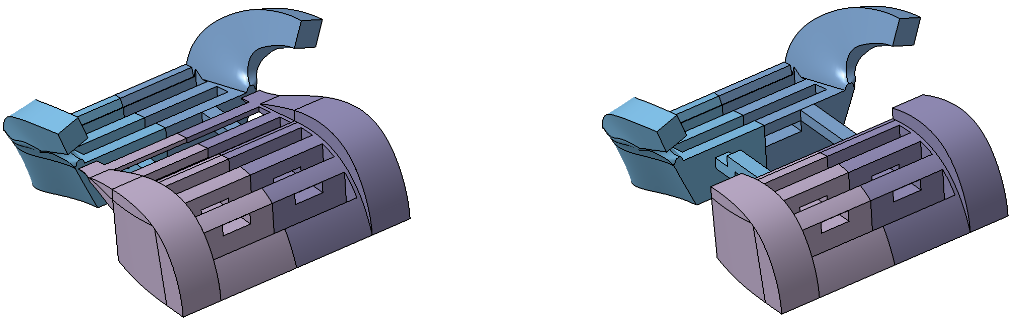

Figure 7.31: *The Frog concept illustrated with (left) and without (right) the middle section.*

Since the ribbed sitting area is supported by these beams there is no need for rotational movement. However there is a need for the beam to not interfere with the remaining of the parts when the booster cushion is compressed and pushed into the front body, this can be solved with a slot as can be seen in Figure 7.32. Finally, when the part is sheared and compressed, there needs to be holes in the front part, in which the beam can be pushed into, this can also be seen in Figure 7.32.

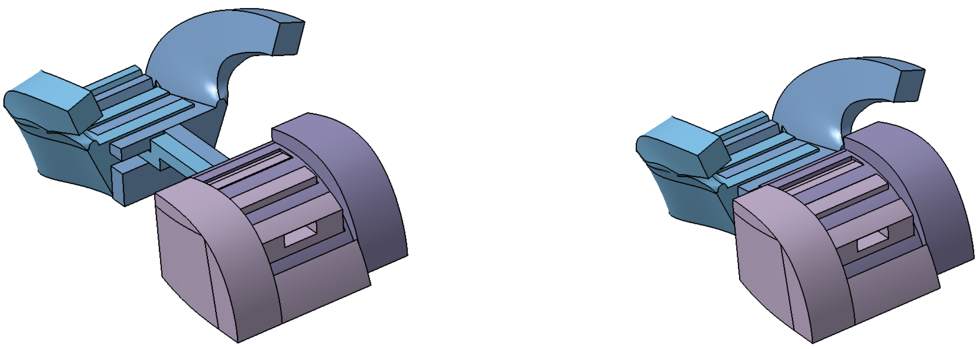

Figure 7.32: *How the Frog concept is not affected by the drawbacks affecting the RibOstrich (left) and how it compresses depth-wise by having the beams travel into the aligned holes (right).*

The inflatable Tire concept is supposed to use a drop-stitch fabric as it is very durable. It however needs to be inflated to a high pressure in order to not deform too much during a collision, which require a pump. In the Pugh and Kesselring matrices the automatic pump outperformed the manual pump and it was thus decided that such a pump would have to come with the cushion. The horns may also have to be strengthened with some support structure depending on how durable they would need be.

7.8.3 User misuse and risks

This category discusses and evaluates certain issues relating to risks and potential misuses by the user. It is also discussed if these risks can be avoided or solved preemptively, and how to mitigate user errors or eliminate them before they appear.

The Ostrich-mechanism in the WaveOstrich was deemed to have many uncertainties when it came to the development of a solution that can consistently, and safely rotate the plates down. It was also noted that the Ostrich-plates will not be visible to the user in the final product which may lead to frustration or confusion as the user tries to identify any faults or errors if they would appear. Because of these concerns and issues raised in Chapter 7.8.2 the WaveOstrich was discontinued from the concept list despite ranking highest in the Kesselring matrix.

For the inflatable Tire concept, a concern was raised over the user not inflating the cushion to target level. This issue can however be easily remedied by including a pressure gauge that indicate if the booster cushion has reached the required pressure range. It could also be solved by having the automatic pump continue until the desired pressure is reached, thus removing the user's judgement from the situation.

The Frog utilize a hidden mechanism so the user would have to learn the order of operations or have a guiding surface that they can follow so that the parts are only manipulated one way at a time, it is also a plus if there are as few actions as possible in order to make it as easier to use.

There were concerns over how durable the telescopic arms on the Turtle-concept really is. When expanding to max width the tube and rod would look like the cross section shown in Figure 7.33. When a vertical load is applied to the mechanism, it is not unlikely it would snap or buckle unless the construction is made overly robust. This problem could be partially mitigated by extending the overlap between the rod a tube when in expanded state. This change would however affect the minimum width the Turtle can compress to which would affect the end products customer value. It was thus decided to discontinue this concept and focus on others.

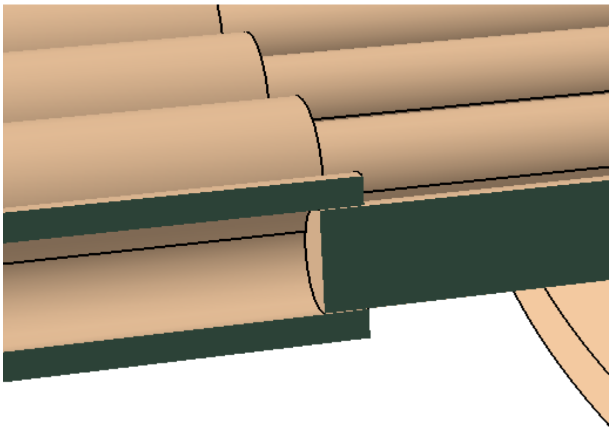

Figure 7.33: *Cross section of how the telescopic arms could look like. If vertical loads are applied, there is a possibility of buckling.*

No major concerns were raised over the WaveCab and RibCab as their mechanisms were visible to the user and thus more easily understood. The only minor thing discussed is that there should there should be indicators of when the concepts are locked in place after compression or deployment, either by a visual locking mechanism, a haptic feedback or audible sound cue.

7.8.4 Conclusion of development evaluation

During the evaluation three of the concepts, WaveOstrich, RibOstrich and Turtle were eliminated which leaves RibCab, WaveCab, Frog and Tire as the final four concepts to be further developed. It was decided to make 3D-models of the three mechanical concepts as that would give a clearer picture over what solutions are possible to implement. It was also discussed how these prototypes should be produced which all ended up being by additive manufacturing except for the Tire-concept which would have to be produced externally seeing as it consisted of drop-stitch fabric and electronic components.

8

Final concepts

The three mechanical concepts were 3D-modeled to make the mechanisms as detailed and realistic as possible. Due to time constraints it was decided to continue with the concept that was deemed to have the most potential for commercial application and to make a prototype in order to perform user tests and observations on it. This concept ended up being the WaveCab and is presented in Chapter 8.1. A product derived from the Tire concept is also presented but is not further evaluated, this product can be found in Chapter 8.2. The development of the final two concepts was discontinued after issues were encountered with the design. The development of them is presented in Appendix J. All four of them will from here on be referred to with other names seeing as they are closer to full products than to concepts.

8.1 SaFE – Formerly the WaveCab

The SaFE booster cushion is the main product developed and modeled up to this point, it is derived directly from the concept WaveCab and the acronym 'SaFE' stands for Slotting and Folding Extendable booster cushion. It is compressible in width by about 10cm and can fold in half which reduces its depth by about 15cm. The maximum dimensions, referred to as the bounding box, is 37% smaller in compressed state compared to the deployed state. The most critical volumes of width and depth does become smaller while the bounding box heights increases by about 3cm. The product can be seen in Figure 8.1 and consist of six separate parts.

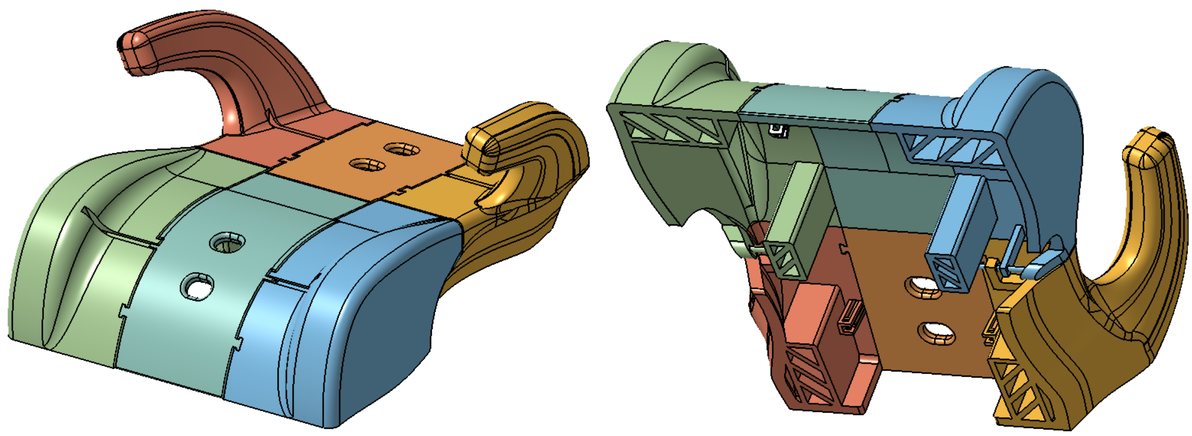

Figure 8.1: *The SaFE booster cushion, seen from above (left) and under (right).*

The six different parts can be categorized into three rear parts (red to yellow) and three front parts (green to blue). The different side parts are symmetrical, meaning that red is mirrored to yellow and green is mirrored to blue. The two parts in the middle are two plates that can protrude a few centimeters out of the main body which enables the side parts to be slid under the plates, which is how the product reduces in width. This process is denoted as ”slotting” or ”to slot” henceforth since it utilizes slotted guiding surfaces, a demonstration of this can be seen in Figure 8.2.

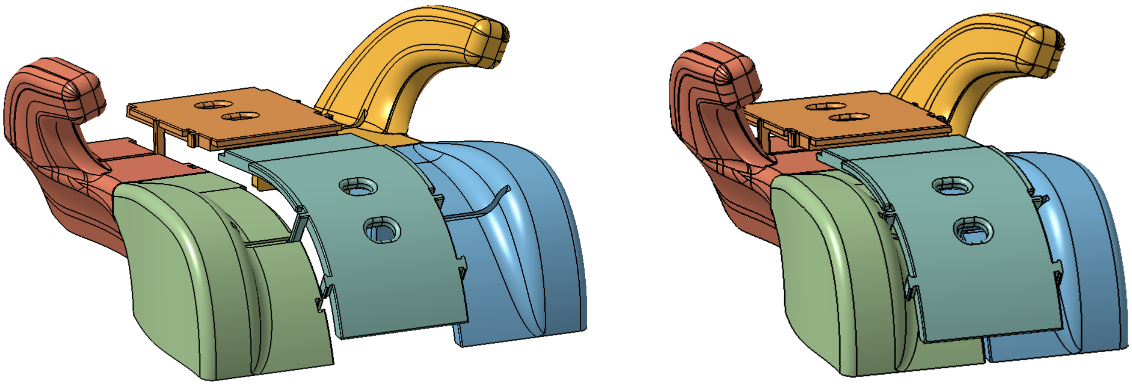

Figure 8.2: *To compress the booster, the middle plates are raised (left) and the sides are pushed together (right).*

The middle plates are connected to the side plates by ‘vertical rail cages’ on the outer parts, as can be seen in Figure 8.3. The middle plates has T-shaped beams, henceforth called ‘plate arms’, and two of these are located on each middle plate. These plate arms can follow the vertical guiding of the rail cages which only allows for vertical movement until it reaches the top. Once the top is reached, new T-shaped slots are available for the plate arms to fit into which guides it towards the horns of the booster cushion, also seen in Figure 8.3. As a result, the two side parts are brought closer together until finally making contact in the middle.

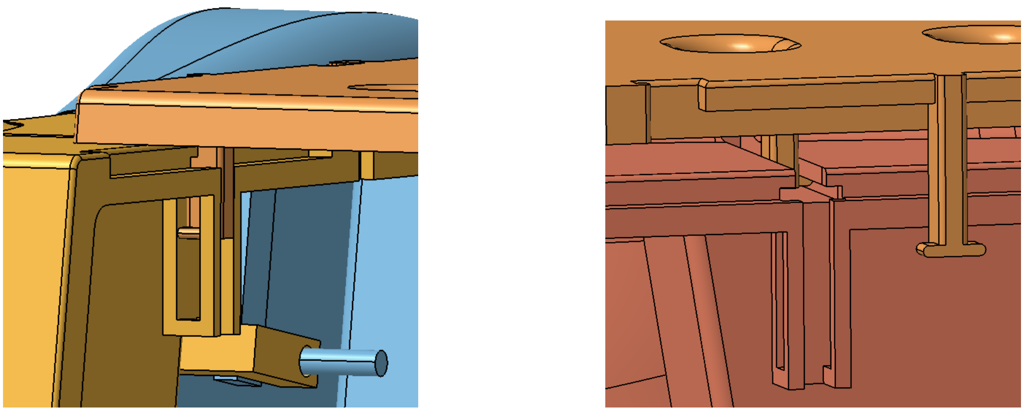

Figure 8.3: *The “vertical rail cage” (left) and the exposed T-shaped slot (right). The plate arms can be observed in both pictures.*

The front parts are connected to the rear parts by an arm with a bushing element on it. There is one arm one on each rear part and fit around an axle on the front part which allow for rotation around a common axis. The axle and bushing which can be seen in Figure 8.4, are symmetrical on both sides of the cushion. With the help of this axis the rear part can rotate around and be hidden inside of the front part as can be seen in Figure 8.5. This process is henceforth denoted as ‘folding’ or ‘to fold’.

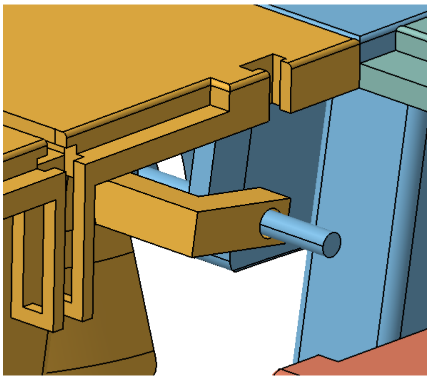

Figure 8.4: *The constructed axle that the rear part rotates around.*

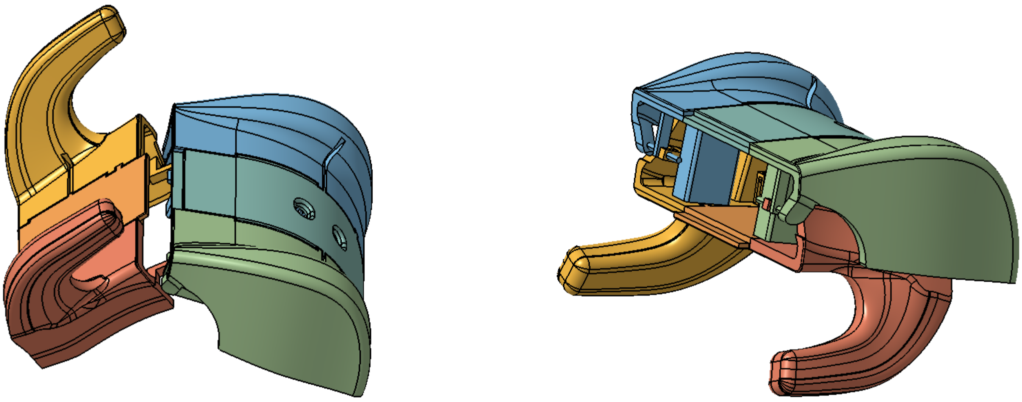

Figure 8.5: *The SaFE folded partially (left) and fully (right).*

These two processes, folding and slotting, can be done in combination in order to minimize the total volume, this is showcased in Figure 8.6. They do not impact each other in any way, meaning that slotting always reduce the volume a certain amount regardless if the folding is used or not. This opens up possibilities and options for the user to choose how much they want to reduce the volume and in what order they want to compress it in. Similarly the deployment process can be done in any order and is just both of the processes done in reverse.

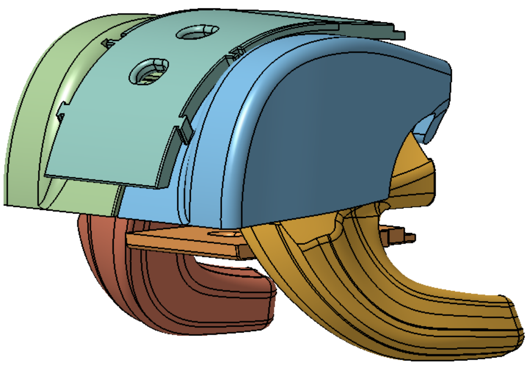

Figure 8.6: *The SaFE booster cushion fully compressed.*

A lot of other details were added to the model, both for prototype purposes, functional purposes and to help support the structure of the model. In Figure 8.7 six patterns with diagonal support elements can be seen. These where added to the cushion in order to bolster its load bearing capabilities. In the same figure four holes can also be observed, these are perpendicular to the direction the middle plates has to be pulled out at and act as a makeshift handle for the prototype. In the final product the plates will be covered by foam and textiles and feature an attached handle.

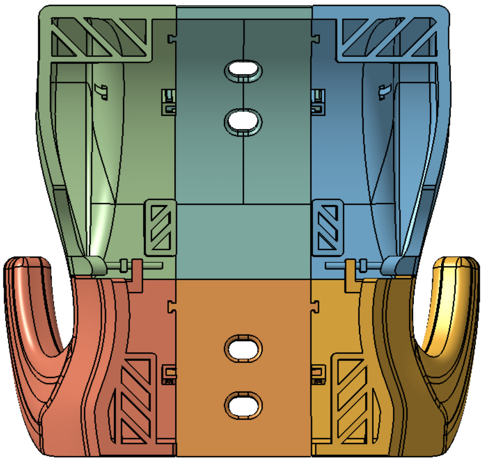

Figure 8.7: *View from below, note the support structures and four holes.*

Finally, in Figure 8.8, several support elements can be seen. The jigsaw puzzle-shaped bits seen on both sides of the orange rear middle plate prohibits horizontal movement and gives a more robust feeling. It also assists in holding the parts together while deployed. There are also some protruding elements on the sides of the middle plates that rests on matching protrusions available on the side components. These assist in making the booster cushion more robust as it transfers load onto a larger area of the side components instead of adding stress to the rail cages As can be seen in the same figure the rear middle plate has an protruding element that rests on the front middle plate. This ensures that while someone sits on the cushion the front middle plate cannot be pulled.

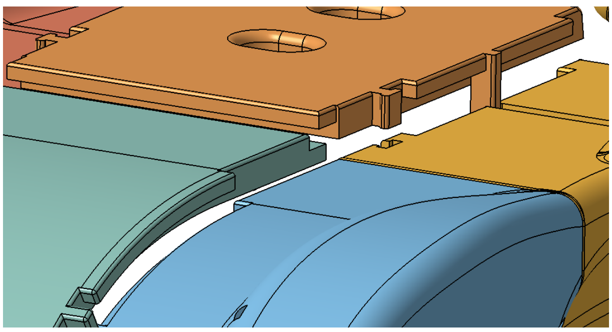

Figure 8.8: *Note the support structure connecting the different parts.*

8.2 AID - Formerly the Tire

AID is the product that is derived from the Tire concepts, the acronym stands for Automatic Inflatable Drop-stitch booster cushion. The product is more on a conceptual level than the SaFE seeing as a potential prototype and product must be produced externally. As thus it is presented in a more conceptual manner since the product is deemed to be plausible, but many details still remain unknown. The front and rear of the cushion are illustrated in Figure 8.9 where three specific parts can be distinguished.

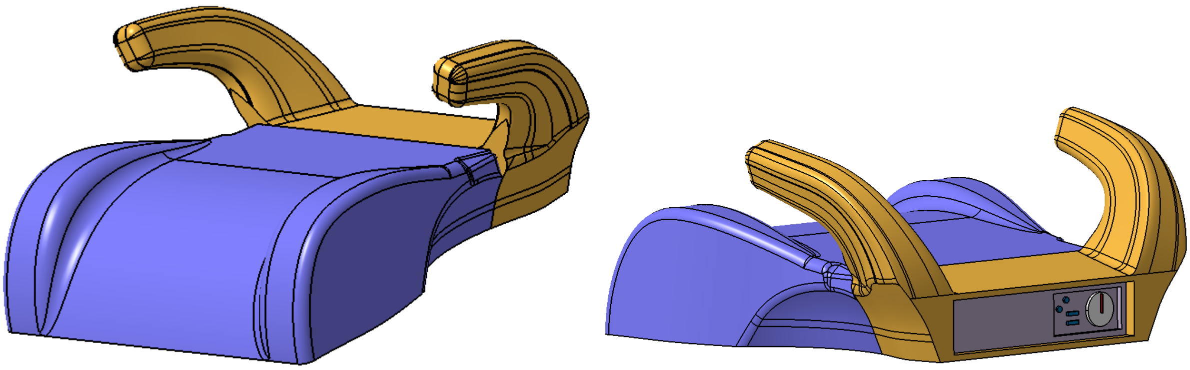

Figure 8.9: *The AID seen from the front (left) and seen from behind (right).*

The blue front part is made out of drop-stitch fabric and is inflatable. The material can sustain high pressure and is also deemed to be tolerant to sharp objects since it is used to construct various water vessels that otherwise would risk to be punctured. When deflated the blue part can be folded and wrapped around the yellow part for easy storage. The yellow part is a solid and encases the automatic pump used to inflate the cushion. It is also connected to the two horns and acts as a solid foundation for them. Depending on which pump is chosen in the end the size may vary but it will be incorporated in the booster cushion as depicted in Figure 8.10. The pump needs to have a pressure gauge to assess the pressure in the cushion, buttons that may be used to inflate, deflate, stop and start the pump with, and finally one or several data connection interfaces that can be used to charge or program the pump with.

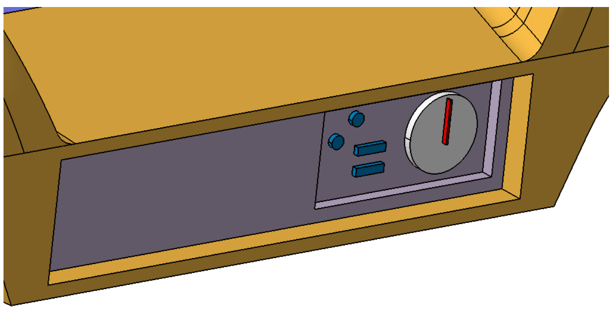

Figure 8.10: *The automatic pump with a control panel can be seen on the back of the AID.*

9

Evaluations and further development

It was decided to improve and make a revision of the SaFE booster cushion after evaluation of the digital model and physical prototype. A static structural FEM analysis was performed that showed high stress areas that needed improvements. A physical prototype was ordered and through observations, several reworks could be done resulting in a revision of the SaFE cushion. Several potential future additions in the form of features were also briefly presented and evaluated.

9.1 Static structural FEM analysis

A digital evaluation was made of the SaFE booster cushion. The analysis was first set up by choosing what data, situation and load case to use. Then the analysis was made of an ordinary booster cushion to both validate that the FEM model would be representative of reality and to have a reference to compare the SaFE booster cushion to.

9.1.1 Data, assumptions and material

Data obtained from a previous dynamic FEM analysis was used in order to get an understanding of what a reasonable load case would be. This previous set of data was obtained from a digital full-frontal rigid barrier crash simulation at 72km/h. In the digital test a Q10 dummy model that weighted 35.5kg was placed on an internal booster cushion model. The cushion model experienced a maximum load at 60 milliseconds into the test with a force normal to the booster cushions surface at 13.4kN, resulting in a z-component of 12.6kN and x-component of 4.7kN. The cushion also deformed 10mm when exposed to these loads. This test was dynamic, and the transferred load depended on the physical behavior of all interacting components, meaning that the cushion was only exposed to this maximum load for some milliseconds.

The test that was chosen to perform on the SaFE booster cushion was a static FEM analysis. In a static structural analysis, the model was subjected to a constant load and thus differ from the dynamic test that was used as a reference. A static structural analysis was performed due to lack of proficiency in dynamic structural FEM analysis and as a result, the load in the static test would not be fully representative of the full behavior in a crash. The model was also made to only have linear deformation and would thus not exhibit a behavior similar to reality when exhibited to internal stresses beyond the materials yield limit, and thus not its tensile strength where the volume or segment would elongate to the point of fracture in a more realistic scenario.

An experienced crash analyst made an estimate of approximately a third of the force may be equivalent in a static test compared to a dynamic one, but there is no way to know for sure without additional comparisons between the two. It was thus decided to use the maximum load measured in the dynamic simulation to see how the cushions would behave in this case. If the SaFE passed this test it would also be able to pass the corresponding dynamic test since the load is static instead of time dependent. The passing mark was chosen to be a maximum deformation of 20 mm in z-direction according to the requirement specification.

A filtered selection was made in the material database CES to decide what materials the cushion could potentially be made of. The following filters were used:

1. A minimum of 20MPa yield strength to sort away the weakest materials.
2. A minimum of 100°C as maximum service temperature.
3. The material needs to be moldable to a high degree.
4. It needs to maintain its durability when exposed to water and be non-toxic.

Several graphs were obtained which visualize these filtered parameters that showcase density on the Y-axis towards other parameters such as Young's modulus, yield strength and price on the X-axis. The graphs can be observed in Appendix K. One material surprisingly excelled over all the other materials, this one material being plywood. It was chosen not to use plywood in the static structural analysis as it is anisotropic and thus harder to analyze since the intended components are curved and thus exhibit a certain difficulty regarding correct application of material parameters. The potential of plywood is however discussed later in Chapter 10.4. The other potential material group was plastics where some thermoplastics had the lowest density while having acceptable stiffness, closely followed by thermoset plastics with higher stiffness but also higher density. The cheapest and least dense plastic was polypropylene, abbreviated PP. PP is also used in some other commercial booster cushions and as was deemed to be a fitting reference material in the digital analysis because of this. PP was set to have the following properties in the test:

1. Young's modulus: 1.3GPa
2. Poisson ratio: 0.41
3. Density: 900kg/m^3
4. Yield strength: 30MPa

9.1.2 FEM analysis of an unmodified booster cushion

Firstly, a FEM analysis was made on the hollowed out base model in order to get an insight on how a conventional booster cushion may behave under high loads. The FEM software used was the generative structural analysis toolbox available in CATIA V5. A mesh was generated from the model, containing parabolic mesh elements with 5mm mesh sizes and a proportional mesh sag factor of 0.2. A clamping (fixed) restraint was applied to the underside of the booster that would contact the seat of the car, and a load was applied to the top surface of the booster, as seen in Figure 9.1. The load had a magnitude of 12.6kN in the Z-direction and 4.7kN in the X-direction. The load was only applied to the surfaces that were expected to be in contact with the user's buttocks, which also results in a higher pressure on the surfaces and a more extreme load case.

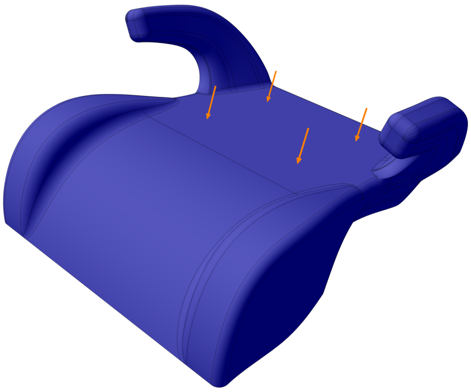

Figure 9.1: *How the load was applied on the traditional booster cushion.*

After the setup the model was computed and analyzed. The results, a representation of Von Mises stress criteria and the deformation can be seen in Figure 9.2 and Figure 9.3 respectively. The model deformed the most in the center of the cushion and suffered a 12.7mm displacement at most. The stress maxima of 43.9MPa was located where the seating area joins the horns and where the seating area joins the back wall. Only the red and orange areas around the maxima had a material stress concentration above 30MPa and thus were the only sections of the model that would suffer from plastic deformation.

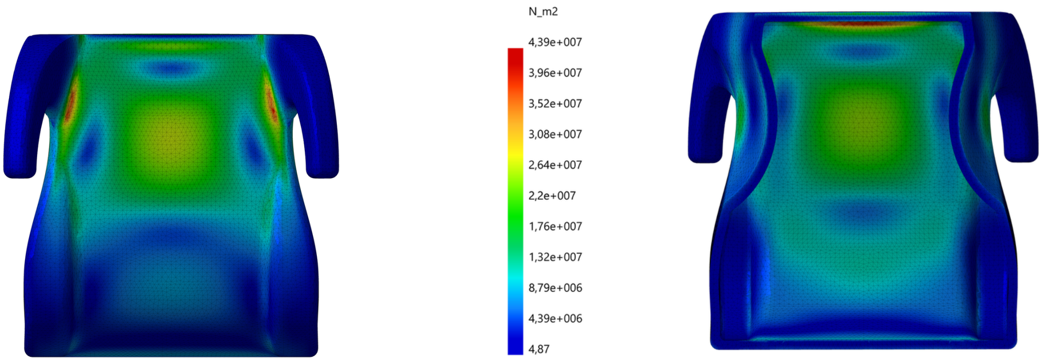

Figure 9.2: *The Von Mises stresses seen from above (left) and from below (right). The red area is 43.9MPa while yellow is where the plastic deformation limit occurs at 30MPa.*

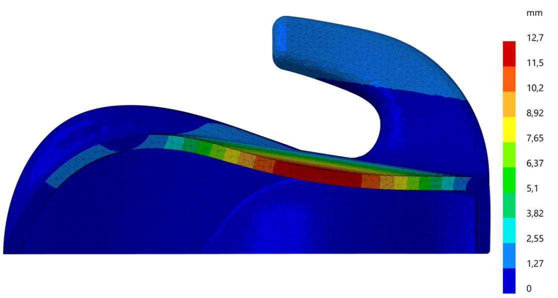

Figure 9.3: *The deformation seen through an intersection of the middle. The red area is the maximum relative deformation of 12.7mm.*

9.1.3 FEM analysis of the SaFE cushion

After the analysis of the conventional booster cushion model, the same mesh, load and restraint configurations were applied on the SaFE model, seen in Figure 9.4. Furthermore, the smooth connection property was applied to all contacting surfaces between the individual parts. This type of connection property allows surfaces to slide on each other while transferring forces and for the surfaces to deform when subjected to loads. This allow for interaction between the parts in a way that is similar to reality. However, no connection property was applied to the surfaces where the middle plates interact with each other since the connection type would not let the plates separate from each other regardless of load.

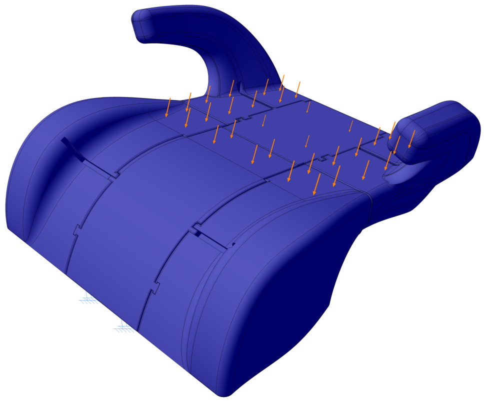

Figure 9.4: *The load distribution on the SaFE booster cushion. The same as previous load case but has a larger number of arrows because of the increased number of surfaces.*

As seen in Figure 9.5, the maximum displacement was 26mm and was located where the front middle plate was the least supported by the surrounding body segments. The rear middle plate did only suffer from 8.2mm displacement which most probably were due to the jigsaw puzzle design elements which then made a smaller segment of the plate unsupported. Apart from the unsupported areas, the plates deformed less than 6mm and the outer segments of the booster deformed less than 3mm.

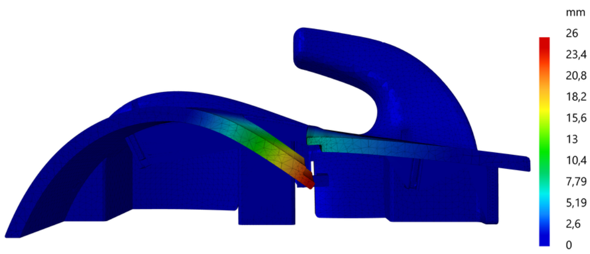

Figure 9.5: *An intersection of the middle of the SaFE. The maximum relative displacement (red) is 26mm.*

When analyzing the Von Mises stress criteria, the maximum stress indicated by the heat map was capped at 50MPa since the value is well above the yield limit of the material. Reducing the range assists in visualizing the different stress areas in the booster cushion that exists beyond the plastic deforming areas. The maximum stress was located in the least supported corners of the rear middle plate, where the stress had reached 713MPa. The heatmap of the Von Mises stress can be seen in Figure 9.6, where the yellow to red colors of the heatmap indicate areas with stresses above the yield limit. Since the strain limit for polypropylene is 47MPa at most and a large area of the components has a higher stress than such, the booster would most probably rapidly deform and collapse. These stress concentrations are located on the unsupported part of the middle plates and would likely show similar behavior and internal stress as the unmodified model if the middle plates would be fully supported on the edges contacting the outer segments.

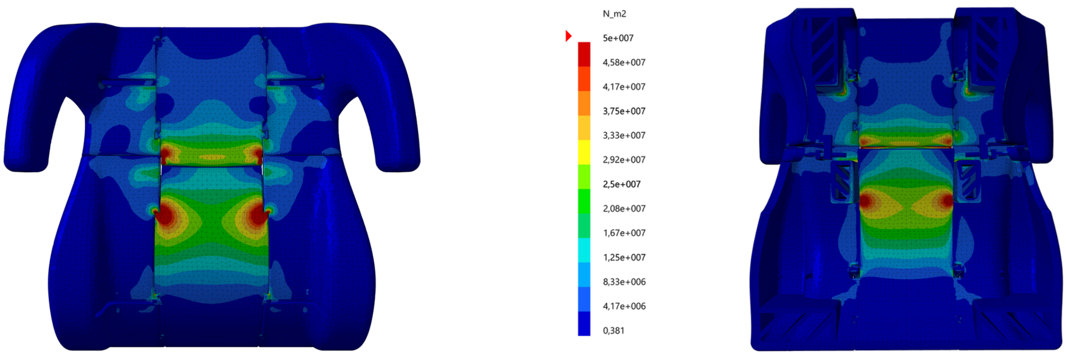

Figure 9.6: *A heatmap of the Von Mises stress seen from above (left) and from below (right). The red and yellow areas are above the yield limit.*

When comparing the heatmaps from both boosters, the most notable difference is both the levels and concentrations of the material stress. As already mentioned, the current design of the middle plates seems to be responsible for the higher stresses, but the design of the support pillars is also a cause. The effect of the support pillars is most noted when comparing what areas of the booster did deform and how much. As seen in Figure 9.7, the outer parts of the booster deformed little to nothing, which indicates that the effect of the outer support elements there may be negligible, so it was decided to remove them for a revision. The displacement in the middle was quite notable and more focus was put on reworking the supporting elements in this region of the booster to better counteract the displacement.

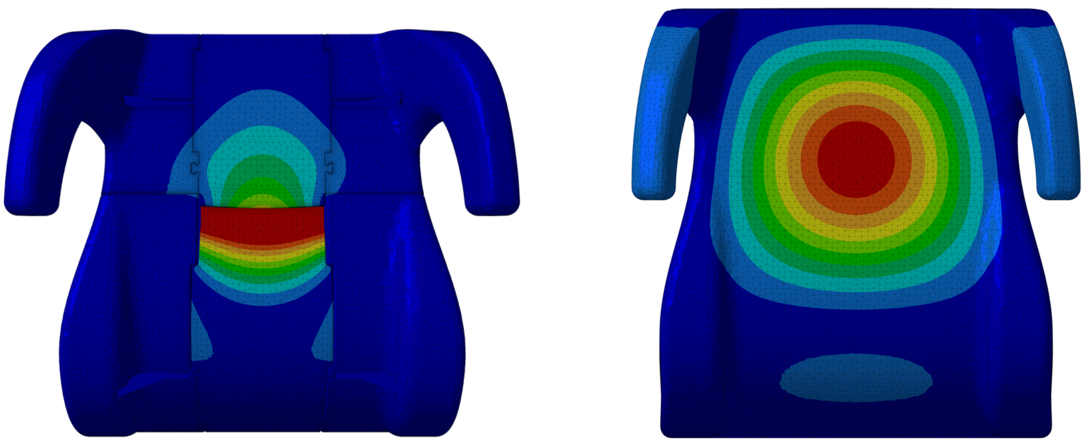

Figure 9.7: *A comparison of maximum deformation areas between the SaFE (left) and a traditional (right) booster cushion.*

9.2 Physical prototype evaluation

All six parts of the model was 3D-printed in 1:1 scale using SLS with PA12 material. The assembled prototype seen in Figure 9.8. A gap of 0.2mm to 0.4mm was introduced between all interacting parts to accommodate for the variation in manufacturing. The original plan was for the model to be evaluated by people not directly involved in the project but due to the prototype having a very loose fit between all parts and time constraints this was replaced with observations with respect to design and a simple test that observed the belt routing.

Figure 9.8: *The printed prototype in its deployed state (left) and compressed state (right).*

9.2.1 Observations

The first most notable observation made in the printed model was how the different part moved a lot more independently than what was expected. This was due in fact to the introduced gaps which became too lenient, but also did not constraint some degrees of freedom of the individual parts. Each part has initially six degrees of freedom, three translational movements and three rotational movements, until they are interlocked with each other, causing the number of degrees of freedom to be reduced when being observed in relation to other parts. The problem is that the parts still have independent small degree of freedom even when interlocked. For example, when the SaFE cushion folds in half it was observed several times how one of the back parts rotated partially independent of each other, forcing the user to grab both sides if they wanted to fold the prototype fully. Another example is that when the side parts have been slid together, they might be misaligned which makes dealing with the mechanism very difficult. See Figure 9.9, for examples of how the misalignment look.

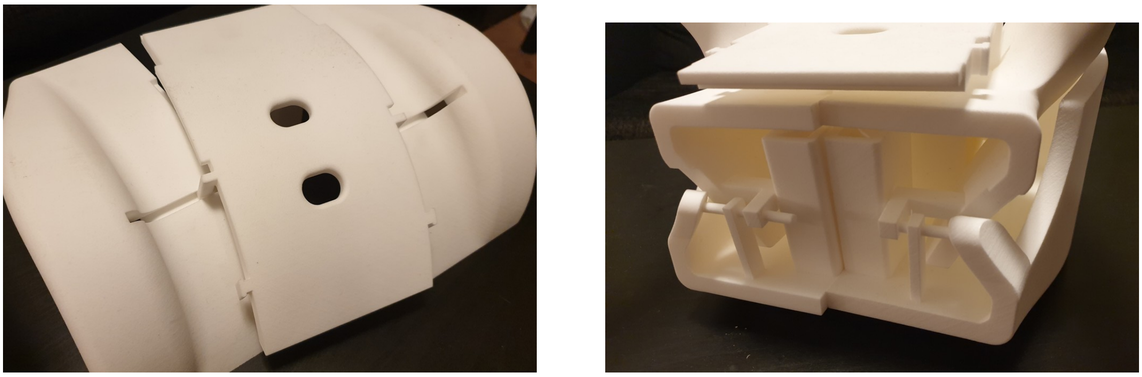

Figure 9.9: *Note how the left- and right-side parts are misaligned causing the middle front part to skew (left) and the axles to be misaligned (right).*

A solution to this observation was to have one central axle which the side parts are connected to. This axis would eliminate translational misalignment between said parts. By introducing two additional axles, one in the rear and one in the front, rotational misalignment between the parts would also be eliminated. The axis on the model broke after a bit of usage so it was decided to use larger hollow cylinders as axes for the next revision.

It was deemed to be difficult to handle the middle parts as the user would have to hold it in place while pushing the outer parts together at the same time, essentially requiring three hands. It was extra difficult with the rear part as the outer parts where unstable due to the heavy weight of the horns. causing them to tip over if not interconnected, see Figure 9.10. It was reasoned that the product could be easier to use by having the parts automatically move together when the middle plate is brought up. The new mechanism that could solve this is further explained in the Chapter 9.4.1.

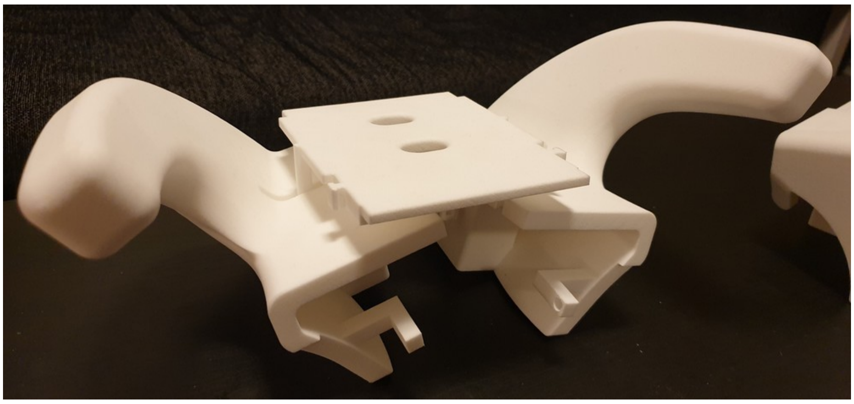

Figure 9.10: *The combination of heavy horns and no common axle caused the side parts to tilt, making compression harder.*

Due to having the T shaped slots open in order to facilitate assembly, combined with the loose tolerances and the stiff mechanism, it was difficult to fully transform the cushion without issues. During the majority of the tests, some parts disconnected, got stuck or the whole process was impaired by some components being misaligned. Therefore, it was decided to not conduct user tests as it would be too difficult for users who are not familiar with the prototype to handle it and would not provide proper feedback on the mechanism.

It was noted that the bottom of the cushion that had surface contact with the car seat may have had too sharp edges and too small surface area to allow forward movement during a collision. As thus it was decided to round off the edges of the front parts and add more contact surface to the cushion. It was also observed that the support pillars in the middle did not have contact with the car seat, making it necessary to rework them as noted in the digital analysis.

9.2.2 Prototype seating test

The prototype was put in a car and both Q10 and Q6 test dummies were seated on it to see how the belt would be placed over the dummies torso when routing the belt over and under the horns. By this time, it was already decided that the SaFE would have to be extended about 45mm height-wise to fully comply with the new UN R129 regulations. Since the prototype did not have this extension yet, a 5cm foam block was added underneath the prototype prior to placement in the car seat.

The test with the Q10 dummy was performed and photos from this test can be seen in Figure 9.11. The shoulder belt becomes more properly placed on the mid shoulder when the belt is routed over the horn. When routed under the horn the belt is placed too far out on the shoulder.

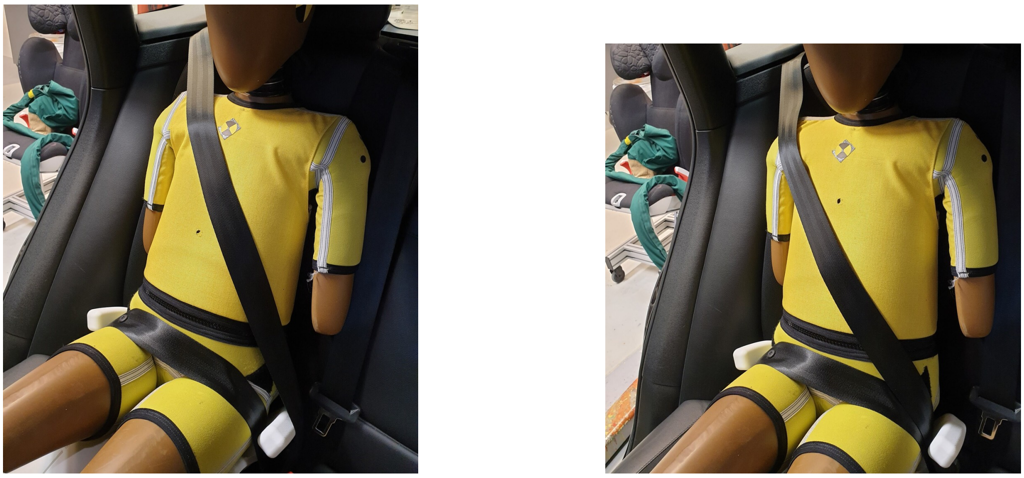

Figure 9.11: *A Q10 dummy placed on a 50mm elevated SaFE prototype with belt routing over the horn (left) and under the horns (right).*

A similar test was done with a Q6 dummy, it was further elevated an additional 5 cm since it was shorter than the lowest stature which the SaFE was dimensioned for, as can be seen in Figure 9.12. The more comfortable routing seems to be the under horn routing since it is placed on the middle of the shoulder. The routing above the horn results in the shoulder belt being closer to the neck, but not close enough to make contact with the neck.

Figure 9.12: *A Q6 dummy placed on a 50mm elevated SaFE prototype with belt routing over the horn (left) and under the horns (right).*

9.3 Cost analysis

A cost analysis was made to get an overview over potential issues that might occur due to manufacturing, material choice or product assembly. Many assumptions were made which may affect the accuracy of the analysis. A more thorough investigation should be made before proper manufacturing is started.

9.3.1 Cost of the SaFE

By analyzing the structure of existing products on the market and analyzing the geometry of the SaFE booster cushion, injection molding was deemed to be a fitting method of production as long as enough units are expected to be manufactured. First a batch size would need to be estimated. Since there were 624 000 children aged 5 to 9 in Sweden [46], it was assumed that one fifth of them were 5 years old, or about 124 800. For the sake of simplicity, it was assumed that only this age group need to transition from the rearwards facing child seat to a frontwards facing one. It was furthermore guessed that only half of them would potentially buy a booster cushion since the other half would utilize their siblings' hand me down boosters or similar, leaving 62 400. Finally, it was estimated that a market share of 15% was realistic with the proper financial backing and marketing, leaving a final production size of about 9 400 units per year.

Since the SaFE booster cushion is divided into six main parts it is necessary to produce all of them separately, which can rapidly increase production cost. If injection molding is used on each part with a production size of 10 000 units per year, this would result in each part costing about 110 SEK to 140 SEK to produce according to data from CES EduPack. This would put the initial production cost at about 660 SEK to 840 SEK (or average 750 SEK) per booster cushion just from the production alone. Totaling in 7 500 000 SEK per year when calculated over the batch size.

The digital model has a volume of $0.003369m^3$. Multiplied with the density of polypropylene, which was chosen as the material for the analysis, this resulted in a weight of 3.1kg per booster cushion. This weight multiplied with the material cost obtained from CES EduPack results in each booster cushion having an additional cost of 38 SEK, resulting in the yearly manufacturing costing 7 880 000 SEK.

A DFA-analysis (Design for Assembly) was made in order to evaluate the cost of assembling the product. The assembly was expected to require 13 steps from loose parts to assembled product. This takes into account the six main parts and eight standard components that is expected to be needed: two threaded rods for the rotating axis, two longer rods for front and back support and four nuts that keep the threaded rods in place. The final cost for the assembly came out to about 4.6 SEK per unit, which adds up to 46 000 SEK with the total batch size.

Summarizing and adding all the costs together result in a total production cost of 7 926 000 SEK. If the final price tag for the product once in store consist of one third production cost, one third profits and one third marketing and administration the end price for the consumer would amount to 2 378 SEK. This is a lot to steeper compared to the products available on the market so it can be reasoned that the calculations are a worst-case scenario, most probably in the estimation of process cost. If all parts could be injection molded at once though it would bring this cost down to 1/6th of the previous mentioned initial production cost of 750 SEK which results in about 125 SEK. This would result in additional labor cost and unknown inaccuracies to the model but setting that aside the total production cost would end up at 168 SEK resulting in a much more reasonable consumer price of 503 SEK.

Another way to estimate the cost is to look at similar products that are on the market. The Graco TurboBooster TakeAlong is similar in many aspects to the SaFE booster cushion. It has a mechanical solution, a similar number of separately produced parts, similar number of standard elements and textile material, a similar weight and a similar form. Given the fact that this can be bought for 480 SEK commercially it would stand to reason that a similar or slightly higher price point could be obtained for the SaFE cushion at around 500 to 600 SEK, which matches the second price point estimation.

9.3.2 Cost of the AID

A cost analysis for the AID-cushion was harder to perform in a similar manner due to the cost behind the drop-stitch production process being harder to obtain than normal production means. It would however be more expensive than current market products just on the basis that it uses an automatic electrical air pump which, when bought separately, cost at least 600 SEK on a consumer level. In a worst-case scenario where the pump must be custom made to fit the cushion, adding the production cost for the solid plastic part and the eventual drop stitch price tag it would not be unreasonable to expect a consumer price point of at least 1 000 to 2 000 SEK.

9.4 Revision of the SaFE booster cushion

It was decided to make a revision of the SaFE booster cushion that would consider findings and conclusions drawn from Chapter 9.1 and Chapter 9.2. This version would spout a new slotting system, revised support structure and mechanically coupled side parts which enables a more robust design. The revision can be seen in Figure 9.13. For more rendered pictures of the SaFE booster cushion see Appendix L.

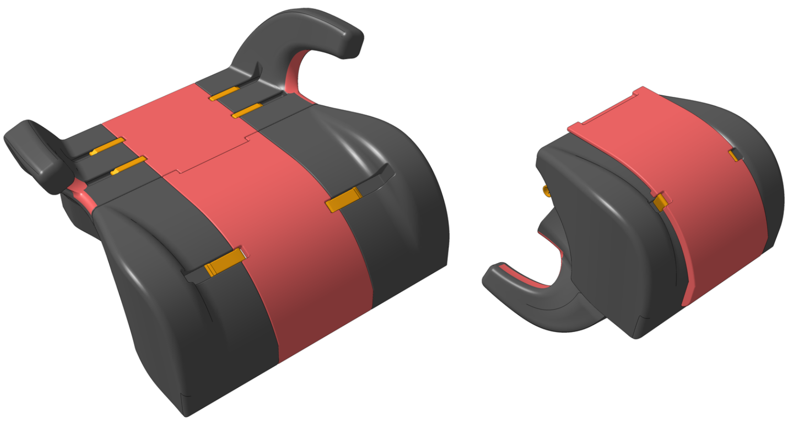

Figure 9.13: *The SaFE revision in its deployed state (left) and in its compressed state (right). The yellow new elements are the reworked plate arms.*

9.4.1 Changes in the revision

As mentioned in Chapter 9.2.2 it was decided to extend the height of the SaFE booster cushion with about 45mm to be able to conform to the new UN R129-regulations for an approved minimum user stature of 125cm. This change was necessary seeing as the original SaFE booster cushion had its form and features modeled from an already existing ECE R44.04 certified booster cushion. The new regulations also included a hip breadth measurement which would require the cushion to be extended over 6cm width-wise to be approved for a maximum user stature of 150cm. As this change probably would impact the way the booster cushion fit into the car seat it was decided to extend with 4cm and to later redesign the horn to be thinner at the base so that the requirement could be passed. This extension allowed for a maximum user stature of 140cm. For a comparison of the new size see Figure 9.14, the size implication is also further discussed in Chapter 10.1. A prototype was also made which arrived close to the completion of the projects, as thus the assessment of this prototype can be found in Appendix M.

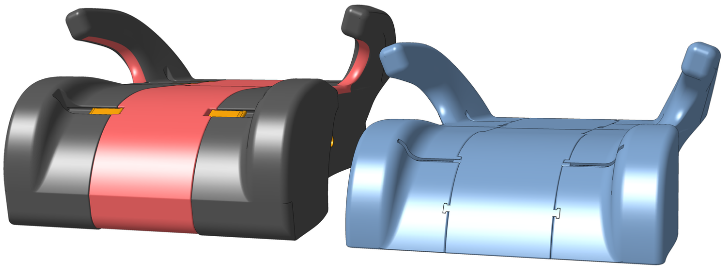

Figure 9.14: *A size comparison between the revised SaFE (left) and the old (right).*

The new size would make the cushion heavier than previously but due to improved support structure it is a little lighter than the previous version weighing in at about 3.08kg. Note that the horns in both designs are solid and contribute a lot to the weight due to this, if they would be as hollow as the rest of the cushion the final weight would be around 2.7kg. Methods and improvements to reduce the weight further are discussed in Chapter 10.4.

Several changes were deemed necessarily to improve the structure, stability and handling of the SaFE. The first of these changes were the implementation of three hollow cylinders or pipes which can be observed in Figure 9.15. The pipes act to limit the number of degrees of freedom each part have. The middle pipe is larger than the previous axle to ensure a stable rotation when the folding is performed while making sure that the front parts are always connected to the rear parts. It is also telescopic in order to reduce in size in conjunction with the rest of the booster. The front shaft in combination with the middle shaft ensure that the left and right parts cannot rotate independently from each other while also making sure the parts can only move sideways, this is similarity true for the rear shaft as well. All the shafts also have end stops implemented which makes sure that the parts cannot be separated from each other.

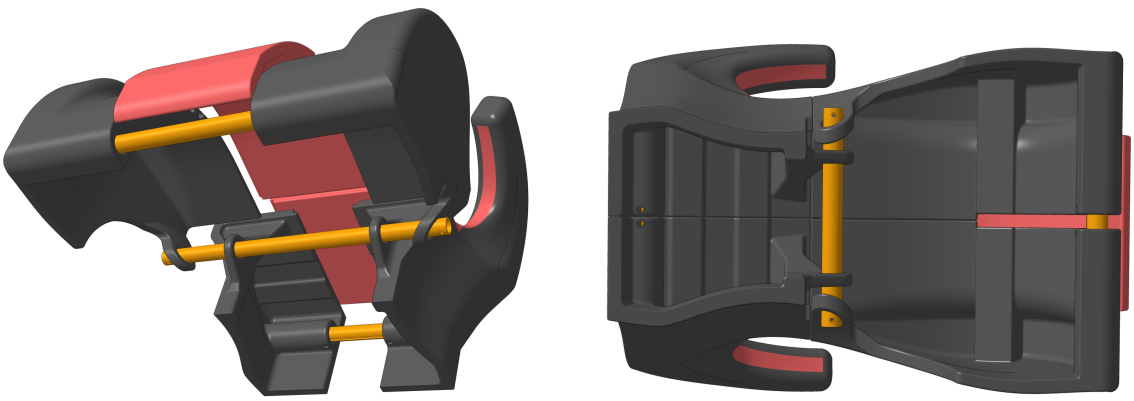

Figure 9.15: *The three pipes used as rotational axes can be seen in yellow (left). Two of the pipes becomes hidden once the side parts are pushed together. (right)*

The old solid vertical plate arms were redesigned to be more flexible. These arms are placed horizontally along the slots in the deployed state as can be seen in Figure 9.16. The arms are connected to the middle plate by joints that can rotate. The other ends of the arms that are connected to side parts does so with joints that can rotate and translate horizontally. There are four small plate arms that connect the back parts, while two wider plate arms connect the front parts. When the middle plates are slightly elevated these arms make it possible to push on the side parts to fulfill the slotting process. The plate arms guide the middle plate to a correct height by a transformation of horizontal force to vertical force by slotting and rotating, a snapshot of this process can be seen in Figure 9.16.

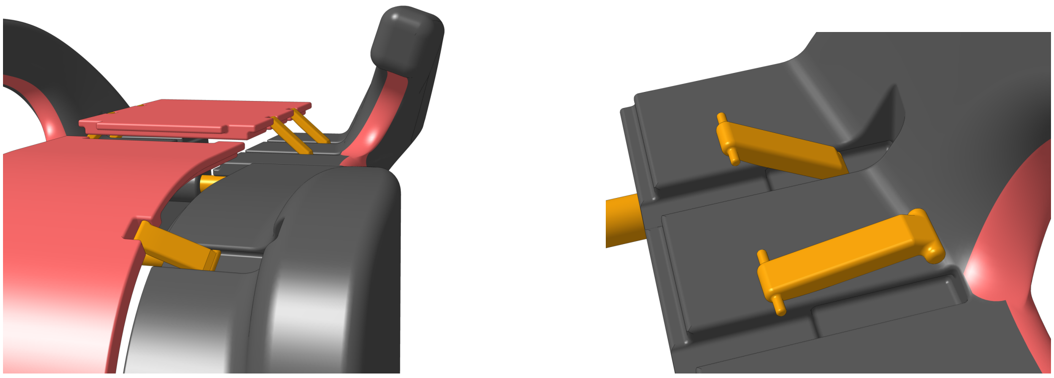

Figure 9.16: *How the plate arms connects the different parts (left) and how they look like (right). Note that one of the plate arms is elevated from its slot to highlight its joint (right).*

Finally, some additional elements were added and removed to improve the safety of the cushion. It was noted that the prototype of the previous version had small contacting surfaces that could potentially sink into the cushion during a collision when in actuality some forward momentum is beneficial in order to properly tension the belt. To ensure this a small extension of the contact surface was made in the front which was rounded off to allow for better sliding as can be seen in Figure 9.17. It was also noted that the support structure did not make contact with the car seat and was deemed unnecessary when judging the results from the FEM analysis. As thus they were redesigned to extend from the side wall which also can be seen in Figure 9.17.

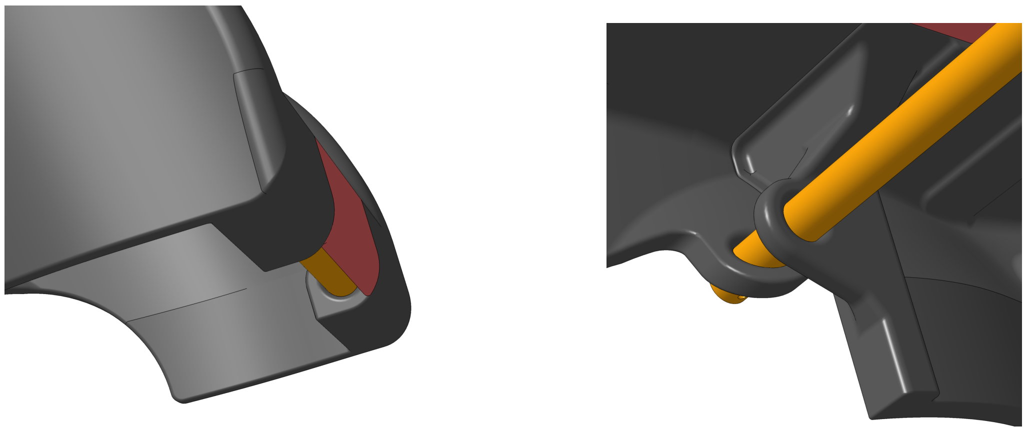

Figure 9.17: *Safety elements, the rounding of the front of the cushion (left) and the support structure that alleviate a lot of the stress from the sitting area (right).*

9.4.2 FEM analysis of the revision

A new FEM analysis was performed which used the same loads and constraints, with the largest difference being a smooth contact constraint between the middle plates. The change was made after a preceding analysis showed that the plates no longer separated during load and that the rear plate otherwise collided into the front plate. The mesh size was changed to 7mm for the rear components and both plates, 8mm for the remaining front components and shafts and lastly 3mm for the plate arms. This allowed for a more effective use of computing resources while still providing a higher resolution mesh where necessary. The force remained the same and was applied to the same surfaces as before but with the addition of the flat surfaces of the top arms as well. As seen in Figure 9.18, the maximum displacement has reduced to 6.22mm compared to the 26 mm displacement of the initial model and 12.7mm displacement of the shelled model, making it the most robust so far. Most of the displacement occurs in the middle plates, as seen in Figure 9.18, which indicates that the plate geometry may be further improved upon.

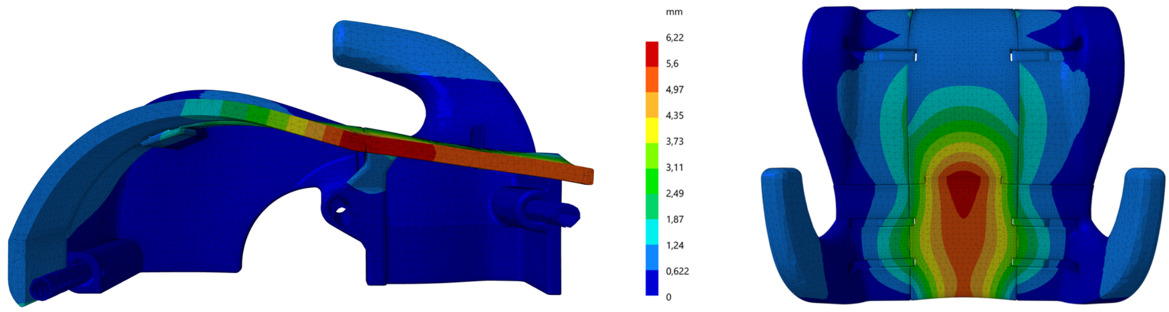

Figure 9.18: *An intersection view of the middle (left) and a view from above (right) of the revised SaFE booster cushion. The maximum relative displacement (red) is 6.22mm.*

The improvement on the internal stress is as notable as the improvement on the displacement, as seen in Figure 9.19, where no visible area on the top side of the booster cushion has a Von Mises stress above the Yield strength. Only small areas on the bottom have an internal stress above the yield strength, and the contact area between the rear plate and rear parts also display an internal stress above the yield strength, as seen in Figure 9.20. These would be the areas to further improve in another revision. Furthermore, the stress maxima were found to be 87MPa in the previously mentioned contact areas, where as the surrounding nodes was had an average stress of around 75MPa. Since the mesh is not perfectly flat and only display the higher stress levels in the mesh nodes that form a line, the force may be more evenly distributed in reality. Since these high stress areas are subjected to a compressive load, their behavior cannot be predicted using the current analysis. A more detailed analysis or a physical test would be needed to gain insight.

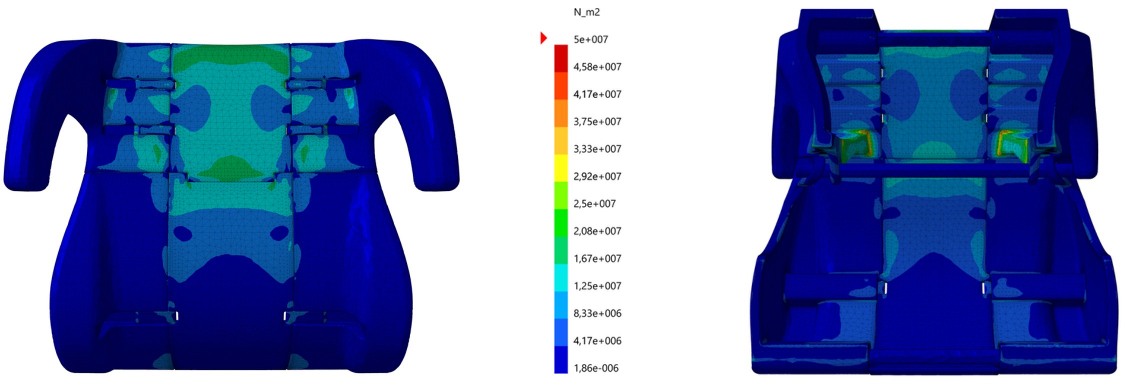

Figure 9.19: *Von Mises stresses of the SaFE with a view from the top (left) and from the bottom (right). Yellow to red is 30MPa to 50MPa and above.*

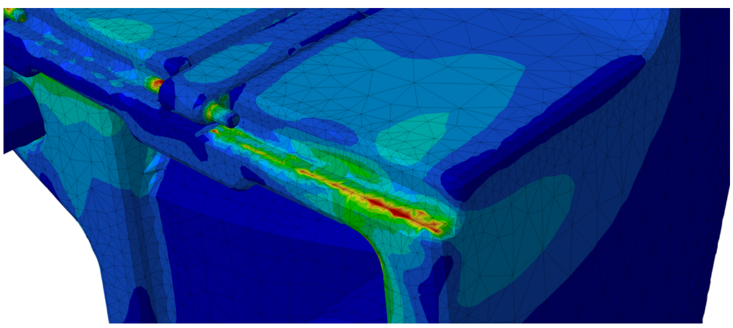

Figure 9.20: *Von Mises stress concentration on the contact area between the rear and middle plate. The red color is material stress above 50MPa, where the peaks measures around 87MPa.*

9.4.3 Fulfillment of requirement specification

The requirement specification aids in maintaining a project at its intended trajectory and also serves as a tool for aiding decision making. It is therefore useful to evaluate how many requirements and wishes have been fulfilled during the project. An evaluation was made on how many instances in the requirement specification was fulfilled by the revised SaFE booster cushion. Out of the previously formulated 23 requirements and 12 wishes, 10 requirements and 2 wishes were fulfilled while 2 wishes were not fulfilled. It was deemed too uncertain if the remaining 13 requirements and 12 wishes were fulfilled. Some did not have the relevant tests conducted and some depended on what future projects involving the products would carry out.

The SaFE product fulfilled its core functions of being able to expand and reduce in volume. While it did not reduce more than the volume wished for, it managed the required volume reduction. It was able to be both reduced and expanded within the required and wished time limits. This test was performed with the prototype when it was evaluated, it was then possible to expand and reduce it in under 10 seconds despite its instabilities. The product was deemed to be possible to operate without prior training but with help of a manual the first time since the mechanism is fairly intuitive and can be mastered at the first try. It is also compliant with the UN R129 standard for users with statures between 125cm and 140cm in regard to seating height and hip breadth.

9.5 Future features to the cushions

During the idea generation phase in Chapter 7.1, several additional features were conceived to be discussed and evaluated after the completion of the booster cushion. Several of these features can be applied to either the SaFE or the AID booster cushion or to the both of them. Chapter 7.8 also brought up additional future aspects such as the questions of upholstery implementation which are properly explored and explained more in this chapter.

9.5.1 Carrying features

This feature was deemed to be more essential to ensure the portability of the booster cushion than volume reduction was but due to the ease of implementing it as a feature it was not the focus of the concept generation. It was decided to include one or two options for the user that would enable them to carry the product better. The different solutions that were previously conceived can be seen in Figure 9.21. The first three, a handle, double strap and single strap is inspired by how certain bags are usually carried. While the last two in inspired in how the cushion could be fastened on a bag or similar.

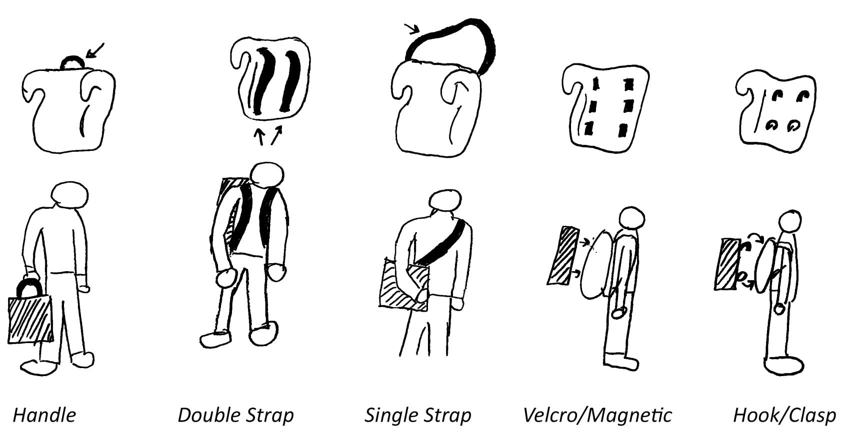

Figure 9.21: *Five different ways the cushion could be carried.*

It was decided that the SaFE booster cushion should mainly utilize a handle as the carrying solution but could also make use of a hook or clasp if need be. The handle would be attached and be part of the textile cover of the front middle plate. This place was decided as it would not disrupt the comfort of the child seeing as both legs would be on each side of it. It was initially suggested that the handle would be placed as depicted in Figure 9.21 but due to the folding mechanism this handle would be inaccessible as it would be covered by the front parts. The clasp or hook if used could be placed inside the cushion in the middle. This would expose the hook for usage when the SaFE cushion is fully compressed and allow for the user to connect it to another bag or similar.

9.5.2 Horn-height adjustment

It was discussed throughout the project what features the horns could have to increase the customer value. The first idea was to allow for different sized children to get correctly placed belt position and belt routing by adjusting the height of the horns. This could be done in several ways and some of the ideas generated is presented in Figure 9.22. These methods were all discussed but great uncertainty remained over how these would fare when structurally loaded or if the mechanism would be too heavy or complicated to fit into the current SaFE or AID booster cushion.

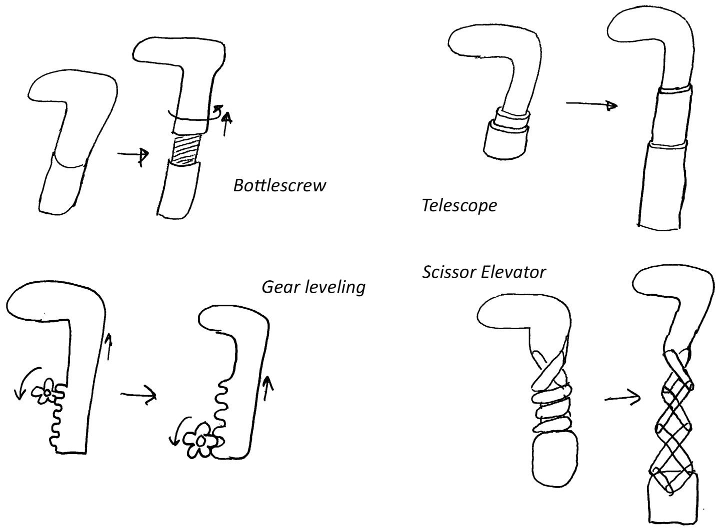

Figure 9.22: *Four different ways to adjust the height of the horns.*

Another idea was if the horns could be twisted or folded out of the way. Such ideas were already present in the Turtle concept and by implementing it in the AID or the SaFE, their bounding box could be decreased further. Right now, the horns protruding from the body makes the SaFE and AID larger than necessary, as can be seen in Figure 9.13. By folding these horns outwards to the side of the booster cushion or inwards to the sitting area, two additional size advantages would be gained. Firstly, it would make the bounding box of the cushion smaller. Secondly, it would allow for further redesigns of the middle plates to make them wider since they would no longer collide with the horns when slotting and thus enabling even greater width reduction. As great as a contribution adjustment to the horns would make, if any of these methods were to be used, they would need to be further evaluated.

9.5.3 Textiles

The textiles of the cushion were briefly touched upon in Chapter 7.8.1. In that chapter it was mentioned that the concept SaFE is based upon can have separate pieces of foam attached to each plate. This still holds true and the product would have to have six separate pieces of foam and textiles, one for each part. For the side part the foam would have to be cut in such a way that it does not interfere with the slots, leaving a space for the middle plates to still slide. The foam and plates would when be covered by six different textile upholstery sections that is fastened to the cushion, enabling the user to remove it should the need arise.

An optimal solution would be to combine the foam and textile to a piece of fabric and then fasten it to the different parts. Two main suggestions seemed the most promising in this category. The first suggestion was to have several small loops that hooks on to pins on the underside of the parts, for an example how this could look see Figure 9.23. A potential downside to this is designing the parts to have small holes for the loops so it can reach the underside.

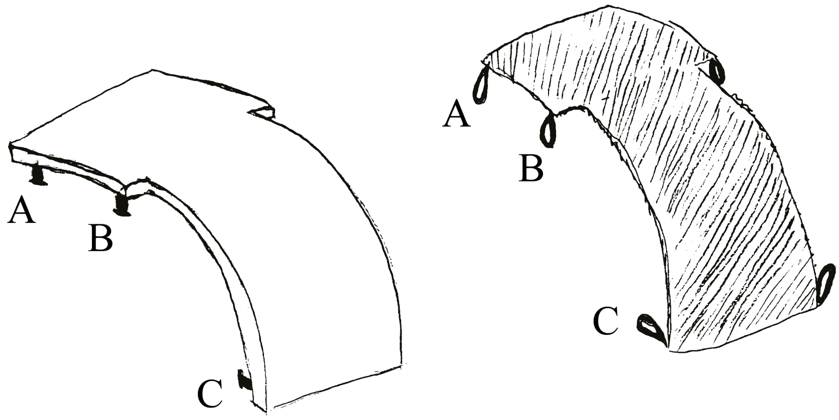

Figure 9.23: *The textile fabric has loops that is fasten to the underside of the cushion parts. The middle front part is used as an example. Each loop is denoted with a matching letter.*

The other suggestion that would be viable is to use a strong Velcro backing so the textile can just be placed and ripped off if need be, see Figure 9.24. A drawback to this might be that the children removes them during a car trip for fun or make them easier to lose which would impact how comfortable the cushion is to sit upon. A test might also have to be made with regards to shearing forces in order to determine how well the upholstery holds up during deceleration. In theory, the Velcro should allow for less movement compared to a traditional upholstery that potentially can partially slide on the booster body before being limited by the geometry.

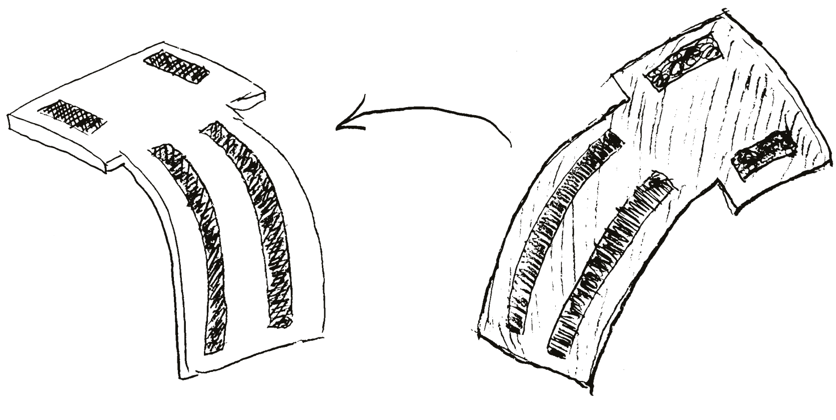

Figure 9.24: *The textile is fastened with Velcro to the cushion part.*

Considering if a handle would be placed on the upholstery as suggested in Chapter 9.5.1, it would be the best to use the loop and hook solution as the force of carrying the booster cushion could separate the Velcro pieces if used. It would also be possible to mix the two solutions for different parts of the SaFE. The AID would be able to employ both fastening solutions, but also use a one-piece upholstery similar to traditional booster cushions since the drop-stitch fabric is not elastic. The upholstery would thus be able to follow the movement of the drop-stitch fabric during deployment, compressing and storage.

9.5.4 Width adjustment feature

During the development phase one of the criteria which the SaFE cushion concept was able to fulfill was that it could be adjustable in width. No such function exists in the current cushion but could be implemented in the future. During the idea generation several ideas were considered that could be implemented depending on the solution of the size changing function. Two of the features generated can work with the SaFE booster cushion.

The first way to implement such a feature is to sell the cushion with differently sized middle plates that the users could use and exchange as they grow older and bigger. The plates are uniform in width so it would only be a matter of altering their width, but all new use cases would need to be structurally validated. The second option would be to make the middle plates somewhat modular in a similar sense. That way the user can remove one or several 'slices' of the middle plate to adjust the width. This would however require a redesign of the middle plates which ensures that the booster cushion is still able to handle the appropriate loads.

9.5.5 Lock-mechanism

The lock mechanism was one of the most situational features idea generated as different concepts could require many different locks or no locks at all. The type of lock needed also depended a lot on the concept and different locks can be used for different purposes on the same product. Over ten potential common and uncommon mechanism were idea generated and evaluated through discussions.

As the AID booster cushion is operated through an interface it only needs a solution that blocks the user from input during usage. This could be implemented with the system itself for the automatic pump. The system lock could go into effect if it detects that the user sits on the cushion, which would hinder potential tampering during a car ride. The interface could also be moved to the bottom of the cushion and thus be blocked by the car seat while the user is sitting on it.

The SaFE booster cushion is thought to need two or three locking mechanisms. The first is an optional magnetic lock for the plate arms which would make them lock in place easier and not flip around all over the place. The lock would make them stay in place when deployed and lock on to the side part when the slotting is finished with similar magnets implemented in the side parts. A similar effect could also be achieved with a friction fit, a spring-loaded hook or a detent. The second lock is to make sure that the cushion stays compressed width-wise. This could be done with small design elements situated on the side parts that clicks together when the side parts touch each other, similar to the earlier mentioned hook or detent. The third locking mechanism is to make sure that the folding stays together. This could also be solved with the methods previously mentioned.

10

Discussion

While there were no major disturbances or changes to the goal of the project, several areas that was originally planned had to be postponed, redesigned or skipped altogether. It is in the nature of product development projects for phases and ideas to be iterated and improved upon until a satisfying result is achieved. The SaFE booster cushion did go through one major revision documented in Chapter 9, but several small improvements were made continuously. As thus since the revision was made, several new ideas for areas of improvements have been made, enough to make a second revision if time were not the limiting factor. This revision is probably for the better however as it was a drastic improvement over the first in every way. If the revision was skipped there would have been more time to develop and incorporate many of the features discussed in Chapter 9.5. The SaFE would be closer to completion, however it would be less robust and much more difficult to use without the revision. The decision to not peruse the development of the AID more than what was done was most probably an optimal choice as more time could be dedicated to make the foundation of the SaFE as good as possible. With that said there is always room for improvements for both products with future recommendations. There are also several topics presented in the report that warrants a further discussion as it will have an effect on the project, its result and its future.

10.1 The consequence of UN R129

During the project it was highlighted that the size of the booster cushions approved under ECE R44.04 which the SaFE booster cushion was originally modeled after, was too small to be approved under the new UN R129 regulation. When this came to light, the SaFE was elevated by 45mm and widened by 4cm to be able to get an approval for use by children with a stature between 125cm and 140cm. However, to get approval for use by children with a stature of up to 150cm the booster cushion would have to be widened additionally by around 2cm. It was decided against making the SaFE wider since the same effect could be achieved by thinning and redesigning the horns instead. The horns already had to be redesign in order to get a correct belt routing, this is discussed further in Chapter 10.4.

The aftermath of the transition to UN R129 will thus mean that future booster cushions will on average be larger in both width and height and as a result take up a larger amount of space due to increased volume. A direct consequence is an increased average weight if the materials used in production are kept the same. An increase in both weight and volume will result in vastly more bulky products with less portability than previous ECE R44.04 approved boosters. This is on one hand good for the SaFE booster cushion as it will be a more portable product and thus have a bigger advantage than other traditional booster cushions approved under UN R129. On the other hand, it must still compete with the smaller, lighter and in some case more portable ECE R44.04 approved booster cushions which will be sold on the market for the foreseeable future.

From a customer point of view this situation is mostly disadvantageous. While UN R129 is great for improved safety it indirectly affects many of the customer needs negatively in relation to portability. What more is that they now have to choose between maximizing portability in a smaller ECE R44.04 booster cushion or increased safety in an UN R129 approved booster cushion. This will be the case if ECE R44.04 booster cushions are still allowed to be sold on the market. During that time the SaFE cushion will offer a middle ground between portability and safety.

10.2 Possible sources of error

There are several possible sources of errors that may have led to skewed results and misleading conclusions along the way. By being transparent about these potential sources, it makes it possible to rectify these deviations and for future contributors to make a more objective perspective over the authors mindset and point of view.

While the interviewees could be considered diverse in their way of life it is unclear if they represented the intended demographic of people who purchase booster cushions. It could be argued that more interviews would have been more beneficial in in order to gain further insights to what customers may value in the product. A focus group interview was also attempted and planned but, in the end, no one showed up. One interview also got canceled due to the CoVID-19 pandemic starting in early March, more of this in Chapter 10.3. The online survey made up a lot for what was potentially missed with more interviews and contributed a great lot to the final products. It can also be argued that several of the answers received can be affected by unknown circumstances in the participants preconceptions or way of living. An example of this is that car sharing is still a relatively new phenomenon, which means that the user base is relatively small. The surveyed and interviewed users who had no experience of car sharing may have had a different ideas about how far they have to walk to the rented car, and thus have prioritized differently compared to how they actually would have. Another circumstance that might have affected the conclusion is that close to all respondents were women and only around half actually owned a booster cushion, and women might have different priorities and value different things than men.

When it comes to the concept generation phase with idea generation, concept crossbreeding and evaluation the main flaw was the team's manpower. Two people with a relatively similar background may risk agreeing too much and value the same thing which potentially could lead to viable concepts being overlooked. This was however recognized early which is why outside help was utilized in a way that did not expose any crucial information. The realization of being biased also helped the authors to be more selective and critical of their ideas. While there were some "darling" concepts during this phase these shifted a lot during evaluations.

The evaluation of the SaFE booster cushion used a static structural FEM analysis when a dynamic simulation would have been more optimal. This is due to the fact of the authors had no opportunity to conduct dynamic simulations, but had proficiency in static analysis. As explained in Chapter 9.1.1. an overestimation of the expected load was chosen for evaluation in order to be on the safe side. The load was also applied to the full sitting area of the model while it would be more accurate to only apply load where the user's bone structure contacts the booster seat. With these sources of error in mind, a dynamic test with a safety margin would be preferable as it would give a more realistic representation of its physical behavior.

10.3 CoVID-19 effects

The project was performed in the spring of 2020, during which the global CoVID-19 pandemic started. As a result, society adapted to work more from home, people became more socially distant and more emphasis was put on maintaining hygiene. While the authors managed to stay clear of the virus the working conditions and results were in part affected.

Due to the change in working conditions, most of the work was done in facilities belonging to Chalmers University of Technology. This meant that discussion and consultation with people from Volvo Cars became less frequent, and sparse which indirectly affected the final products since a lot of valuable inputs never came to fruition. One of the planned interviews was also cancelled due to delays prior to the pandemic. Fortunately most of the planned interviews were already done by early March.

It is worth noting that the virus could have lasting implications for the problem area in which this project is based upon. Since people became less prone to travel and visit others it stands to reason that car riding has decreased as well. It would also be logical to think that car sharing may have been more affected than ordinary car ownership since people would be more wary of shared spaces due to the spread of disease. If this stigma is long-lasting it could affect the growth of the car sharing market and in turn affect a portion of the consumer base the SaFE and AID booster cushions was created for.

10.4 Future development

For the SaFE booster cushion the most critical next step is to redesign the horns to potentially do four things. The first action is to make the inner facing side of each horn about 10mm thinner to get the booster cushion approved for use for children with a stature up to 150cm as opposed to 140cm which it is the currently aimed approval. The second step is to thin the horns on the outer side to reduce the weight of the booster cushion as well as making it fit better inside the front when it folds. The third thing is to design the horns in a way that make belt routing optimal for all possible statures between 125cm and 150cm. The fourth and final development step with the horn is too properly evaluate the additional horn features presented in Chapter 9.5.2. Improved design of the horns could greatly increase the customer value as the beltfit can can be improved. Also, if the horns can be folded or moved out of the way it would decrease the bounding box volume which would increase the storage options.

The next step would be to further enhance the models structural integrity by making dynamic FEM analyses. While the static analysis made in this report prove that the cushion can handle the extreme loads received during a collision, a dynamic simulation would still be preferable in order to gain valuable information on the booster's behavior. These dynamic test also includes looking at other forms of collisions and load cases that might occur, such as a side-collision or when the load is unevenly distributed on the cushion. It is also recommended to perform a fatigue test on the cushion which subjects it to a simulated cyclic load corresponding to a user sitting on it repeatedly. The purpose of this test is to see if there is a risk of any fatigue cracks developing over time which may impact the function of the mechanism. Both tests can also be valuable in optimization of the cushion with regards to weight, stiffness and crash performance.

The current cushion is most probably heavier than necessary since it is dimensioned for a higher load case than needed and the design can be redesigned in order to achieve a stiffer geometry. This could strengthen the individual parts while at the same time make them thinner and still perform as well when handling high loads. Such design elements could be ridges that covers the underside of the cushion, it would however require an expertise to know where and how to place these. By introducing these support elements and thinning the shell of the cushion it should be possible to achieve a weight of under 2kg for the SaFE booster cushion while still being approved under the UN R129 regulations.

The weight can be further affected by evaluating material choice. In Chapter 9.1.1 plywood was briefly mentioned for its superior properties over other materials in certain key areas. It was not evaluated because of its anisotropic nature but could potentially be a material that could work for the SaFE booster cushion. However, there is no known precedent of a booster cushion or booster seat using plywood as material so it would have to be thoroughly researched before application. Another idea is to make the different parts out of different materials to make the most use of each material property in order to boost part performance.

The SaFE would also need to go through several user test to see eventual behaviors not taken into account when designing. One of these test would be a proper ergonomic evaluation together with users in order to test the comfort when sitting and how well the belt fits. By knowing this, eventual readjustment could take place to make the cushion more appealing. Likewise, an evaluation of the risk of jamming or pinching when operating the mechanism would be beneficial for the user's safety with succeeding implementation of protective covers.

The AID booster cushion would likewise require further testing and evaluation with the first step being an in depth dynamic FEM analysis to determine how the cushion behaves and how much it deforms during a crash. In theory, the high internal pressure in combination with the drop stitch material should allow for minimal deformation in any direction, but it is not known how the cushion would perform in a scenario where it is not fully inflated. In such scenario, there is a risk that the top surface of the cushion moves forward while the bottom surface is static until restrained by the drop stitch. In the same scenario, there is also a risk that the booster deforms more than allowed. In order to prevent this form of misuse, the pump could have an internal pressure sensor in order to maintain the correct pressure and warn the users if a pressure drop should occur. After the digital evaluation has been made, the development of a prototype is recommended in order to get an estimate on inflation time, comfort and user opinions. Due to the unique nature of the components and length of time this would require it is possible this could be suitable for a future master thesis. The project would perhaps be suitable for a textile engineer or someone experienced working with inflation and electrical pumps. The project would also benefit from a cooperation together with a drop stitch manufacturer since the material itself has niched usage and thus scarce documentation on its physical properties and behavior.

Both concepts feature horns which can guide the belt in 3 different ways depending on what parts of the belt are routed over or under the horn. This design can be deemed to be a better fit for the ECE R44.04 regulations where more than one intended belt path is allowed. Since UN R129 only allows for one intended belt path, the design of the horns could be re-evaluated in terms of belt routing for all intended users, potential misuse and ease of use.

11

Conclusions

The aim of this project was to develop one or several booster cushions suitable for a shared mobility future. The SaFE and the AID was conceived with this aim in mind, with the SaFE receiving a revision to make it even more suitable. What the concept of shared mobility future entailed is that the had to be easy to carry around. Beside this there were also aims at making the cushion easy to use, make sure the cushion can protect the child and provide user and customer value.

When the term easy to carry was interpreted from interviews and surveys it was concluded that the aspects of carrying solution, volume and weight were to be prioritized in that order. While volume was the primary focus during development, the carrying solution was deemed to be an addition that would be easy to add later. This aim can be considered fulfilled as the volume reduction makes it easier to carry, but future additions to the cushions will improve it further. The weight is also considered in the end and future recommendations over how to decrease weight is given.

The easy to use criterion was interwoven within the selection process of the concepts. This factor was also improved upon with the revision as the mechanism was reworked due to the first mechanism being difficult to handle. While the SaFE is not as easy to use as it could be there are clear areas and recommendations for how to achieve this.

When it comes to aspects pertaining to customer and user value, several things have been implemented that would increase value. However, there are still unaddressed features left on the customer needs list that could be implemented to add further value, and some of these have been recommended as part of further development. A possible source of error here however is the user insights that were used to define the value have mostly been sourced from users that could loosely fit the intended target group. By using this input as the primary guide in the development process there is a potential risk of missing or not meeting all the demands and wishes of the actual users.

The final aim of having a protective booster cushion can also be partially fulfilled. While not all sorts of tests have been performed, a static FEM analysis has been made on the SaFE and it is constructed to meet the new UN R129 regulations. It is probably more robust than necessary and optimization can be done to the strength and weight while still having the same protective abilities. Ideally more dynamic tests should also be performed.

While all of the aspects of the aim can be considered fulfilled to a degree, there is room for improvements in all of them as well. These improvements are documented in the report and will lead to booster cushions that are more suitable for a future in shared mobility.

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A

Anthropometry

The anthropometric data like length or weight for humans is distributed normally and large populations varies greatly by age and by country. In Table A.1 average anthropometric data for length and weight of children from Sweden, the United States, and China is presented. The data is interpreted from growth charts from the various countries and are rounded to whole centimeters for lengths and in fifths of a kilogram for weight. Note that the data from the different countries are from surveys conducted during 1999, 2000 and 2005 respectively. [47]

Table A.1: *Average length and weight for boys and girls from Sweden (SWE), The United States (USA) and China (CHN). The data is interpreted from growths charts published between 1999-2005 and may differ a small amount due to accuracy of graphs, interpretation and rounding. [48, 49, 50]*

Group	Boys						Girls					
Unit	Length (cm)			Weight (kg)			Length (cm)			Weight (kg)		
Age	*SWE*	*USA*	*CHN*	*SWE*	*USA*	*CHN*	*SWE*	*USA*	*CHN*	*SWE*	*USA*	*CHN*
4	104	102	104	17.4	16.2	16.6	104	101	103	17	15.8	16.2
5	111	109	111	19.6	18.4	19	111	108	110	19.2	18	18.3
6	118	115	118	21.8	20.6	21.3	118	115	117	21.4	20.2	20.4
7	125	122	124	24	23	24.1	122	122	123	24.8	22.8	22.6
8	131	128	130	26.6	25.6	27.3	129	128	129	26.6	25.6	25.3
9	136	133	135	29.6	28.4	30.5	135	133	134	29.8	29	28.2
10	141	139	140	33.2	32	33.7	141	138	140	33.4	33	31.8
11	146	143	145	37	36	37.7	147	144	147	37.4	37.4	36.1
12	152	149	152	41.4	40.4	42.5	154	151	152	42	41.6	40.8

The average height for children does not differ by much when looking across Sweden, China and the United States, as boys and girls all follow a similar trend up until the lower teens. The average weight increments are also similar for both genders across all countries. There are some notable differences such as the US heights being lower in average in all ages, but this may also be due to the way the data was analyzed. This data can thus be interpreted as no major regional differences needed in booster cushion design in order to accommodate for anatomical differences when it comes to region or nationality.

B

Personas

Personas is a method to describe a set of end users through a fictional synthesized person that share characteristics, goals, ambitions, behaviors and attitudes with the end users and customers. By using these personas, it is easier to imagine them using the product, to see their need and obstacles that needs to be averted. It also depersonalizes the product and help to see things more objectively. The two personas are described in Chapter B.1 and B.2 and an AI generated photo of them can be seen in Figure B.1.

Figure B.1: *The two personas, Yi Yang (left) and Kenneth Karlsson (right).*

B.1 Persona: Yi Yang

Age: 31
City: Gothenburg
Education: University (Mechatronics)
Status: Married
Occupation: Software developer

Biography: Yi is a software developer living in central Gothenburg. Together with her husband, Yogi, she owns a small software company that develops software that enhances self-driving cars. The two of them have three kids, two sons, 6 and 11 years old, and one daughter, 5 years old. Yi sees herself as a frontrunner when it comes to sustainable living, choosing to have no car herself, buying ecological products and supporting local businesses as best she can. Her lifestyle causes her to have a troubled relationship with her relatives. Her grandparents live in China, resulting in few visits as Yi wants to fly as seldom as possible and they are unable to fly due to age. Her parents live in Mora which also causes discord as Yi and Yogi does not have a car themselves, thus having to rely on trains and buses.

Goals

- Be a sustainable role model to their kids.

- Take her company to new industry heights.
- Start working out more.

Likes: Sustainability, family, soup, to grill, smart technology, skiing.
Dislikes: Flying, rain, crowds, hypocrites, aging.
Skills: Knows several programming languages, fast runner, problem-solver.

Scenario: Yi and her family are planning a two weeks ski-trip to different resorts that also will include a visit to her parents. As they do not have a car, they plan to rent one through a newly established car sharing fleet that their company have worked closely with. By traveling with a car pool car, they will have to carry around a lot of luggage around including the booster cushions that two of their kids utilize as the car will be used by someone else after their journey. This is bothersome seeing as they will have to switch cars multiple times during their trip.

B.2 Persona: Kenneth Karlsson

Age: 38
City: Kalmar
Education: High school (Music)
Status: Single (Previously married)
Occupation: Manager at a supermarket

Biography: Kenneth is a divorced middle-aged man living in a midsized house in the outskirts of Kalmar. He works in the nearby local supermarket and makes enough money to live comfortably. He has worked here for 11 years and his colleagues are some of his best friends that he regularly spends time with. His ex-wife, Karin, lives on the other end of the town, a 20-minute drive away and together they have two daughters, Klara and Kristin, aged 7 and 10. The daughters alternates between living with each parent every second week and Kenneth enjoys and values his times with them greatly. When alone he likes to work on his garden which is a never-ending hobby needing care and new supplies as new ideas and subprojects pops up.

Goals:

- Spending as much time as possible with friends and daughters.
- Finish his garden project and other unfinished projects, such as finally learning Finnish.
- Would like to take a car trip to Finland during the summer.

Likes: Stability, flowers, his daughters, colleagues, comfort, metal music, Finland, cooking.
Dislikes: Chaos, winter, ex-wife, mushrooms, others' unruly kids.
Skills: Good with animals and greenery, tech-savvy, handy, logical.

Scenario: Each week Kenneth must drive his daughters to the other side of the town to leave or pick them up at their school. His daughters have booster cushions that secure them properly in the car and once a week he must remove the cushions and the daughters must keep the booster cushions throughout the school day as they need them when their mom comes to get them. The bulkiness of the cushions makes it difficult to properly store and their daughters may be ashamed of carrying them around. Kenneth is also usually the designated driver when he is with friends and he must put the cushions in the back of the car to make space. Because of these things he handles the cushion a lot and he would like a solution to deal with their bulkiness.

C

Interview Questions

Questions mainly primarily directed towards children.

- How often do you travel by car? (How many times a week and on what days)
  - Are the trips short or long? What is the destination? (School, shopping, sports)
  - Who is the driver? (Mom/Dad, grandparents, others)
  - Do you use a booster cushion on all trips? (Difference between short and long trips)
- Is the cushion always in the car?
  - When the cushion is elsewhere, who puts it in the car? (The child or the adults)
  - Do you secure the belt yourselves? (Possible demonstration)
- How does your booster look like? (Color, form, softness)
  - What is good about sitting on it?
  - What is bad with sitting on it?
- Have you ever traveled without a booster cushion? (When)
  - What is good about not sitting on a booster?
  - What is bad about not sitting on a booster?
- What do you think about this cushion compared to your own? (Showcase brought cushion)
  - What do you like about it? What do you not like about it? (Comfort, color, form etc.)
- If you could choose, would you like to travel without a cushion? (Figure out why)
- Do you know why you use a booster cushion? (Get their image of what a cushion does)
- How would you like it to look? (Illustration if possible)
  - Ask about color, form weight, comfort, support, features.

Questions directed towards adults, ask some of the questions above as well.

- Any additions to the questions the children received?
- What is the brand of the used cushion?
  - Did you look at any test or review before choosing this booster cushion?
  - What made you choose this specific cushion? (Children influence, features?)
- Do you have several cars?
  - Does the cushion move between the cars? (How often and why)
- Do you move the booster cushion around in the car? (Between seats or to the trunk)
- What do you think work well with the booster cushion?
- What do you think works less well? (Problems with misuse?)
- Do you always check if the cushion and belt are correctly placed?
- If you were to utilize a car sharing service with the children would you use your current booster cushion? Or would there be some problems with that?
- If you could decide how the booster cushion would look like, with no limits, what would you like?
- How is the booster cushion stored today?
- Would you consider renting a booster cushion? (From who)
- Would you consider lending a booster cushion? (From who)
- Would you consider buying a booster cushion second-hand? (From who)
- How did it feel to use the booster cushion the first time? (Uncertainty with something)
- Do you think it feels safe?
  - Why do you think it feels safe/does not feel safe?

D

Survey Questions

1. What is your gender?
   - Female
   - Male
   - Non-binary
   - Other
2. Where do you live?
   - Medium to large city, at least 200 000 inhabitants
   - Large town, at least 50 000
   - Town, at least 15 000
   - Small town, less than 15 000
3. What type of residence do you live in?
   - A house
   - An apartment
   - Other
4. Do you own a car?
   - Yes, more than two
   - Yes, two
   - Yes, one
   - No
   - No, but I use car sharing when needed
5. Do you have children?
   - Yes, more than three

- Yes, three
- Yes, two
- Yes, one
- No

6. How old is your child or children?
    - Child 1
        - 0-1 years
        - 1-4 years
        - 5-11 years
        - 12-18 years
        - 18+ years
    - Child 2
        - 0-1 years
        - 1-4 years
        - 5-11 years
        - 12-18 years
        - 18+ years
    - Child 3
        - 0-1 years
        - 1-4 years
        - 5-11 years
        - 12-18 years
        - 18+ years
    - Child 4
        - 0-1 years
        - 1-4 years
        - 5-11 years
        - 12-18 years
        - 18+ years

- Child 5
    - 0-1 years
    - 1-4 years
    - 5-11 years
    - 12-18 years
    - 18+ years
- Child 6
    - 0-1 years
    - 1-4 years
    - 5-11 years
    - 12-18 years
    - 18+ years

7. What other kinds of child restraint devices does your children use?
    - Baby protection
    - Rear facing child seat
    - Forward facing booster seat with
    - None of my children longer use any child restraint device
    - Other (Please specify on the free text field)
8. What brand or model is your child restraint device?
9. What made you choose this/these specific product(s)?
10. Does any of your children use a booster cushion without backrest? (An example picture is shown)
    - Yes
    - No
11. Check the boxes of all statements that correspond to you or your children's opinions/experiences with a booster cushion
    - It is heavy to carry
    - It is hard to carry due to not having a good carrying handle
    - It takes up much space in the car
    - It is hard to place in the car

- It is complicated to know how to place the belt
- My children find it to be uncomfortable
- My children find it childish
- My children does not sit correctly in it
- Other
- Nothing

12. Is there anything else that you or your child find annoying or difficult with the booster cushion that was not mentioned above?
13. If you would sell your car and completely switch over to borrowing a car or utilizing rental services, car pooling, car sharing services or similar: What issues do you see with using a booster cushion in such setting?
14. Would you consider buying a second hand/used booster cushion?
    - Yes
    - Yes, from friends or family
    - No
15. Would you consider borrowing a booster cushion?
    - Yes
    - Yes, from friends or family
    - No
16. Would you consider renting a booster cushion?
    - Yes
    - No
17. If you have at any point not used a booster cushion for your child, what was the reason for it?
    - It was a short trip
    - The ride was with someone else's car, was nothing available
    - Had multiple children in the car and there was not enough booster cushions available
    - The child did not want to use the booster cushion
    - Taxi ride, nothing available
    - The booster cushion was lost

- The booster cushion was placed in another car that was not available
- Forgot it at home
- Other (please specify below)

18. Please elaborate your answer to the question above. What would have been a good solution to avoid the situation mentioned in the previous question?
19. How many times per week does the children go for shorter car rides (<20 minutes)?
    - 0
    - 1-5
    - 6-10
    - 11-15
    - 16-20
    - 21+
20. How many times per week does the children go for longer car rides (>20 minutes)?
    - 0
    - 1-5
    - 6-10
    - 11-15
    - 16-20
    - 21+
21. What activities does the children partake in when they ride in the car (Talking, watching movies, using a smartphone, reading, or other things)?
22. How often does the booster cushion need to be taken in and out of the car?
    - Every day
    - Multiple times per week
    - About once per week
    - About once per month
    - Never
23. If the booster cushion is taken out of the car, what is the reason for this?
24. Where is the booster cushion stored when not in use?
25. Have you ever used a car sharing service with your child? If so, how was it in regard to

child restraint devices/comfort/usage? Did you bring your own child restraint device and was it difficult to use in any way?

26. Have you ever used a taxi service together with your child? How was the child restraint device supplied? Did the taxi service include one or did you bring your own?

27. Do you see any issues with the combination car sharing + child restraint devices?

28. Scenario: You are buying a booster cushion for your car. Besides safety, comfort and usage, what do you prioritize when choosing between weight and volume? Is it important that it is light or that it takes little space? Why?

29. Scenario: You are buying a booster cushion for use in car sharing (which means that you need to bring the cushion to and from the car for every ride). Besides safety, comfort and usage, what do you prioritize when choosing between weight and volume? Is it important that it is light or that it takes little space? Why?

30. Scenario: If you are going to use a car sharing vehicle that already has a booster cushion in the luggage, would your child have used the already existing (and previously used) booster cushion from the luggage or would you have chosen to bring your own booster seat instead and carried it around during the day? Why?

31. Scenario: If you are public transport and need to bring a booster cushion, how would you have preferred to carry it? Tick the boxes of all the answers that would fit you or your child. (Example: If you usually travel with a full backpack, then a booster cushion would not fit inside of it. If your child usually has a backpack, then the booster cushion would not be able to be used as a backpack)

    - You carry it like a messenger bag (the booster cushion has one carrying strap)
    - Your child carries it like a messenger bag (the booster cushion as one carrying strap)
    - You carry it like a backpack (the booster cushion has two carrying straps)
    - Your child carries it like a backpack (the booster cushion has two carrying straps)
    - You carry it and hook it onto your existing backpack (the booster cushion has a hooking mechanism)
    - Your child carries it and hooks it onto their existing backpack (the booster cushion has a hooking mechanism)
    - You carry the booster cushion in your backpack (the booster can shrink to half its ordinary size)
    - Your child carries the booster cushion in their backpack (the booster cushion can shrink to half its ordinary size)

32. Do you have any input on the question above or do you have any other ideas on how a booster cushion can be transported?

33. Is there any question we have missed? Do you have anything to note about the survey or anything that has come to mind during the survey?

E

Benchmarks

NAME	WIDTH (MM)	LENGTH (MM)	HEIGHT (MM)	WEIGHT (KG)	RATING/STANDARD	COLORS	PRICE (SEK)	FEATURES	Recommended Weight Kid	Image of default pose and alternate pose if any
Axkid Mate	420	355	190	0.9	ECE 44.04	Black, Blue, Red	195	Removable upholstery	15–36 kg	
Booster Connext	430	440	240	1.4	ECE 44.04	Black, Red	299	Removable upholstery	15-36 kg	
Turbo GO™ Folding Backless Booster Car Seat	376	386	226	1.8	FMVSS 213	Pink, Teal, Green, Black	195	Foldable horn, belt positioning clip	40-100 lb.	

UberBoost	368	356	114	0.6	FMVSS 213	Blue, Grey, Black, Pink	340	Inflatable, belt positioning clip	40-100 lb.	
Bubblebum	280	280	110	0.5	ECE 44.04, FMVSS 213	Various colors and patterns	350	Inflatable, belt positioning clip	40-100 lb.	
TurboBooster® TakeAlong™	410	400	240	2.7	FMVSS 213	Grey, Purple	480	Foldable, dual cup holder, Machine-washable seat cushion	40-100 lb.	
BoostApak	400	360	180	1.7	ECE 44.04	Grey, Green, Black, Pink	700	Convertible to backpack, belt positioning clip	15-36 kg	
SitSac	400	380	230	1.8	ECE 44.04	Black, Green, Red, Blue, Grey	849	Clip-on backpack, straps for carrying the seat on one's back	15-36 kg	
Mifold	120	250	40	0.75	ECE 44.04, FMVSS 213, RSSR CMVSS 2013	Black, Grey, Blue, Pink	385	Foldable, belt clip	40-100 lb.	

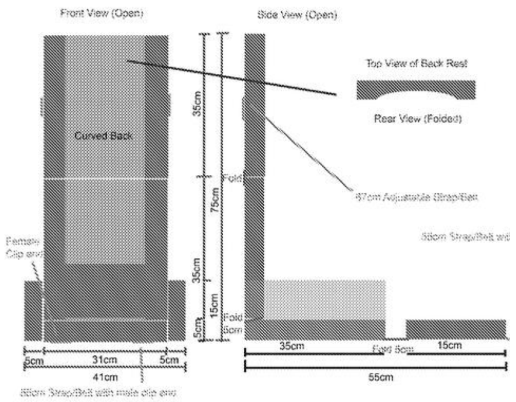
Mifold One	240	240	36	0.7	ECE 44.04, FMVSS 213, RSSR CMVSS 2013	Black, Red	385	Compact, belt clip	40-100 lb.	
Graco RightGuide™ Portable Seat Belt Trainer™	313	298	64	0.45	FMVSS 213	Black, Red	385	Foldable horns, belt clip	50-120 lb.	
Booster seat 39-804	415	470	255	2	ECE 44.04	Grey	100	Removable upholstery	15-36 kg	
Booster seat 39-800	370	415	210	1	ECE 44.04	Black	249	Removable upholstery	15-36 kg	

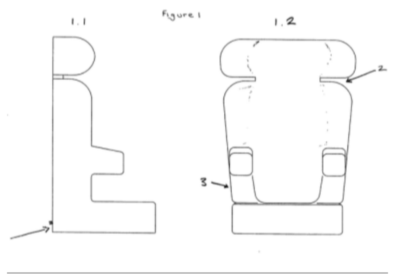
MAKER	NAME	TYPE/THING	RELEVANT FEATURES	Image of default pose and alternate pose if any
Primus	Aeril small	Campfire stove	Axial-symmetric folding mechanism	
Urberg	Airmat Nova	Inflatable air mattress	Inflatable individual cells	

SitPack	SitPack 2.0	Ultracompact chair	Telescope mechanism	
Primus	Kamoto	Portable fireplace	Flat-folding mechanism	
Red Paddle Co	9'6" COMPACT	Inflatable stand up paddle board	Stiff and durable inflatable construction due to drop-stitch construction	
ClypX	ClypX	Seat belt adjuster	Positions seatbelt instead of increasing height, ECE 44.04 and FMVSS 213 certified	
Nachfolger	HY5 TT edition 2020	Rearward facing child's seat	Inflatable, built in pressure monitor with warning	
Volvo Cars	Inflatable Child Seat Concept	Rearward facing child's seat	Inflatable, integral pump controllable via Bluetooth, drop-stitch fabric	

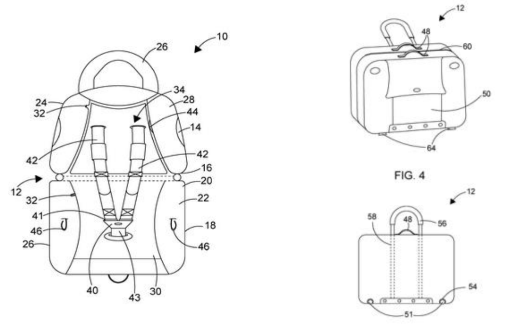
F

Patents

[Patent 1]	Sections of relevance in prior art	
[Patent name]	A foldable high-back booster seat	
The Sky Sofa - A compact, foldable, portable child seat for commercial airlines to make it more comfortable for young children to fly and sleep on a plane		
AU2017200148		
[Patent holder]		
HAMILTON MICHAEL		
[Priority filing date]		
2017-01-10		

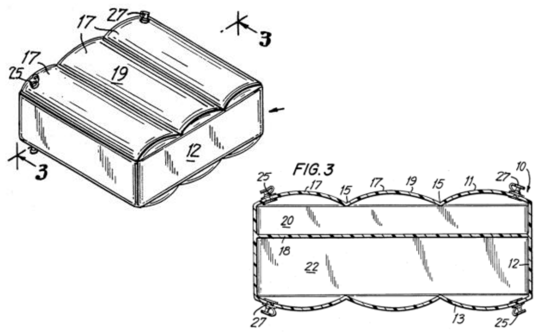
[Patent 2]	Sections of relevance in prior art	
[Patent name]	Relevant due to being inflatable and using a compressor driven by the car's 12V supply via the cigarette lighter. Not entirely relevant due to be a high-backed booster seat.	
Inflatable child car safety booster seat		
GB2429147A		
[Patent holder]		
MARTIN SEYMOUR		
[Priority filing date]		
2005-07-18		

[Patent 3]	**Sections of relevance in prior art**
[Patent name]	A suitcase that can transform into a car seat
A child car seat	
GB2561701A	
[Patent holder]	
Elijah Okpe	
[Priority filing date]	
2017-03-03	

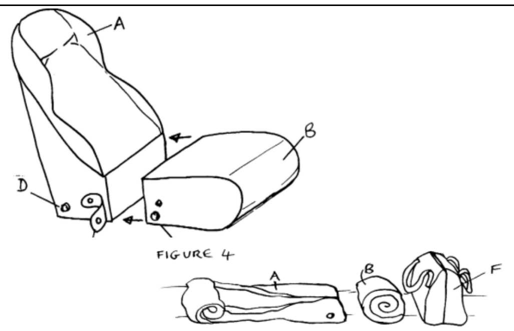


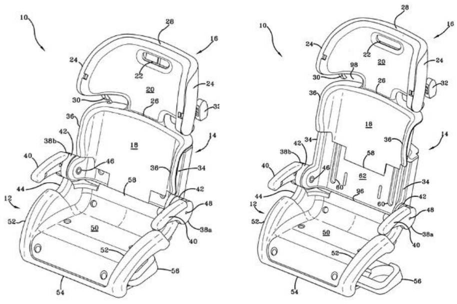
[Patent 4]	**Sections of relevance in prior art**
[Patent name]	A child safety seat that can fold together into a backpack construction
Portable child safety restraint system for use in, e.g., car services, has child safety seating system which is removable entirely from backpack or permanently secured to or within backpack enclosure	
US2019184862	
[Patent holder]	
SELLY IND LLC	
[Priority filing date]	
2018-12-14	

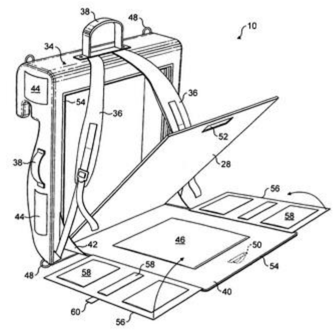
[Patent 5]	**Sections of relevance in prior art**
[Patent name]	Inflatable cushion with two separate bladders for adjustable height, not meant for vehicles.
Inflatable booster seat	
US5333336A	
[Patent holder]	
LANGSAM; ROBIN L	
[Priority filing date]	
1992-10-19	

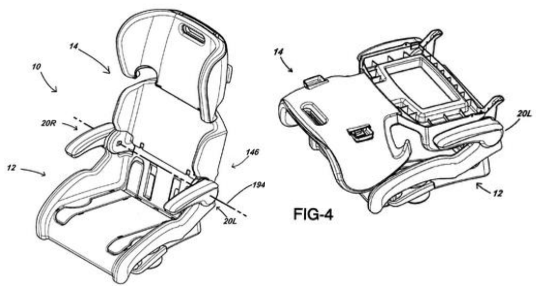


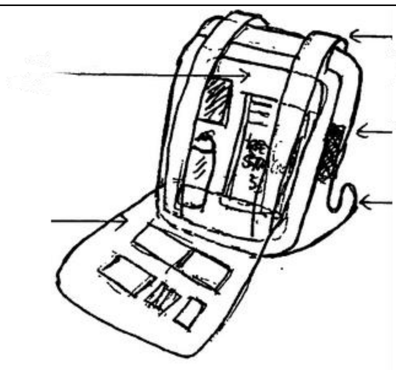
[Patent 6]	**Sections of relevance in prior art**
[Patent name]	Inflatable seat with removable backrest
Inflatable travel seat for a child	
GB2388770A	
[Patent holder]	
SARAH MARIE * MIDGLEY	
[Priority filing date]	
2003-11-26	

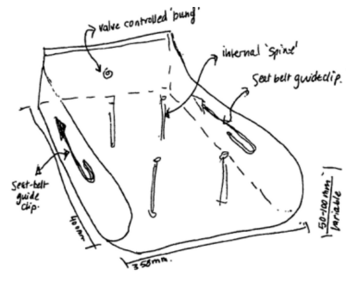


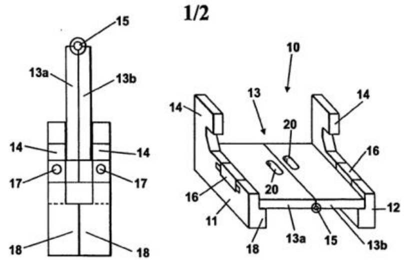
[Patent 7]	**Sections of relevance in prior art**	
[Patent name]	Foldable booster seat with high back	
ADJUSTABLE AND FOLDABLE BOOSTER CAR SEAT		
US2004189068		
[Patent holder]		
MEEKER R & D INC		
[Priority filing date]		
2003-03-07		

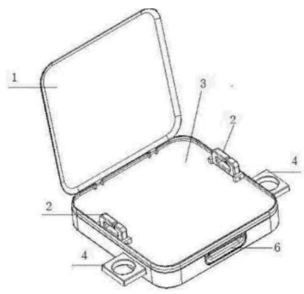
[Patent 8]	**Sections of relevance in prior art**	
[Patent name]	Hollow booster with shoulder straps for carrying	
Portable booster car seat with storage capability		
GB2436521A		
[Patent holder]		
LOUISE SMITH; NICOLA BROWN		
[Priority filing date]		
2006-11-22		

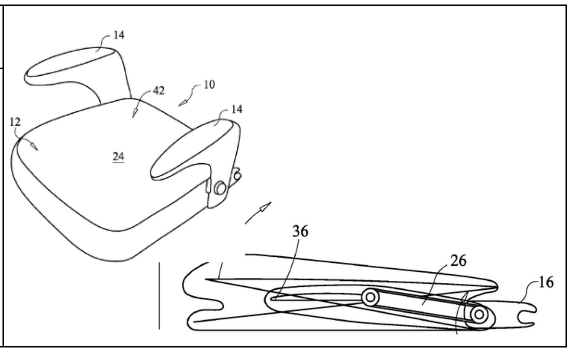
[Patent 9]	**Sections of relevance in prior art**	
[Patent name]	Foldable booster seat with high back	
Low Cost Adjustable and Foldable Car Seat		
US2007236061A1		
[Patent holder]		
MEEKER R & D INC		
[Priority filing date]		
2007-06-19		

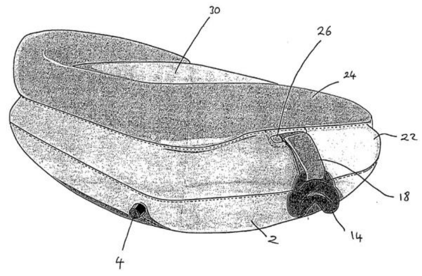
[Patent 10]	**Sections of relevance in prior art**	
[Patent name]	Combined booster seat and rucksack	
Rucksack usable as a child's booster seat		
GB2442196A		
[Patent holder]		
JOHN CONNELL; KATE CONNELL-WYNNE; NICHOLAS CONNELL-WYNNE		
[Priority filing date]		
2006-09-27		

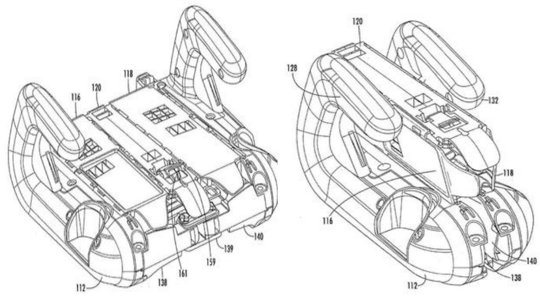
[Patent 11]	Sections of relevance in prior art	
[Patent name]	Inflatable seat with clips on the side for belt guidance. Has internal "spines" in order to divide the seat into multiple airtight compartments	
Inflatable child booster seat		
GB2442437A		
[Patent holder]		
NICOLA DAWN LOUISE MOORES		
[Priority filing date]		
2006-10-03		

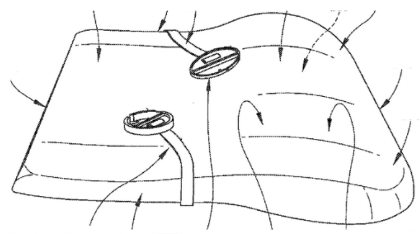
[Patent 12]	Sections of relevance in prior art	
[Patent name]	Foldable backless booster, folds in x-direction	
Child booster seat		
GB2444902A		
[Patent holder]		
MILES DADSON		
FORD GLOBAL TECHNOLOGIES, LLC		
[Priority filing date]		
2006-12-21		

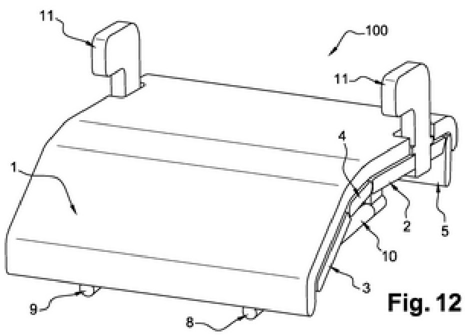
[Patent 13]	Sections of relevance in prior art	
[Patent name]	Combined suitcase and booster seat with cup holders	
Portable children's safety seat		
CN208393178U		
[Patent holder]		
MAX INF NINGBO BABY PRODUCTS CO		
[Priority filing date]		
2018-06-22		

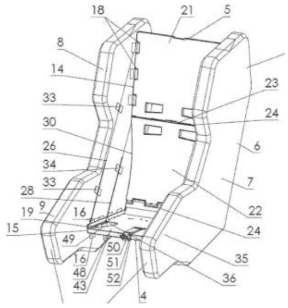
[Patent 14]	Sections of relevance in prior art	
[Patent name]	Booster seat that folds in z-direction	
FOLDAWAY CHILD BOOSTER SEAT		
US2010176635		
[Patent holder]		
GLANCE PATRICK M.		
[Priority filing date]		
2009-01-14		

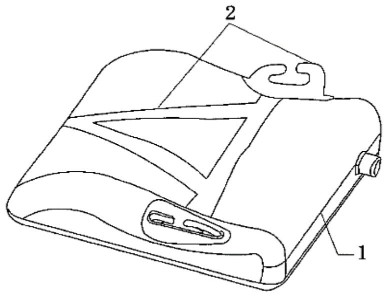
[Patent 15]	**Sections of relevance in prior art**	
[Patent name]	BubbleBum	
BOOSTER CUSHION FOR USE WITH A VEHICLE SEAT		
WO2010112175A1		
[Patent holder]		
KELLY, GRAINNE		
EMAGINATION LTD		
[Priority filing date]		
2009-04-03		

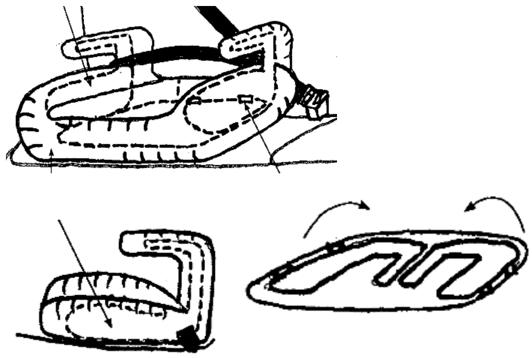
[Patent 16]	**Sections of relevance in prior art**	
[Patent name]	Graco TurboBooster TakeAlong foldable booster	
Child's booster seat		
CN107757436A		
[Patent holder]		
GRACO CHILDRENS PRODUCTS INC		
[Priority filing date]		
2016-08-19		

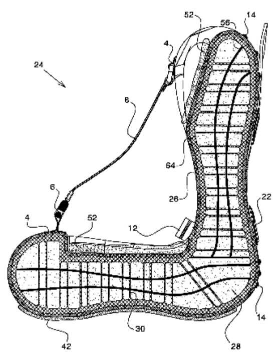
[Patent 17]	**Sections of relevance in prior art**	
[Patent name]	Flat booster with clips that guide the lap belt	
BELT-POSITIONING BOOSTER SEAT FOR VEHICLES		
US2016121763		
[Patent holder]		
DOREL JUVENILE GROUP, INC.		
[Priority filing date]		
2013-03-05		

[Patent 18]	**Sections of relevance in prior art**	 Fig. 12
[Patent name]	Foldable backless booster	
Car booster seat for child, has support structures arranged on seat element, where seat support is moved between folded position and unfolded position, in which support is held away from support structures		
FR2990900A1		
[Patent holder]		
RENAULT SA		
[Priority filing date]		
2012-05-23		

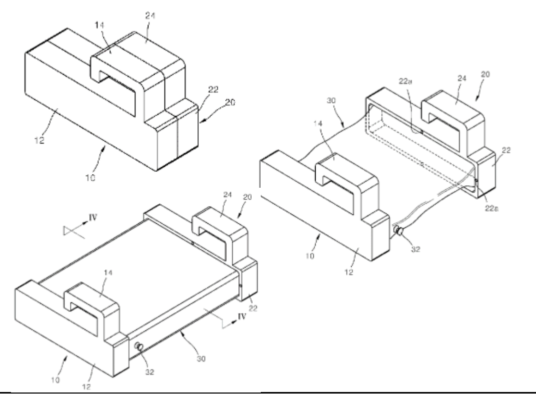
[Patent 19]	Sections of relevance in prior art	
[Patent name]	Nachfolger HY5 inflating child safety seat	
CHILD SAFETY SEAT		
US2019248321A1		
[Patent holder]		
NACHFOLGER GMBH		
[Priority filing date]		
2016-07-27		

[Patent 20]	Sections of relevance in prior art	
[Patent name]	Inflating booster cushion. Does not have horns, has clips instead. Claims to be ECER44.04 compliant	
Inflatable cushion		
GB2474551A		
[Patent holder]		
FU XI JIONG		
[Priority filing date]		
2009-03-27		

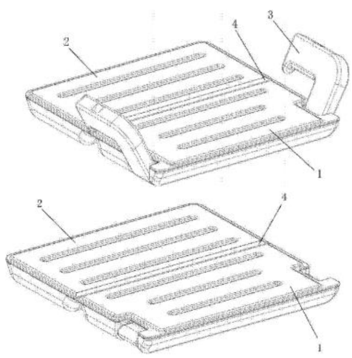
[Patent 21]	Sections of relevance in prior art	
[Patent name]	Inflatable booster cushion with optional backrest. Has a solid frame with inflatable cushioning around the frame	
Inflatable car seat with sliding back panel		
GB2466490A		
[Patent holder]		
MATTHEW DAVID FREDERICK CARTER-JOHNSON		
[Priority filing date]		
2008-12-23		

[Patent 22]	Sections of relevance in prior art	
[Patent name]	Inflatable booster/child seat with internal cross sections in order to maintain shape	
COMPACT INFLATABLE VEHICLE CHILD SAFETY SEAT/BOOSTER/CARRIER		
WO2009055954A1		
[Patent holder]		
FELDINGER, MEIR; FELDINGER, MENACHEM		
[Priority filing date]		
2007-11-01		

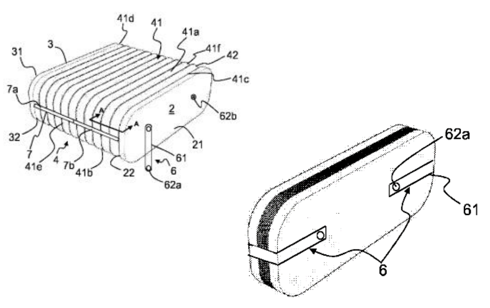
[Patent 23]	**Sections of relevance in prior art**
[Patent name]	Inflatable booster with rigid horn and inflatable middle section, allowing it to collapse in X-direction
Booster seat with improved portability	
KR101971352B1	
[Patent holder]	
인제대학교 산학협력단	
[Priority filing date]	
2017-08-29	



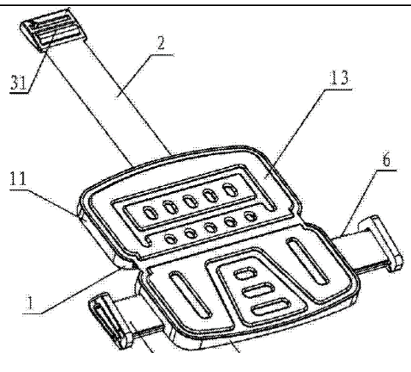
[Patent 24]	**Sections of relevance in prior art**
[Patent name]	Similar to Graco right guide portable seat belt trainer
Portable and foldable's children increase seatpad	
CN206537177U	
[Patent holder]	
LI SHUZHANG	
[Priority filing date]	
2017-02-24	

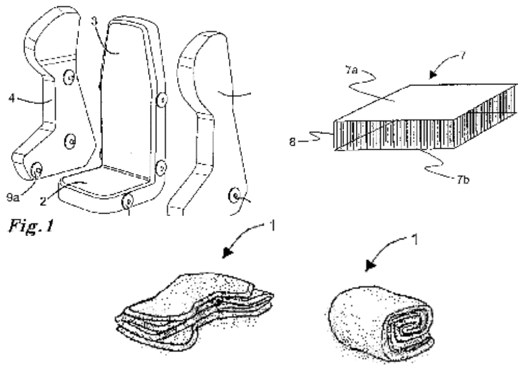


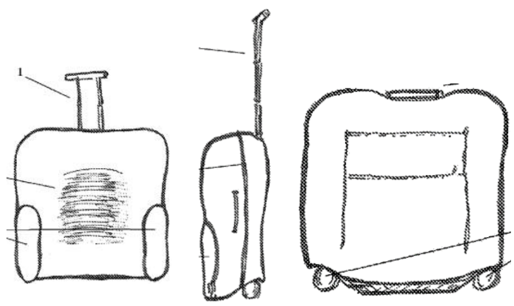
[Patent 25]	**Sections of relevance in prior art**
[Patent name]	Booster seat with or without back capable of collapsing in x-direction due to an accordion-like structure
SEAT	
WO2017216586A2	
[Patent holder]	
TRAFOLD LTD	
[Priority filing date]	
2016-06-17	

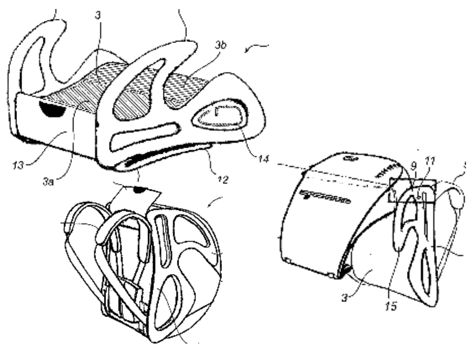


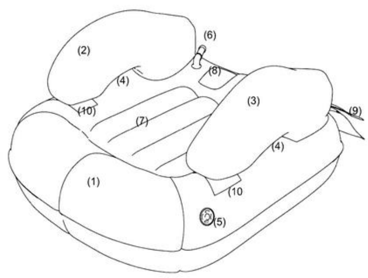
[Patent 26]	**Sections of relevance in prior art**
[Patent name]	Mifold or a very similar product
Portable children's safety cushion	
CN205365307U	
[Patent holder]	
JIANGMEN YILONG IND CO LTD	
[Priority filing date]	
2016-03-14	

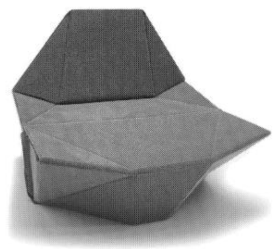


[Patent 27]	**Sections of relevance in prior art**	
[Patent name]	Volvo Cars Inflatable Child Seat Concept	
REARWARD FACING INFLATABLE CHILD SEAT		
US2012242128A1		
[Patent holder]		
JOHNSTON ROBERT; MENDIS KOLITA; VOLVO CAR CORPORATION; WESSMAN BJOERN		
[Priority filing date]		
2011-03-23		

[Patent 28]	**Sections of relevance in prior art**	
[Patent name]	Booster seat that also acts as a pull along luggage with wheels and retracting handle	
Child's booster seat convertible into a piece of luggage		
GB2480809A		
[Patent holder]		
BERTRAND DANIEL FAYN; SUSAN DARLINGTON TUDOR SMITH		
[Priority filing date]		
2010-06-01		

[Patent 29]	**Sections of relevance in prior art**	
[Patent name]	SitSac	
COMBINED BOOSTER CUSHION AND BAG		
WO2005100083A1		
[Patent holder]		
MINNO; MUNTHER, MARIA		
[Priority filing date]		
2004-04-19		

[Patent 30]	**Sections of relevance in prior art**	
[Patent name]	Inflatable backless booster seat	
Inflatable child booster cushion/seat for use with a vehicle		
GB2527137A		
[Patent holder]		
SUSAN SPAVEN		
[Priority filing date]		
2014-06-15		

[Patent 31]	**Sections of relevance in prior art**	
[Patent name]	A foldable seat comprising of multiple rigid substrates that are connected by flexible hinges. Can be folded in an origami structure to form the shape of a seat	
A FOLDABLE CHILD BOOSTER SEAT		
WO2016202289		
[Patent holder]		
GOORIS, Frederic Frans Petrus		
[Priority filing date]		

G

Reuirement specification

Criteria	R/W	Goal Value	Verification method	Comment/Note	Reference
Functions					
Able to expand in measured volume	R	Go from compacted to assembled state	Digital model test		
Able to reduce in measured volume	R	Decrease to 66% from assembled state	Digital model test		
	W	Decrease to 50% or less from assembled state	Digital model test	50% is the best that competitors (Graco takealong/Bubblegum) can reduce in volume	
Possible to carry product around	R	Possible to carry or transport during longer timeframes without changing carrying position	User test	The product is intented to be carried to and from cars	
Allows for adjustable height	W	Adjustable height with + (0 to 50mm)	Product test	Suggestion from design, unsure of feasability, low priority	
Performance					
Time to expand volume	R	< 2 minutes (auto) or < 30 seconds (manually)	User test	The Nachfolger HY5 inflates in 2 minutes	
	W	< 1 minutes (auto) or < 15 seconds (manually)	User test		
Time to reduce volume	R	< 2 minutes (auto) or < 30 seconds (manually)	User test	Reduction times are set to the same as expansion	
	W	< 1 minutes (auto) or < 15 seconds (manually)	User test		
Feeling of robustness and stability	R	Perceived as robust	User test		
Ease of use	R	Possible to operate without prior training but with help of a manual the first times	User test		
	W	Possible to operate on first try without prior instruction	User test		

Size					
The cushion should fit within established maximum allowed envelopes	R	< 440 mm width < 325 mm height < 535 mm depth	Measurement	Size is for maximum assembled state	ISO 13216-3:2017(E) 4.9 ISO/B1
Raise user	R	Shall ensure that the top of the child's head is at or above a horizontal plane at 770 mm vertically from the Cr axis when seated in the car	Digital evaluation, Measurement	Minimum booster height depending on the lowest intended stature	UN Regulation No. 129 supplement 3
Life length					
Static load	R	>7300 loading cycles	Fatigue test	(10 years, 2 loads per day)	
	W	>14600 loading cycles	Fatigue test	(10 years, 4 loads per day)	
Assembly load	R	>3650 assemblys (expand+reduce)	Fatigue test	(10 years, 1 expansion + 1 reduction per day)	
	W	>7300 assemblys (expand+reduce)	Fatigue test	(10 years, 2 expansion + 2 reduction per day)	
Maintenance					
Cleaning	R	Removable washable upholstery or whole booster cushion is washable	Maintenance test	Being possible to maintain is a de facto standard	
Competitors Solution					
Exceed competitors solution when combining weight, size, portability and safety	W		Comparision	As long as it is safe enough, this is fullfilled	
Safety					
Not deform more than necessary during a collision	R	Deform less than 25 mm according to Canadas test method 213.2	Digital Evaluation		Canada/FEDERAL: MOTOR VEHICLE RESTRAINT SYSTEMS AND BOOSTER SEATS SAFETY REGULATIONS (407)
	W	Deform less than 20 mm in Z-direction during MPDP crash test			
Able to position lap belt correctly	R	Position lap belt over in contact with pelvis, with top part of lap belt below ASIS of pelvis.	Digital evaluiation, user test		
Able to position upper belt correctly	R	Position shoulder belt mid shoulder diagonally over torso	Digital evaluiation, user test		
Provide barrier to prohibit unintended user interaction	R	Hinder unintended expansion or reduction when not expected by user	User test		

Customer Requirement					
SEE CUSTOMER NEEDS LIST (Seperate Appendix)					
Regulations and Standards					
Follow the USA/FEDERAL: 49 CFR 571.213		Approved under USA/FEDERAL: 49 CFR 571.213			USA/FEDERAL: 49 CFR 571.213
Not possible to remove or detatch components not designed to be removed or detatched without the use of specific tools	R	Comply with paragraph 6.2.3 in UN-R 129/03 Suppl.1 2	Digital evaluation, user test		UN Regulation No. 129
Guide the seat belt	R	Has only one adult safety belt-route	Digital evaluation, Product test		UN Regulation No. 129
Has a contact point between booster seat and seat belt	R	Contact point >150mm from Cr point	Digital evaluation, manual measurement		UN Regulation No. 129
Angle between horizontal line and tangent line in which the belt touches the thighs		>10°	Digital evaluation, manual measurement		UN Regulation No. 129
Fulfil minimal dimensions of hip breadth for intended user height	R	32cm	Digital evaluation, manual measurement	Hip breadth of a 95th percentile child with 150cm stature	UN Regulation No. 129 paragraph 6.3.2.1
Aesthetics and finishing					
Markings for belt	R	Detailed marking for intended belt path			UN Regulation No. 129
Discreet color	W	Dark colours or matching car interior		Insight from NTF to get children to use the cushion to a older age	NTF Employee
Appropriate Warning label	R	Label according to UN-R129			UN Regulation No. 129
Custom upholstery	W	Motives popular among children		Insight from NTF to get children to use the cushion more willingly in the begining	NTF Employee

H

Customer needs list

Table H.1: *The customer needs list, grades denoted with an (*) are mostly situational depending on solution*

Relevant task/function	Need	Importance	Feasibility
Extra feature	Functions both as a storage solution and booster seat	*	*
Product	Has adjustable size when deployed	5	2
Product	Is easy to clean	5	4
Product	Has low volume when undeployed	5	3
Transport	Is easy to carry and transport	5	5
Deployment mechanism	Cannot be tampered with by children	5	*
Product	Is comfortable for the user to sit on	5	4
Transport	Is comfortable to carry	5	4
Product	Does not block or cover any belt buckle when deployed	4	2
Deployment mechanism	Can be deployed easily	4	3
Deployment mechanism	Performance is not affected by water	4	*
Transport	Can be carried/transported by both adults and children	4	4
Product	Allows for a belt path that is comfortable for the user	4	3
Product	Allows two adults to sit comfortably in the back seat while deployed in the middle seat	3	*
Product	Is perceived as very safe	3	3
Product	Wide enough for a majority of users	3	2
Product	Is affordable/cheap	2	2
Deployment mechanism	Is self-deploying	2	*
Product/Transport	Has low weight	2	2
Extra feature	Has one or more cup holders	2	4
Extra feature	Can be used as a chair booster	1	5
Product	Can be quickly deployed	3	3

I

Kesselring matrix criteria

I.1 First iteration of criteria and grading

1. Height reduction: Rates how much the concept can reduce height wise when in compact state. The following grading where used: Under 33% of original volume (5), under 50% of original volume (4), under 66% of original volume (3), under 90% of original volume (2), doesn't reduce or less than a 10% reduction (1).

2. Width reduction: Rates how much the concept can reduce in width. The following grading where used: Under 33% of original volume (5), under 50% of original volume (4), under 66% of original volume (3), under 90% of original volume (2), doesn't reduce or less than a 10% reduction (1).

3. Depth reduction: Rating over how much the depth measurement is decreased in compact state. The following grading where used: Under 33% of original volume (5), under 50% of original volume (4), under 66% of original volume (3), under 90% of original volume (2), doesn't reduce or less than a 10% reduction (1).

4. Measurement increase: It was observed that some concepts managed to decrease a measurement in a dimension while simultaneously increase in another dimension, for example the Ribs concept. This criterion exists to reward concepts that does not increase in any direction and to penalize concepts that do increase in a dimension. The measurement used for comparison is the bounding box of the product when in deployed state and compact state. The following conditions were used: No measurement increase (5), less than 10% increase in a direction (4), less than 30% increase in any direction (3), less than 50% increase in any direction (2), more than 50% increase in any direction (1).

5. Price: This criterion was a rough estimation of what the market price would be for the product when finished. The estimations were based on existing similar products, number of features and complexity of the mechanism. The limits were set to: Sales price below 400 SEK (5), sales price below 600 SEK (4), sales price below 800 SEK (3), sales price below 1000 SEK (2), sales price over 1000 SEK (1).

6. Mass: This was estimated in a way that was similar to the prize. The estimation was based on number of components, their solidity, expected material and reference products already on the market. The limits set here are: under 1 kg (5), under 1.75 kg (4), under 2.5 kg (3), under 3.25 (2), over 3.25 kg (1).

7. Deployment complexity: This criterion is a measurement over how many steps needed to fully deploy the booster cushion from its compact state. A simple action such as pulling something out or sliding a component was counted as a step. It was decided that just

pushing a button to start an automated deployment process would count as less than one step and to be graded a (5). One or two steps is rated a (4), three or four steps a (3), five or six steps a (2) and more than six steps is a (1).

8. Deployment speed: This criterion is a rating of the time taken to fully deploy the cushion from its compact state. It is different from the previous state as the complexity can be simple but still have a long deployment time and vice versa. The speed was divided into a manual speed and an automatic speed as some users provided feedback that they would be okay with longer deployment times if it was fully automatic. As thus the limit was set to: Less than 5 seconds manually or 30 seconds automatically (5), less than 15 seconds manually or 60 seconds automatically (4), less than 25 seconds manually or 90 seconds automatically (3), less than 35 seconds manually or 120 seconds automatically (2), more than 35 seconds manually or 120 seconds automatically (1).

9. Mechanism intuitiveness: This metric was used to get a sense of how easy it would be for an inexperienced person to use the booster cushions deployment mechanism. Contrary to other criteria, this one used a non-quantifiable grading system as it was deemed the most fit for this kind of metric. If the cushion could be deployed on the first attempt by a person completely unfamiliar with the product it would be awarded with a rating of (5). If the person could deploy it on their first attempt after seeing a demonstration it would be graded a (4) and if it would take multiple tries after seeing a demonstration, it would be graded a (3). If a short guide like visible instructions was needed it would be graded (2) and if an instruction manual was needed to successfully deploy it correctly it would be graded (1).

I.2 Changes to the second iteration

6. Mass: All concepts in the previous Kesselring this metric scored either 3 or 4 points which meant that the grading needed to be refined. It was changed so that concepts under 1.5 kg received a (5), under 1.75 kg received a (4), under 2 kg received a (3), under 2.25 kg a (2) and finally over 2.25 kg a (1).

8. Deployment speed: A similar reasoning was used here. Most concept received either 5 or 4 points and a separation of these was needed to gain a more beneficial evaluation. The new gradings were: under 2 seconds manually or 15 seconds automatically (5), under 5 seconds manually or 30 seconds automatically (4), under 10 seconds manually or 60 seconds automatically (3), under 15 seconds manually or 90 seconds automatically (2), over 15 seconds manually or over 90 seconds automatically (1).

10. Adjustable settings: A new metric that was added. The metric is supposed to award concepts that can be adjusted or have some sort of adjustable height or width settings seeing as that was a highly requested by customer in the survey. It was decided to evaluate this function this early in the project as the mechanism is closely connected to the possibility for adjustable settings. The scoring was the following: the cushion can be adjustable in width freely and in height (5), has the potential to be freely adjustable in width (4), has preset width-levels that can be used (3), has one preset other width setting (2), has no adjustable settings (1).

J

Discontinued products

It was chosen to discontinue the other two products developed after Chapter 7 seeing as complications arose during the modelling. Both utilize the rib concept and while it is a novel way to compress a product width wise it may also be confusing to properly convey that function to users.

J.1 RaFE - Formerly the RibCab

The RaFE booster cushion was modeled after the concept RibCab and the acronym stands for Ribbed and Folding Extendable booster cushion. Similarly, to the SaFE cushion, this one could also fold in half but utilized another method than the slotting method. Instead the product made use of its ribbed body for horizontal compression, the model of the RaFE can be seen in Figure J.1.

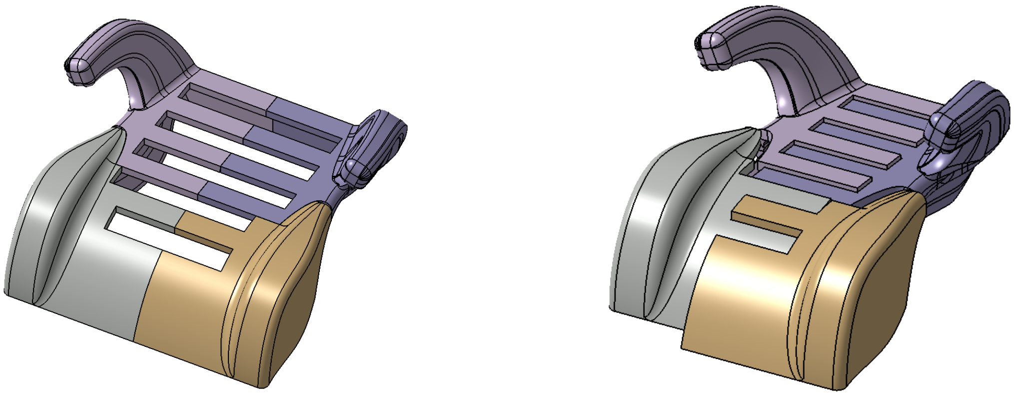


Figure J.1: *The RaFE cushion in its deployed form (left) and in its semi-compressed form after ribbing (right).*

The mechanism works as described in Chapter 7.8.2. The form of the body is based on the Rib concept and can by shearing depth wise and then pushing the sides together to compress width wise. This process is denoted as "ribbing" and is used in the product described in Appendix J.2 as well. After ribbing it is possible for it to fold similarly to the SaFE cushion. The difference here is however that RaFE needs to rib first before it is possible to fold in order to align its axles.

Once the modelling had started it was quickly realized that the cushion would have a lot of protruding parts once folded in half due to its ribbed nature. This would make it more difficult to store, transport and handle the product in a relatively safe manner for the user. For a look at these protrusions see Figure J.2. The steps and order of the process was deemed to be quite unintuitive which could also confuse the end user. It was thus decided to discontinue the product early in the modelling process.

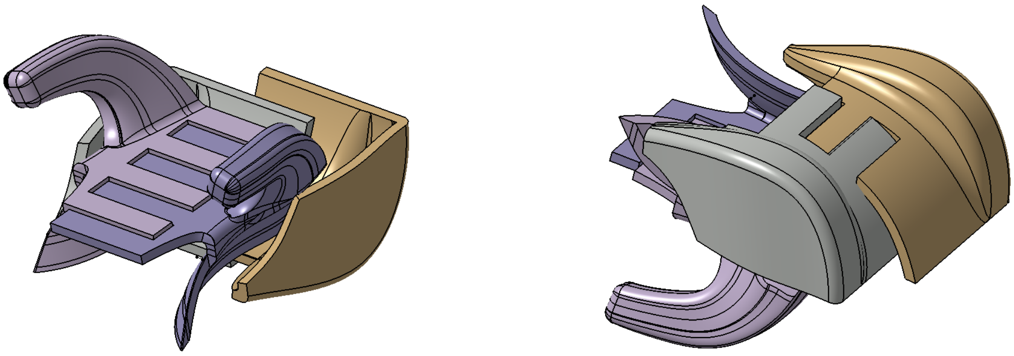


Figure J.2: *The RaFE cushion in compressed form seen from below (left) and above (right).*

J.2 RaCE - Formerly the Frog

The RaCE booster cushion is a product derived from the Frog concept and share the main attributes together with additional features to make it more user friendly and functional. RaCE stands for Ribbed and Compact Expandable booster cushion and is depicted in Figure J.3.

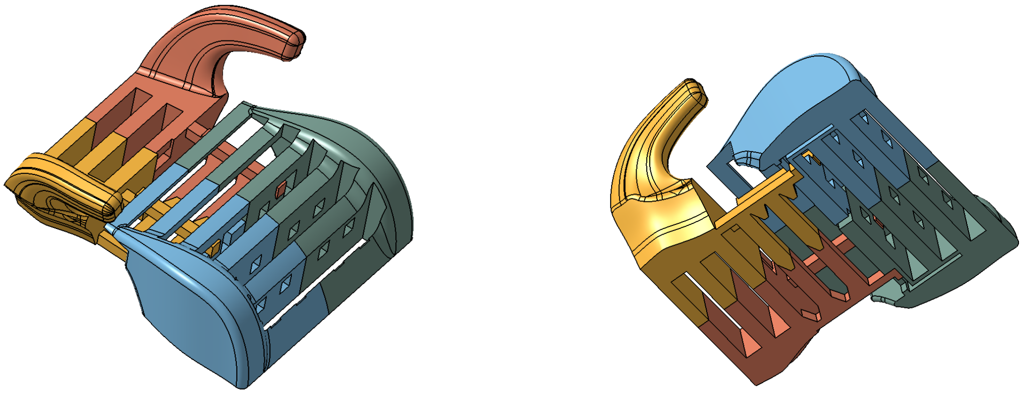


Figure J.3: *The RaCE booster cushion seen from above (left) and from below (right).*

The RaCE cushion can be divided into four parts as can be identified from the four different colored parts. These different parts can be categorized in four different ways; as rear parts (yellow, red), as front parts (blue, green), as left parts (red, green) and as right parts (yellow, blue). The front and rear pairs can be seen in Figure J.4. They are semi-symmetrical in that they share overall form and measurements but still has unique elements that help them fit better together.

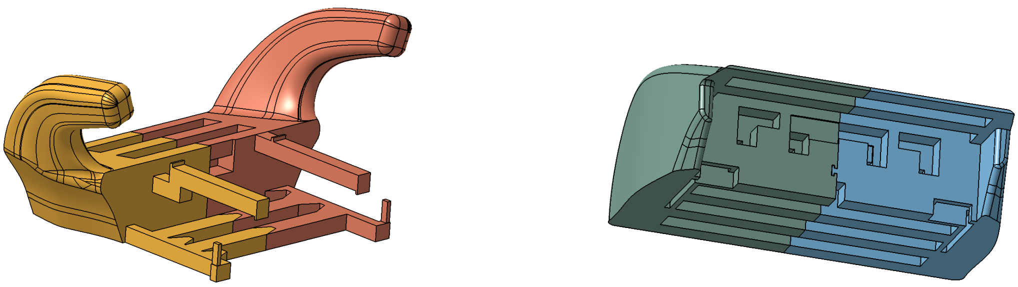


Figure J.4: *The RaCE booster cushion back parts (left) and front parts (right).*

To compress this cushion the user must follow a five-step process which can be seen in Figure J.5. The first step is to separate the two rear parts by pulling them apart, this step lines up the rear parts beams to the holes in the front parts. Step two is shearing the right parts backwards and the left parts forward and can only be done in this direction. Step three consist of pushing the left and right parts together, thus compressing fully horizontally. Step four is pulling the rear parts down, this action lines up the beams vertically with the holes. Step four can also be performed any time after step one as long as it is done before step five. Finally, step five consist of moving the back parts into the front parts with the holes as guides.

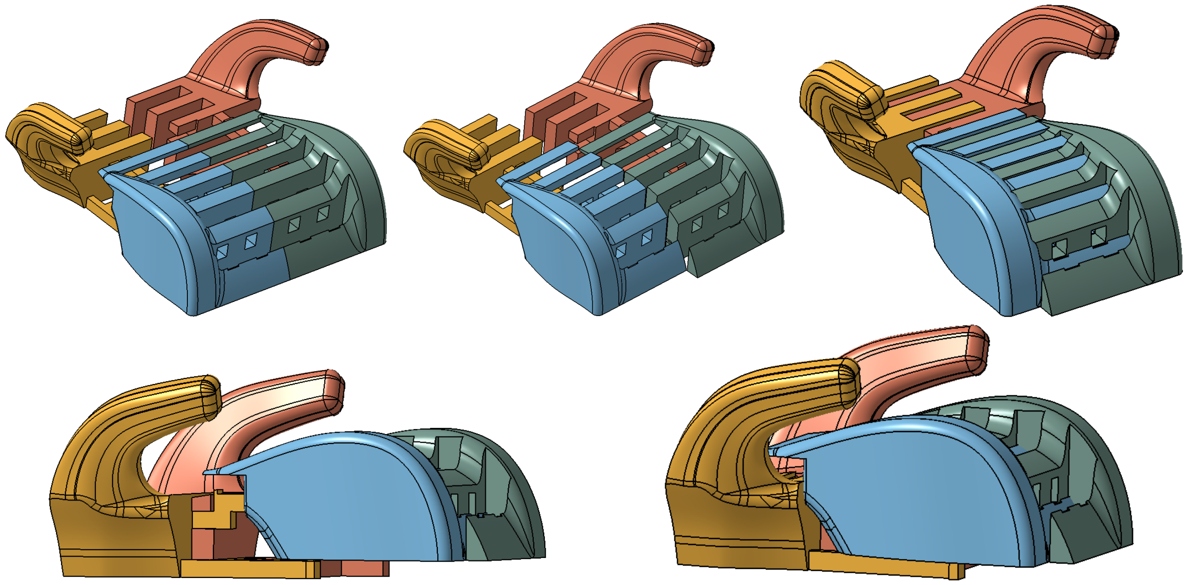


Figure J.5: *The five-step process how to compress the RaCE cushion. Step one is top left, step two is middle top, step three is top right, step four is bottom left and step five is bottom right.*

While the booster cushion is partially developed it was decided to prioritize the SaFE cushion instead for further testing as several potential problems was noted with the RaCE, the biggest of which being deemed to complicated and unintuitive to use.

K

Material

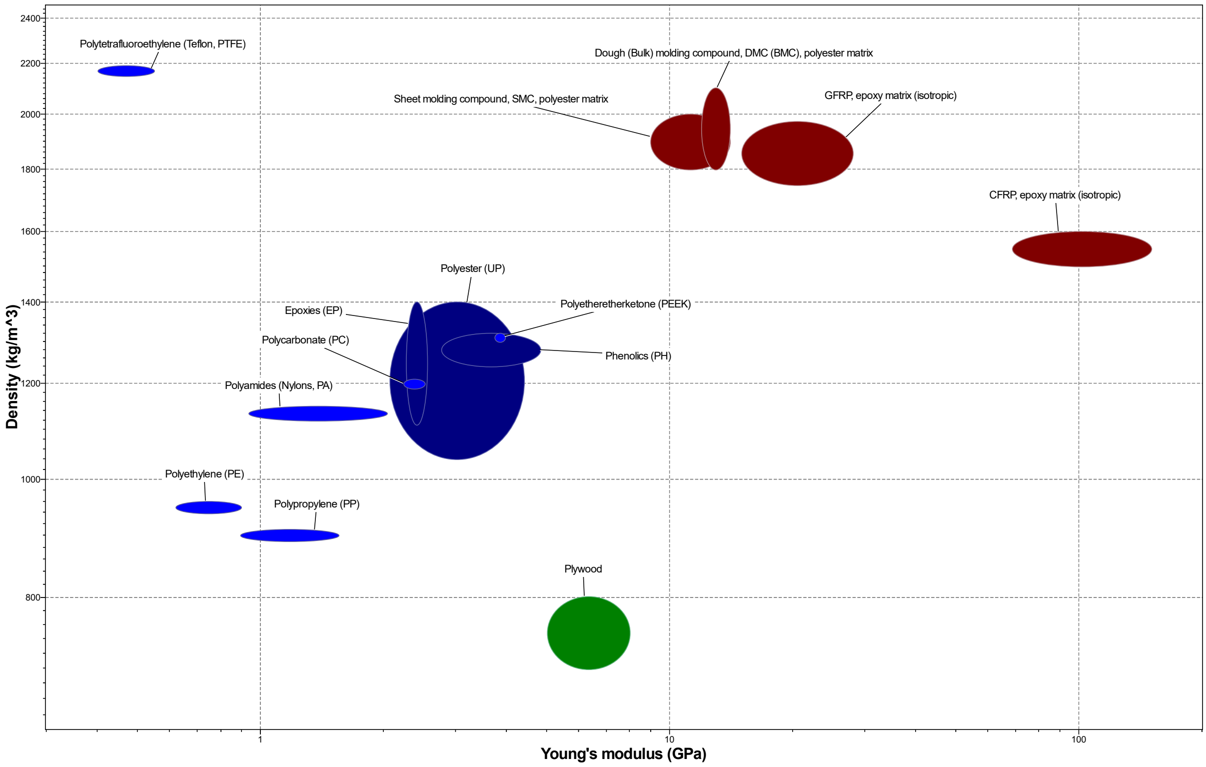


Figure K.1: *Materials plotted over density (Y) and Youngs modulus (X).*

Materials plotted over density (Y) and Yield strength (X).

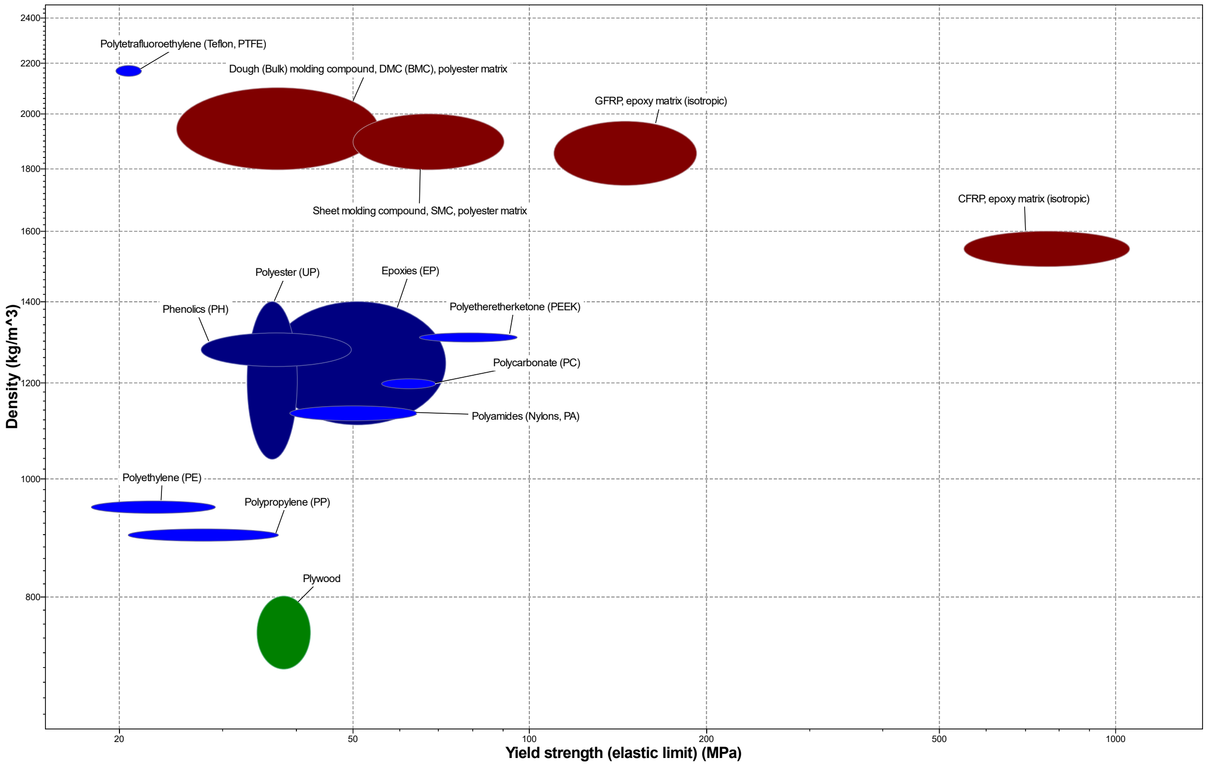


Figure K.2: *Materials plotted over density (Y) and Yield strength (X).*

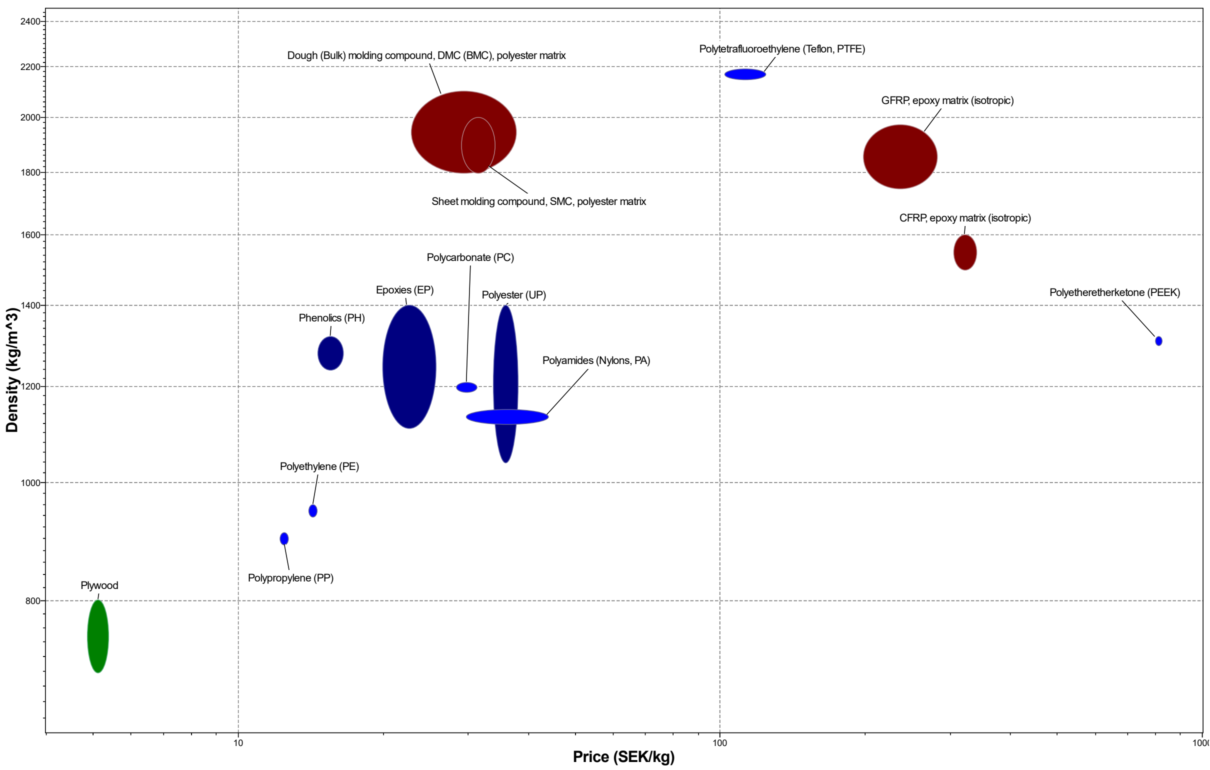
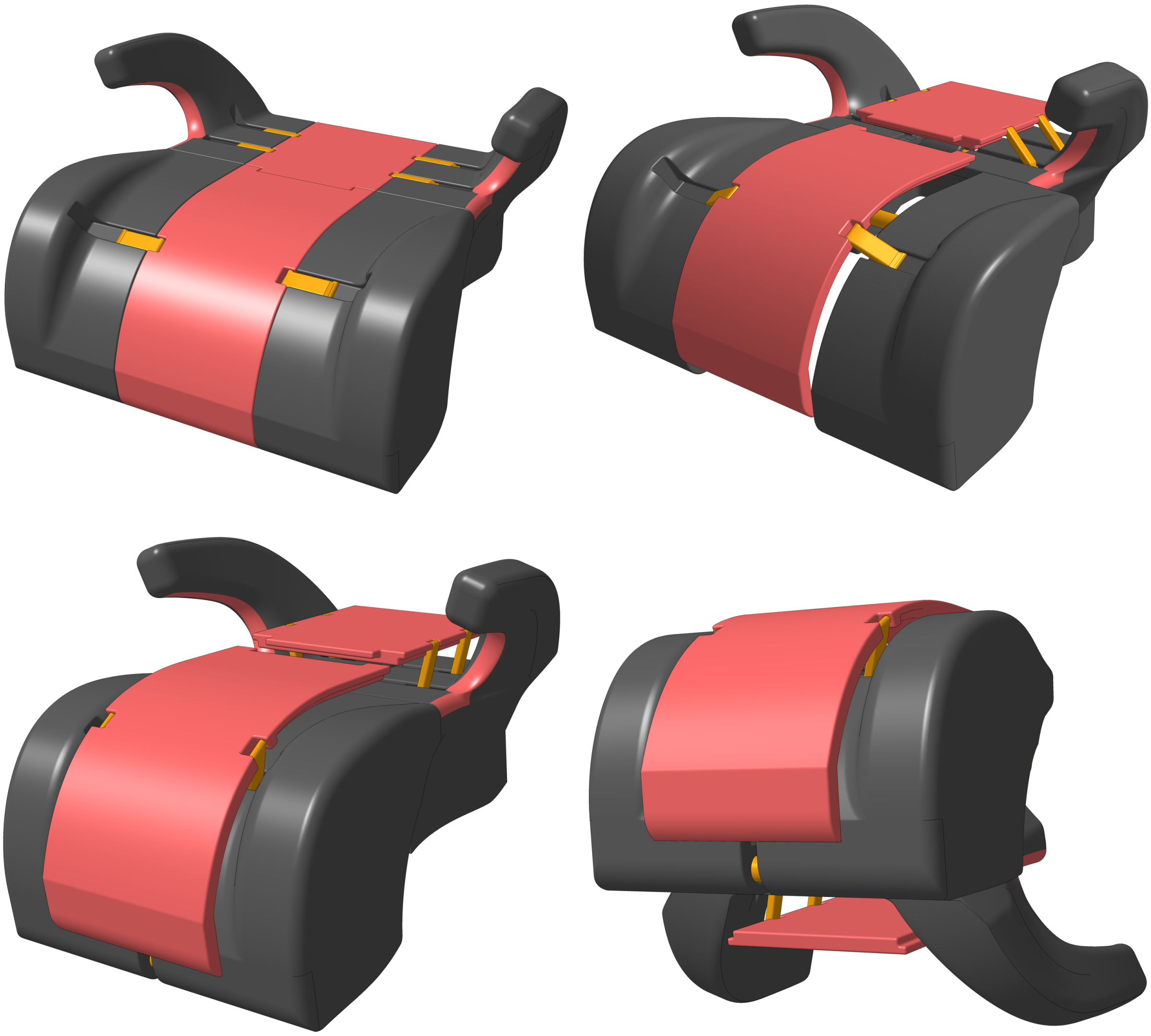
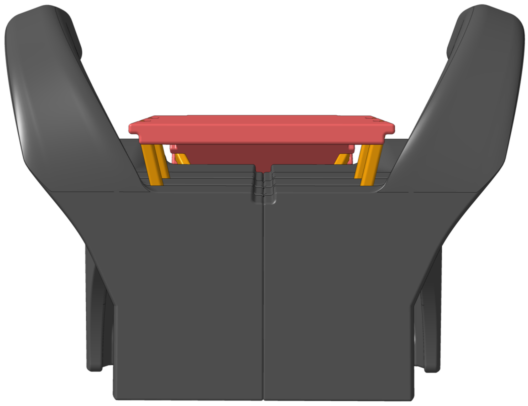


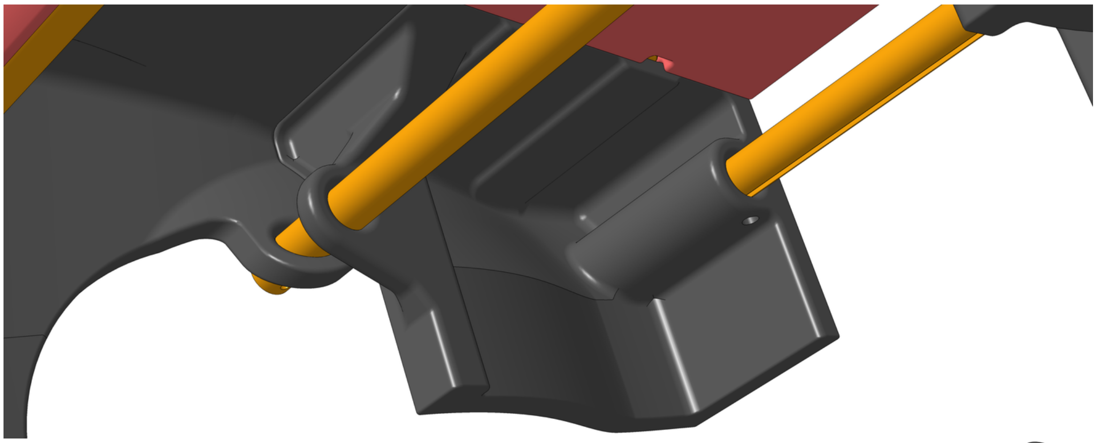
Figure K.3: *Materials plotted over density (Y) and Price (X).*

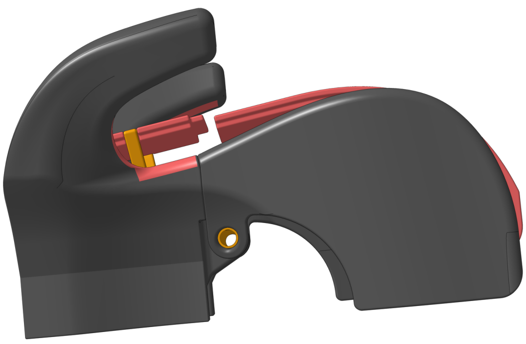
L

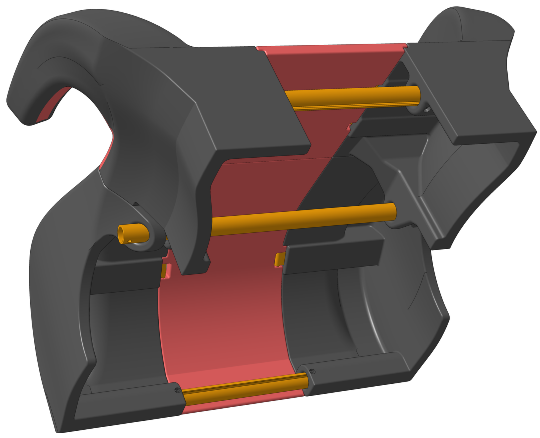
Renders of the SaFE revision











M

SaFE revision prototype assessment

A prototype was commissioned of the SaFE revision and the observations and discussions about it are included in this appendix instead of the report as the report itself was close to completion. Therefore, the discussion in Chapter 10 did not take this prototype into consideration. The printed prototype can be seen in Figure M.1.

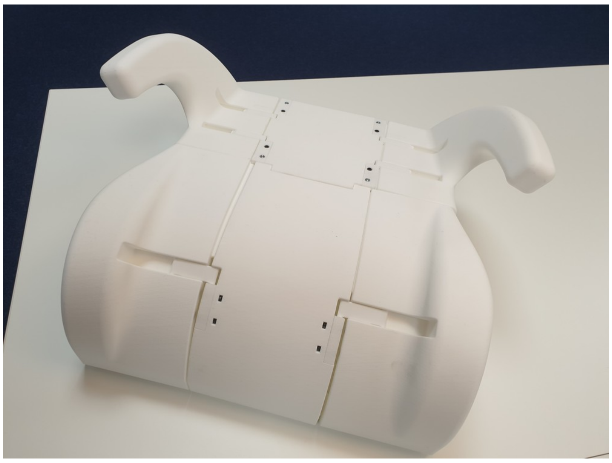


Figure M.1: *Overview of the second prototype.*

M.1 Overview

The prototype provided a real sense of scale when compared to the previous prototype, see Figure M.2 and highlighted how large impact R129 had on the booster cushion's dimensions. The prototype had close to the same mass as the previous one but gave a more robust impression when handled.

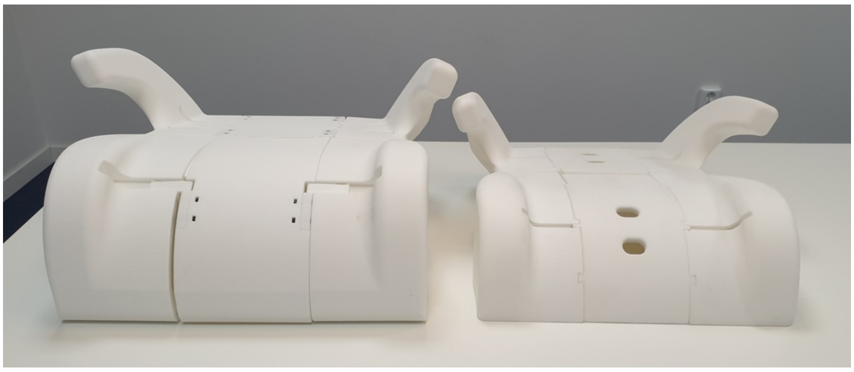


Figure M.2: *Comparison between the first and second prototype.*

The middle plates for the prototype was modified in order to be possible to assemble and required screws to fully assemble the plate arms as can be seen in Figure M.3. The holes for the shafts also provided some initial resistance and they had to be enlarged by removing some material using sandpaper.

Figure M.3: *Close up picture of the modified middle plate.*

M.2 The shafts

The prototype of the revision was easier to handle than the previous version due to the shafts located underneath. However, the shafts still provided some resistance to being pushed together unless an even load was applied. For example, if the load was applied to the rear part, the middle and front shafts became slightly skewed and no longer parallel to the mating holes, leading to increased friction when sliding into the hole. The rods could become skewed due to only a short length of the shaft being inserted into the hole when the booster cushion is fully deployed. The skew is probably initiated by surface friction where the end of the shaft catches on an irregularity existing in the hole of the wall and stops while the other end rotates slightly before the shaft meets the wall of the hole.

The phenomenon could potentially be remedied by designing a variant that allows for the shaft to go deeper into the hole when fully deployed, thus reducing the possible angle between the shaft and hole. The phenomenon should also be reduced by lesser gaps between the mating components since a large part of the friction is caused by play between the shaft and hole, but it can theoretically be solved by an increase in shaft and hole diameter since it would reduce the skew angle if the size of the gap would be the same. The third recommendation is to ensure that the mating surfaces are smooth, as the rough surface of the SLS manufactured prototype most probably aggravated the phenomenon.

M.3 The mechanism

The mechanism was a clear improvement over the previous iteration. When deploying the booster cushion and pulling the outer components apart, the middle plates are guided by the new plate arms and falls into place without need for further input. When compressing the cushion width-wise by pulling up the middle plates, the side components are partially pulled in under the plates. When compressing, the middle plate sometimes partially falls back into the deployed position and locks up the mechanism, in which the user must lift it once again before being able to push the side components together. Another problem is that the rear plate sometimes comes down before the front plate, this is a problem as the rear plate is supposed to lock the front plate in place by being above it. As a result, the front plate is unable to fall correctly into place.

A potential solution to the issue regarding the middle plates falling down into the deployed position is to adjust the mechanism. This can be done by redesigning the section of the side parts which interacts with the plate arm by constraining them to rotational movement. If the plate arm only can rotate instead of both moving along the y-axis and rotating, it would enable the possibility of compressing the cushion width-wise by pulling up the plates. It would also prohibit the plate from reverting to the deployed position without user interaction. The issue with the rear plate blocking the front plate could be remedied by removing the interfacing parts as the plates are supported by the corresponding side parts and thus should be able to handle the required loads without them. Another locking mechanism could also be introduced which could sync better with the mechanism.