A Product Development of Safety Car Seats for Children

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Abstract

Car accidents happen daily, and it is very important to protect all involved in a car no matter the age. Persons that are old enough and can take care of themselves, uses car seat belts to be protected in traffic. A child, however, must be placed and fastened in a safety seat by a parent or another caregiver, to be fully protected. Children that are correctly secured in safety seats have a 2.7 times bigger chance to survive a car crash without serious injuries compared to unstrapped children (Berg et al., 2000; WHO, 2004). Regardless tests and safety seats that are available on today’s market, there are still issues that needs to be eliminated. Daily users of this product are a good starting point since these people want a safe seat for their child that can be easy to install and affordable; and they can best tell what issues they encounter.

Based on several scientific articles in a combination with interviews and observations, issues with the safety seats could be confirmed. The primary issue is the seat belt that is attached to the safety seat. Children can develop a habit of wriggling out of the belt in safety seats. There are belt collectors available on the market which holds the shoulder belts in place. In this way, it is harder for the children to slide out of the belt and helps to keep the belt properly positioned (BeSafe, 2018). Instead of having this as an accessory, it has been considered in the belt that have been developed. Another issue is that the belt is complicated to fastened since two straps has to be simultaneously clicked in the belt buckle. If this is done incorrectly, the belt cannot be fastened, and it takes time to try it again. To make this easier, two straps and the strap between the child's leg will be fastened separately in a seat buckle each. In this way, parents and other caregivers will be able to fasten the belt easy and properly. They will also be sure that the child is safely fastened and will minimize injury during an accident or another situation.
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1 Introduction

The introduction is a shallow view of the project’s scope. Here, the reader will get an insight into the purpose and goals, background, as well as the specifications and limitations.

1.1 Background

Motor vehicle crashes while driving 40 km/h is all that is required for a child to get injured or die (Trafikverket, 2018). A child in its early age is vulnerable and in the case of an accident its head and neck are thrown forward and backward with an enormous force. (Trafikverket, 2013). According to regulations, children must have safety device if they are under 135 cm. and it is recommended to use it until the age of 12 (Trafikverket, 2018). To understand what is happening in an accident, researchers are using software for simulations of motor vehicle crashes. By studying the motions of a child when exposed to high crash forces, researchers can make an appropriate design and construction, and therefore prevent injuries.

1.2 Aim of the Study

This project is about developing a child restraint system to protect the children from getting injured or die in vehicle accidents. What is the regulation today in Sweden? Is it the same in the rest of the world? Can a better child restraint system be developed in this project? These questions will be answered during the project and the focus will be on the parts such as the belt and neck- and head support.

The purpose is to develop a functional safety child seat which will be safer compared to the seats that are available on the market. The seat must manage forces during accidents and minimize injuries of the children.

To succeed with the purpose, the goal will be to focus on the seat belt. This is an issue because some children have the tendency to wriggle out of the belts that are placed on the shoulders, see figure 1.1. Also, the belt is hard to fasten by a parent or another caregiver; the shoulder straps must be simultaneously clicked in the seat buckle that is attached to the strap which goes between the child’s legs. The fastening will therefore be considered to facilitate for the involved persons. This development will be achieved by considering researches, interviews and observations and market research.
1.3 Limitations

Since there is a variety of car seats between different ages, this project will be limited to children between three and seven years; this niche depends on a higher safety and developed seats appropriate for this group. If the age difference is broader, the seats are adjustable and becomes more universal which may not be safe for all ages.

The project has been performed without a cooperation with a company, this with the purpose to develop a product on a more independent basis.
2 Method

The purpose is to describe the methodology of the project definition and product evaluation. Interviews, observations, market research and scientific articles are methods that have been used to collect correct and critical information regarding safety car child seats.

Product evaluation requires different kinds of methods and the methods used here are brainstorming and pairwise comparison. The reader will further be presented with methods that are used within product development and specifically used while developing a car seat for children.

2.1 Data Collection with Triangulation

According to Flick U. (2018, p.530), the purpose with triangulation is to aim a broader, deeper and more comprehensive understanding of what is studied. However, triangulation is a criterion within qualitative research, it can be used when other methods and their results are employed for critically evaluating the results that are obtained with the firstly used method, and the term “triangulation” is used to pragmatic combine several methods. This methodology can be understood as a source of extra knowledge about the issue under a study and not only a way to find what is already known from a first approach. It can also be an extending research program which includes systematic selection of various methods and combination of research perspectives. The triangulation can be applied by combining qualitative methods such as interviews and observations, quantitative methods such as questionnaires and tests, or a combination of both qualitative and quantitative methods.

In this project, a triangulation with the combination of both qualitative and quantitative methods will be used. The methods that will be used are a market research, observations, interviews and collecting data through scientific articles that were found in databases. These methods have been selected to provide with the understanding of the problem with safety car seats for children. A market research shows the current state on the market, while interviews with different persons gives a good knowledge about everyday use of car seats. Thus, an explanation of different encountered problems is given. Own observations will provide with better understanding of the product by getting a sense of how it works and what problems can occur while installing it in the vehicle or fastening the child. Lastly, scientific articles will give a hint of what work/experiments have been done within this study area.
Since the market research was the first step of understanding today’s market, a summarize was made and can be seen in Appendix D. The purpose is to give the reader a knowledge of different car seats which applies brands, price, dimensions, what age they are intended for and what are their advantages and limitations. Also, the result from the interviews can be seen in Appendix A. The interviewed persons were asked the same questions and the advantages is that they could tell about their own experiences about limitations, advantages and disadvantages.

The observation was made the 10th of February in a store of child car devices called Babyproffsen and is based in Malmö. The store had several types of seats and brands to select between. While observing the different seats for different ages, some question appeared which will be answered during the project:

- How can the seats be attached to the car?
- Are the seats adjustable? (Adjust the height of the neck and head support and angle the seat).
- Why are some of the seats heavy compared to each other?
- Are the seats weight and child’s weight in correlation with each other?

2.2 Product Evaluation

Product evaluation considers the development of the product. Brainstorming is the first step to generate several concepts, of which one concept will be selected, see Appendix C. Based on the concept selection, an engineering specification will be made, see table 2.1. Here, significant criteria for the product will be weighted. The table shows in what phase the criteria will be used, in what unit they are weighted, what their target value is and if they are required, desired or limited.
Table 2.1 Engineering specification with criteria that will be considered through the development.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Used at Phase</th>
<th>Unit</th>
<th>Target Value</th>
<th>Requirement/Desire/Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Construction</td>
<td>kg</td>
<td>&lt; 5</td>
<td>D</td>
</tr>
<tr>
<td>Strong (yield strength)</td>
<td>Construction</td>
<td>MPa</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>Low cost</td>
<td>Construction/Manufacturing</td>
<td>SEK</td>
<td>&lt; 999</td>
<td>D</td>
</tr>
<tr>
<td>Safe (can handle forces in accidents)</td>
<td>Concept Generation/Construction</td>
<td>N</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>Comfortable (much space, area)</td>
<td>Construction</td>
<td>m³</td>
<td></td>
<td>D</td>
</tr>
<tr>
<td>Easy to assemble during manufacturing</td>
<td>Manufacturing</td>
<td>Number of Pieces</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Good recyclability</td>
<td>Construction</td>
<td>Number of Different Materials</td>
<td>D/R</td>
<td></td>
</tr>
<tr>
<td>Easy to manufacture</td>
<td>Manufacturing</td>
<td>Time</td>
<td></td>
<td>D/R</td>
</tr>
</tbody>
</table>

After defining the criteria and targets, they must be weighted to each other in purpose to find the focus point of the product. This will be achieved with a pairwise comparison. The scale in this comparison is number -, 0 and +; where - stands for the vertical criteria which is more important than the horizontal criteria, 0 stands for equally important and + stands for the horizontal criteria is more important than the vertical criteria.
The criteria that will be considered in the developing process are Safe, Good Recyclability, Easy Manufacturing and Easy Assembling; these criteria had the highest total number of plus and minuses.
3 Theory

This chapter will give the reader a deep knowledge of how car crashes affect the children and seat, what the standards and directives are, and summarizes of scientific articles with the purpose to give an insight of the science within this area. This will be an ingoing theoretical background for the product development.

3.1 Performed Tests on Safety Seats

Folksam is an assurance company that has tested safety child seats. They have researched this area for a couple years and they have in the tests used data from real car accidents to make sure that these safety child seats that they recommend have managed through all forces that are included in a car crash. The recommendations are that babies 0-9 months must have baby protection, safety child seat must be faced backward to the driving direction for children up to 4-5 years or about 25 kg and the safety child seat can be faced forward for children up to 10-12 years or when they reach a length of 135cm (Folksam, 2018).

![Folksam logotype of good choice of child car seat and best seat in their test.](image)

3.2 Standards and Directives

According to Swedish regulation (Trafikverket, 2017), children that are shorter than 135 cm. must have special devices that will protect them. These devices can be in form of baby seats, children car seats and seats with belts, and they primarily must be adapted to children's age, weight and length.

A significant factor to consider while selecting car seat for children, is that the child should sit backwards for as long as possible. This is due to that children's bodies are not enough developed and strong enough to manage forces they are exposed to
during car accidents; this applies primarily for the children’s neck and head which can lead to serious and fatal injuries. However, a rule is to use the backwards facing seat until the children has grown enough or until the top of their ears reaches the edge of the backrest.

ECE R44/04 (European Standard of Child Seat Equipment) is a regulation used until 2018 for approving child car seats and is replaced by a new regulation called UN R129 (NTF, 2018).

“The Swedish regulation states in summary (TSFS 2014:52):

- Children with a stature less than 135 cm. must use a special protective device (child restraint); infant seat, child seat or booster seat/cushion, approved according to UNECE Regulation 44 or Regulation 129.
- Children in rear-facing child restraints should not sit on a seat equipped with a passenger airbag unless the airbag has been deactivated” (Trafikverket, 2017).

A part of the new regulation UN R129 is i-Size which include rules to bring better adapted safety child seats to a child’s length and weight. The approved child seats will be better at side collision as well (I-size.org.uk, 2018).

ISOFIX is a standardized system in cars that have attachment points and these fastness points can be used to install a safety child seat. A safety child seat must be provided with the Isofix attachments to be installed in a car with Isofix points (NTF, 2018).

The organization UNECE (United Nations Economic Commission for Europe) has formed a new regulation for children’s safety in vehicles that they call UN Regulation No. 129. This is concerning 50 countries worldwide including European Union countries and should be followed. The regulation is created to reduce deaths in vehicle crashes and is focusing on the children. The following are the new improvements in the UN Regulation No. 129. Children of 15 months or younger must sit in a rear facing direction, rules are created for better side protection, ISOFIX fastening point system in vehicles makes sure that the safety seat equipment will fit, better tests have been performed for the purpose to create better regulations and the selection of right safety car seat for the child is easier to do now by only looking at the right height of the seat and the child.

In the European Union year 2010 nearly half of children were killed of those who were in road crashes and under age of 15. Germany in year 2013 had 4406 children under 15 years injured in road traffic. Russian Federation’s statistics from year 2015 points at 19219 injured children in accidents and 397 dead under the age of 16. In
United States year 2013 there were 1149 dead children under age 14. Year 2014 in Uruguay were 60 victims, children under the age of 19. In Australia 2014 there were road crash fatalities and 65 children killed between age 0 and 16. Japan had in year 2013 the number 94 children killed under age of 15. The same year in India 5760 children died under 15 years old. South Africa had between 2010 and 2011 17.5% children under 19 years that were killed in the traffic fatalities. The Sultanate of Oman had in year 2012, 122 children killed and 1510 children up to 15 years injured in traffic accidents (UNECE, 2016).

In EU a child restraint system in vehicles must be used for children under 135 cm. or 150 cm. The height can be decided by the countries themselves and a couple of other rules can differ from country to country in EU. In Germany children younger than 12 years and under 150 cm. must use a children restraint system in the car. In Japan the same rules are for the children under six years. Russian Federation does not allow children under 12 years and under 150 cm. tall to be transported without a child restraint system. In United States every state can decide their own rules regarding child restraint system and today the rules are that children younger than age four or eight (depending on the state) must be seated in a child restraint device while being transported in a vehicle (UNECE, 2016).

Manufacturers can get their design approved if they have followed the description of this regulation. The new in the regulation is the “i-Size” system that means the child restraint system has the fastening points that can be attached to a vehicle’s two ISOFIX anchoring points. ISOFIX is the same in all vehicles that has it, ISOFIX is universal (UNECE, 2016).

![i-Size system](image)

*Figure 3.2 Part of regulation 129 is “i-Size” and this logotype is showing it.*

The child restraint systems have different sizes depending on a child’s body size and weight and the manufacturers must decide which category their safety child seat is made for (UNECE, 2016).
According to figure 3.3 the children that are 15 months or younger must sit in rear facing direction or lateral and it is forbidden to change to forward facing direction too soon. The head and the neck must be protected, and the device must pass the side impact tests that are created by UNECE (UNECE, 2016).

3.3 Researches within the Field

Scientific articles contribute with further knowledge about the subject child safety car seats. Some of the articles describe different problems such as lack of knowledge of the stakeholders of seats, but also important factors such as ergonomics while developing this type of product.

Snowdon et al. (2008) writes in the research paper “Safety seats are designed to create a tight coupling of the restrained child and the vehicle and to distribute the remaining load as widely as possible over the child’s strongest anatomical structures”, (NHTSA, 2001; WHO, 2004). A child correctly secured in a safety seat is 2.7 times more likely to survive a crash without serious injury than an unrestrained child (Berg et al., 2000; WHO, 2004). This study by Snowdon et al. (2008) has showed frequently misused car safety child seats. The children are often not correctly restrained in its child seat with belt. In other cases, they are not at all restrained by rules but by the cars own seat belt earlier than it is recommended. Snowdon et al. (2008) continues "Most caregivers are unaware that they are misusing safety restraint systems, and their perceived susceptibility or risk from such misuse is lower than the real risk (Will and Geller, 2004)."

Harper and Strumpf (2017) found that there are less death and injuries in motor vehicle crashes now days than years before mostly because of the changes and
improvements in technical solutions in vehicles “Many of these changes are safety innovations such as mandatory frontal airbags, side and rollover airbags, electronic stabilization control, automatic crash warnings, improved vehicle lighting, automatic seat belt reminders, and shorter vehicle design cycles.”

Harper and Strumpf (2017) confirms in their article the importance of being restrained with belt in car seat “There is strong evidence that seat belts save lives, and it remains important to continue to increase seat belt use in the U.S.”.

Authors (Lu and Lai, 2013) of the article “Constructing Ergonomic Safety Modelling for Evaluating New Designs of Child Car Seats” are writing about a computerized program system to help engineers in an adequate way to create a design of safety car child seat. By this computerized program that is concerning a complex design of safety child car seats is taken man-machine features and how man, in this case a child, is moving when the child is in a vehicle that rides. It is important to design both functional and comfortable seat with aid of this program. When using the computerized program, the researchers are aware of motions of a child in a vehicle when it is riding and how much space there is for the child to move. The researchers are simulating in the intelligent man-machine system in the computer. These simulations can be done over and over again, the soon the engineer has created the model and want to test his or her design by intelligent man machine model the opportunity is great to see if the design is successful. Children from one year to three years are studied. Lu and Lai defined the components in a safety car child seat and includes 13 parts such as child safety belt, assistant safety belt, buttock support, back support, lateral support, contact surface, top slots, bottom slots, shoulder straps, buckle, crotch strap, harness adjuster and frontal railing.

![Figure 3.4 Simulations of child motions in motor vehicle crashes.](image)
To get an appropriate design of the safety seat must dimensions be considered from the aspect that the seat could be used by all body shapes. It may need, for example, an adjustable height system and a large sitting area. It must also protect the child’s fragile body parts (that is the neck and the head) and it should be comfortable. The computer program is a part of the Solidworks software program (Lu and Lai, 2013).

Authors (Henary et al., 2018) of the article “Car safety seats for children: rear facing for best protection” are focused on comparing a rear facing car seat versus a forward-facing car seat. The study is considering the children of age zero to two years and the statistics of accidents where there were hard injuries and even death of children in accidents. The study is limited to only consider the cases where there were properly restrained children and not consider the cases of obvious misuse of the safety car child seats. The conclusion is that rear facing car seats should be used as long as possible before switching to forward facing car seats. The instructions of the use must be followed for best protection. “By supporting the entire posterior torso, neck, head, and pelvis, a rear-facing car seat (RFCS) distributes crash forces over the entire body rather than focusing them only at belt contact points”. The children must stay in the rear facing direction because of the safety in event of a vehicle crash. Switching too early to the forward-facing direction can mean more cause in accidents. The authors of this article write about the rules in United States regarding facing direction of the seat and the American Academy of Pediatrics writes “for optimal protection, the child should remain rear facing until reaching the maximum weight for the car safety seat, as long as the top of the head is below the top of the seat back”. In practice this means in several cases that the child can be one year old or weight 9,2 kg. In the study there are two different types of motor vehicle crashes that were considered such as side crashes and frontal crashes. The recommendations are to use rear facing car seats because of the less risk for hard injuries and death. The correct use of the safety car child seat is very important, and the high safety is depending on it as well in the case of an accident (Henary, B et al., 2018).

The document “Vehicular child safety seat” (Onishi, I., Imamichi, T., 1997), is a patent and has been found in Google Scholar. It is an invention of a vehicular child safety seat; the concept has been presented with pictures and a pre-study of problems that can occur while using this product. The child safety seat will be placed on the seat in the vehicle and fastened by the vehicle seat belt. The safety seats have occurred as a very important factor in recent years, and several seats have been developed in order to increase the safety in vehicles of a newborn baby, a baby, an infant and a child (referring on school age). In consideration to vehicular child safety seats, the Japanese Industrial Standard has established standards that are detailed in “Vehicle Equipment-Child Protection Device: JIS-D 0401-1996”.
According to this, a child protection device is classified into baby bed (including newborn baby, infant seat) for both forward and rear facing directions, and child seat. These classifications are divided into weight range of the child; W1 is less than 10 kg, W2 is at least 9 kg and less than 18 kg, W3 at least 15 kg but no more than 25 kg, and W4 at least 22 kg but not more than 36 kg. However, the child protection device for W1 is supposed to be fixed to the vehicle’s seat in a direction which is lateral (sideways) or forward facing, considering babies aged 0-10 months. Weight class W2 refers to a device which is fixed to the vehicle’s seat either forward or backward faced considering infants from six months to three or four years. Weight class W3 refers to a device which have an elevated seat bottom plane and considers children between three or four years to six years.

The authors have an interesting point is that the usage of child protection devices in vehicles in Japan is significantly lower than compared to US and Europe. A factor is that the parent has a lack of knowledge in recognizing the danger with vehicles. Another factor is that if a child is reluctant to child safety seats, there will be a possibility that the device will not be used. This is followed by the lack of danger which is appreciated by adults who are associated with vehicles. To avoid this issue, a child should be seated in the child protection ever since the babyhood; before a baby begins to take notice so that it will take it for granted to be placed in the device while being in the vehicle.

In the document, to make this invention special, it will be developed considering using it for children of various ages from babyhood to childhood. The seat will be fastened with the vehicle’s seat belt and a support plane for supporting a child. The support plane is provided in a selectable manner so that it can be configurable into a first state forming a bed plane which enclosed the head and side of the children when laying in a transverse position in the vehicle. It will also have a second state forming a seat plane so that the child can be seated either forward faced or backward faced. When the seat is in the transverse position, it will be used for a baby, and when it is in a more upright position and rotated either forward and backward it is suitable for an infant, toddler and older child sitting upright. Other aspects that have been considered regarding safety are children’s neck, head and position in the seat.

In the article “Promoting Correct Car Seat Use in Parents of Young Children: Challenges, Recommendations, and Implications for Health Communication” (Nancy L. Weaver et al., 2012), when child safety seats are used properly, the morbidity and mortality decrease of child passenger that are involved in a car accident. Child safety seats or belt-positioning booster seats that are used correctly provides the best protection in a crash. This applies for children that are large enough to use adult safety belts that fits properly. Children between two and six
years who are placed in child safety seats or booster seats are 28% less likely to be killed in a car accident compared to those who are using a seat belt. Also, booster seats that are belt-positioned reduces nonfatal injury by 45% in four to eight-year old, compared to those who use safety belts alone. However, one of the primary aims of injury control efforts is to increase correct using of safety seats that are age-appropriate.

In article “Promoting Correct Car Seat Use in Parents of Young Children: Challenges, Recommendations, and Implications for Health Communication” there are several challenges in encouraging the use of correct child safety seats. This depends primarily on a big variety of child safety seats that are available on the market; marketed for children of different age, height as well as weight limits from various manufacturers. Another important factor is the installation of safety seats in vehicles. However, in this article the focus will be on increasing the safety of child passengers.

The authors continue to write about American Academy of Pediatrics (AAP) have recommendations based on data from crashes both in lab and on the road. The aim with child safety seats is to prevent the ejection of a child from the vehicle while the forces are spread of the crash across the strongest parts of the child’s body. While purchasing child safety seats, decision is often based on factors such as accessories, aesthetics, convenience features, price, availability, maximizing time of use, and use for multiple children. The result of this is that selected seats may not fit correctly in the vehicle or fit the child for longer use; considering height and weight. Misuses are often multifactorial, and a factor is not proper installation. A proper installation requires the child safety seat to be secured correctly in the vehicle. Errors that are associated with this issue is too loosely secured seats in the vehicle, failure to tether the seat and improper placement of the seat in the vehicle.

To reach out with information that is important while installing a seat properly, the information must be relevant so that the reader will consider and process the information that is being presented; this will result in a more sustained behavior and change. It is noticeable that there are variations in car seats ability to accommodate children of a weight. Some seats can accommodate a rear-facing child until approx. 15 kg. while other do not. Hence, the caregivers (e.g. parents) must ensure that the seat will accommodate specifically their child by consulting the manual. Other factors that must be considered are the angle of the vehicle seat, the footprint (width and depth) of the car seat, and the location and length of the belt stalks. These factors are important to establish to gain knowledge of what car seat can be used in a particular vehicle. Specifications of a selected child safety seat must carefully be followed, as well as the limitation use of multiple children in a vehicle while
selecting a specific seat. An example is that if a 13-month-old has a forward-facing car seat, health professionals may be pressed to encourage the caregivers to purchase and use a convertible seat that would allow the child to stay rear-facing for a longer period of time. The technician of the car seat must inform the caregiver with the best recommendations and the manufacturer’s instructions so that the caregiver can make the decision. However, this can be followed by an issue since the parent(s) are using a car seat according to the manufacturer’s instructions and considers this as a correct use; even though their use does not conform to current best practices. The caregiver knows its child best and should therefore be able to know which seat to select; what seat can fit into the vehicle, what is the price point and the circumstances.

3.4 Stakeholders

Stakeholders of a child seat are several, not only consumers that in this case are parents that are buying and children that are using child seats. Internal customers of these seats are those who are involved in different departments in a company and are having contact with the product. Examples are design engineers, sales staff, manufacturing personnel, service personnel among others in the company. Organizations such as Trafikverket, Folksam etc. are considered as stakeholders as well because they are testing and setting requirements of the products.

3.5 Different Ways of Mounting the Seats

According to Bäst-I-Test (2018), there are two most common ways of fastening the seat in the car. A safety car seat, that is backward faced and anchored by the car’s seat belt, is attached to the car partially with the car’s own seat belt and anchoring straps. An advantage with this mounting is that seats with the highest approved maximum weight can be found within this category - up to 25 kg. Another advantage is that there are still no size requirements for this kind of safety seat, and therefore it can be very spacious and thus used during a longer period. The disadvantages with this anchoring is that the seat can be incorrectly installed in the car. This will, however, increase the risk that the child does not sit safely in the car as intended.

ISOFIX is a variant of backward faced seats that have anchors that are mounted to ISOFIX brackets in the car. The advantage with this anchoring is that it is impossible to mount it incorrectly, and it is easy to mount and dismount. The brackets in the car has a load of 33 kg., and since it is assumed that a backward
A rear-facing chair weighs approximately 15 kg., ISOFIX chairs have a maximum weight capacity of 18 kg. A disadvantage is that the child will grow faster from an ISOFIX seat compared to a rear-facing seat that is installed with the car’s belt and straps.

3.6 Motor Vehicle Crashes (MVCs)

Some examples of crash safety devices in vehicles are seat belts, airbags and headrests. Forces that affects the vehicle while driving and crashing into another vehicle or similar are also affecting the passenger(s) which leads to violently hurling in one direction. The car’s safety equipment is created with the purpose to help against hurling out or hurling into something else in the car and avoiding injuries (Trafikverket, 2017).

Chassis construction, weight, and a vehicle’s inner equipment are some of the main parts that are responsible for what happens when accidents occur. When these are well made, a passenger’s safety is higher, and safety depends partly on the construction (Trafikverket, 2013).

According to Trafikens grunder (2016:114), in an accident all involved are exposed to great forces; which can be greater than the gravity. The shorter the distance is when the vehicle is braked, the greater are the forces that the vehicle is exposed to. Some of these forces are taken up by the vehicle deformation zones, which results in a longer time for the collision; the negative acceleration will be decreased. However, even though the vehicle is constructed to reduce injury in case of an accident, persons and loads must have the same negative acceleration, otherwise they will continue with the same velocity forward. The solution is to use seat belt, load securing, and a safety car seat for children. An object’s or a person’s weight is independent of the velocity. However, it is important to know that the weight is increasing if the person or object is not fastened and a rapid braking occurs; this is called a crash weight. For an example, the crash weight of a child which is weighing 6 kg. corresponds to 300 kg. - consequently, 50 times greater than the actual weight.
4 Results

The theory is crucial while developing a product, and in this project the theory has contributed to a better understanding and deeper knowledge of the problem. This applies primarily while using and installing safety seats. In this chapter, however, the disadvantages have been eliminated and the results from the interviews, 3D-CAD model and simulations will be presented as well as calculations and experiments. It is important to mention that experiments and calculations have been done with the compliance of ISO standards.

4.1 Interviews

While selecting seats for children, the first important thing is safety and then comfort and price, which has been shown from the interviews. There are both forward- and backward facing seats. The interviewed persons use one each, the one that uses the forward facing depends on that their child is too big for the seats that are facing backward. The seats are used in both front and the rear seat and the children are between one and four years old. Some of the disadvantages with the seats that are used daily is the size and the weight. Also, other disadvantages are the installation of the seat in the car and the five-point seat belt that is used to fasten the children in the seats. Since the seats are not installed with ISOFIX, the challenge with the first mentioned is that a balance must be achieved between the strap and the seat belt so that the safety seat can be fastened properly. The second mentioned is that the seat belt must be applied in two steps which can be hard when a child is sitting in the seat. Two straps need to be hold at the same time and then click into the strap which goes between the children’s legs, see figure 4.1. If one strap is dropped, the second strap cannot be clicked in since both straps must click into the third strap simultaneously. Preferable is to have a belt that can be fastened in one step and easier to handle. A last aspect is that all cars are not fully customized for having seats since some of them can be low and some seats can be hard to fasten in the car; hard to put the children in the seats due to low roof. An advantage is to use an adjustable seat which one of the person use. The height can therefore be adjusted and fit into different cars and grow with the child.

The result from the interviews is that the parents are not quite satisfied with the safety seats they use for their children. These factors have been considered during the project to develop a well functional seat that is safe, affordable, comfortable and easy to install.
4.2 Calculations and Experiments

By improving the protection of children, a test method that simulates lateral impact needs to be done according to SIS-ISO/TS 29062:2009 (Swedish Standards Institute, 2009). Such tests involve child restraint systems, CRS. Each CRS must be tested in its worst-case conditions, either it is forward- or rearward-facing, and must correspond to maximum intrusion close to the child’s head. In ECE Regulation No. 95, side tests and similar accident that may occur in real life, applies to that the rearward-facing CRS needs to be positioned in the rear seat while the forward-facing CRS needs to be positioned in the front passenger seat. When an accident occurs, the worst case depends on the impact point which can be either in the front or the rear seat of the vehicle.

Methods that are used within these kinds of tests are inexpensive and the specification has been developed through a progression of tests that includes impacts on full-scale vehicle. Considered points are double sled dynamics tests and single sled with a hinged panel which represents a vehicle’s side structure.

The tests result of ECE Regulation No. 95 side impact tests have shown that it becomes evident that injuries are caused by a combination of structural intrusion and vehicle acceleration. The definition of the intrusion are intrusion shape, depth and velocity. Also, geometrical properties such as door panel height, distance between the side structure and CRS can have considerable influence. According to this standard, a side impact test procedure of a CRS should be handling several boundary conditions, see table 4.1. However, additional to this the time of the
impact between the intruding panel and CRS/dummy\(^1\) must be controlled for appropriate definition of consequences.

**Table 4.1 Properties during a side impact test procedure.**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrusion velocity range</td>
<td>7 - 10 m/s</td>
</tr>
<tr>
<td>Intrusion depth</td>
<td>approx. 250 mm</td>
</tr>
<tr>
<td>Sled acceleration range</td>
<td>10g - 15g</td>
</tr>
<tr>
<td>Door panel height with respect to CR point</td>
<td>approx. 500 mm</td>
</tr>
<tr>
<td>Distance between panel and CRS centre line</td>
<td>approx. 300 mm</td>
</tr>
</tbody>
</table>

During a side accident which is caused by the front of another vehicle, the first mentioned is exposed to a lateral acceleration and a velocity change. The side that is struck may intrude into the compartment were the passenger is sitting, and impact occupants that are seated adjacent to the impact. Here, the acceleration affects the reaction of the anchorages and the inertial displacement of the CRS, while the direct loading on the CRS are affected by the side intrusion.

However, a complex interaction according to the above mentioned cannot be replicated completely in a simple sled test procedure and must therefore be divided; reproduced body acceleration by the sled acceleration and simulated intrusion by the motion of a hinged panel that is mounted on the sled. This have been achieved by using two vehicles with the same mass but the velocity of the vehicle that is struck in the side is one half of the striking vehicle. The method simulated a side impact of approx. 50 km/h. An interesting point is that mathematical simulations showed that the velocity change in the direction of travel of the struck vehicle had a marginal influence on the dummy. During the test, the anchorages were mounted considering some movement in the Y direction, up to 200 mm. The aim with this was to avoid excessive deformation of the ISOFIX attachments on the CRS during the side impact test setup.

Since the sled acceleration range is between 10g-15g, in this project 15g will be selected with the purpose to have a margin during an accident. The force that will affect the child safety seat is given in the following equation:

\[ \text{Force} = \text{Sled acceleration range} \times \text{Mass} \]

\[ F = 15 \times g \times m \]  

were \( g \) is being the acceleration of gravity, 9.81 m/s\(^2\), and \( m \) is the mass of the safety child seat given in kilograms.

### 4.3 Child Safety Seat Belt

Children can develop a habit of wriggling out of the belt in safety seats. A solution to make car travel easier and safer, is to use a belt collector which holds the shoulders belt in place. This makes it harder for the children to slide out of the belts and helps to keep the belt properly positioned (BeSafe, 2018). According to O’Neil et al. (2013), harness straps must be correctly adjusted and positioned. The straps should be fitted in a way so that the fingers slide of the straps when pinching the webbing at the shoulder. It is important that the belt collector is positioned mid-chest or at armpit level. Results from researches, that have been done of safety seats including belt collectors, have shown that 18% had the straps incorrectly positioned, 52% had straps that were too loose and 48% had belt collectors that were incorrectly positioned.

Due to the information above and interviews, issues regarding the seat belt from the safety seats have been an important factor during this project. The belt has therefore been developed in a way so that the children will be safely fastened, but also so the parents or other caregivers will be able to fasten the seat belt in an easy way, see figure 4.2. Instead of having two straps that has to be simultaneously clicked in the belt buckle, two straps will be fastened separately in a seat buckle each. These buckles will be fastened on a plate made of a plastic and covered with fabric; considering forces during accidents as well as the comfort to not hurt the child. The plate will have a loop so that the strap between the child’s leg can be fastened to the belt. Also, since belt collectors are an option to hold the two straps over the shoulders in place, this is considered in the belt that has been developed. In this way, no accessories are needed, and the caregivers do not have to consider if the child will wriggle out of the belt.
4.4 3D-CAD and Simulation

The child car seat is created as a 3D model in the software Inventor considering ISO standard 13216-3:2006, see appendix E. The ISO standard 13216-3:2006 is also a Swedish Standard and has guideline dimensions such as height, depth, width and anchorages; designed for the child restraint system that should be followed by manufacturers.

Firstly, the skeleton is created out of aluminum 6061 square pipes 10x10x1 mm that are welded with welding method MIG. The aluminum anchorages are welded to the skeleton. Secondly, sheets of aluminum 1050A with a thickness of 1 mm are covering the inner and outer space, following a sandwich method with the skeleton between the metal sheets. The space between the sheets is filled by an isolation material. The isolation material is soft as a sponge and also used to do the seat comfortable to sit on and avoid vibrations, see figures in appendix E. Lastly, before clothing, there is Styrofoam 40mm on the inner sides and 50mm on bottom where sit area is and 40mm back. The Styrofoam has the function to make seat comfortable. With its lightness the Styrofoam is needed in this product development because the target is as light seat as possible.

An FE-analysis is performed on the anchorages, see figures in appendix F. The result from the Von Mises Stress is 3.7 MPa the weakest point. The material’s yield strength is 275 MPa in normal conditions and 55 MPa when welded. This means that the strength of the assembly is high compared to the forces that it can be exposed to. The force of the anchorages can be given from equation (1) as follows:
Here, the weight of the seat is given which is 5.45 kg. and the result is that both anchorages are exposed to 802 N; 401 N on each anchorage. The force used in the simulation on one anchorage is rounded to 400 N, see appendix F.
5 Conclusion and Discussion

5.1 Conclusion

- Scientific articles, books and relevant information from the Internet have contributed to a knowledge of how this product work and how today’s market looks. Since the safety, price and low weight were important factors, criteria could be set.
- By interviewing daily users and observing the product, several problems could be noted regarding the seat’s functions and installation in the car.
- ISO standards have contributed to the dimensions of the seat, calculations of the force during accidents and a development of a seat that is safe.
- Product development resulted in child restraint system that is safe, light, easy to assemble and recyclable material aluminum.

5.2 Discussion

This project has been a little bit challenging since none of us have children and we do not use this product daily. We really had to put our soul into it and gain all knowledge available. It has been very fun to be a part of such a project and to develop a functional seat, which is hopefully better than existing products. We have been time-conscious, and our goal was to have everything done a couple of weeks before deadline so that we could have the time to read the report several times and finish it in detail.

To clarify the bullet list above, scientific articles, books and relevant information from the Internet have contributed to a knowledge of how this product is expected to work and how today’s market looks like. A market research gave an insight in competitors’ seats and what their advantages/ disadvantages are; their cost, what weight and age of the children they can handle, and the seats weight. This was easy to manage since all these data is available on the Internet of different retailers. Based on the pairwise comparison, safety, easy assembling, easy manufacturing and low weight showed to be the most important factors and was therefore set as targets, in form of criteria. These factors mean a lot since they differ from the seats that are available on the market and can in that way contribute to a competitive product. By interviewing persons, we noticed that they had a lot of opinions about the seats disadvantages. Afterwards, we considered to observe different seats in a store. By observing on our own, it was easier to understand what problem the daily users encounter and get different ideas of how we could develop a seat and ask us the question “How can our seat be better than the existing ones?”. This has been a
good way to find out what daily users encounters and what can be developed on the seat to facilitate. If we should have skipped this step, we would not have understood the problems and we should not have been able to consider factors that needs to be developed; for example, the belt. It is also very good to listen to other people about their ideas and opinions, in this way, focus is placed on the customer and that is appreciative.

The regulation today in Sweden is that children less than 135 cm. must use a special child restraint system approved according to UNECE Regulation 44 or Regulation 129. In the rest of the world the rules differ, for example, in Germany children younger than 12 years and under 150 cm. must use a child restraint system in the vehicle. In Japan the same rules are for the children under six years. Russian Federation does not allow children under 12 years and under 150 cm. tall to be transported without a child restraint system. In United States every state can decide their own rules regarding child restraint system and today the rules are that children younger than age four or eight (depending on the state) must be seated in a child restraint device while being transported in a vehicle.

The target on this safety seat was on low weight, easy assembling, recyclable material and high safety. High safety is priority number one and this seat fulfils the criteria from regulation 129 from UNECE. The seat consists of material aluminum and is therefore recyclable. It has a low weight, lower than most of the seats observed on the market. It is easy to assemble because it consists of 3 steps in manufacturing. The first step is welding the skeleton. The second step is placing the sheets outside and inside as a sandwich which has the isolation material between the outer and inner sheets which is the third step. This isolation material is also placed on the sitting area and round the sitting area, the back and the sides.

Our engineering specification is based on the market research, whereas we limited weight and price. Since we limited the usage of the seat for children between three and seven years old, during the project we realized that we had included seats for younger children below this limitation; we limited the seat’s weight to less than five (5) kg. which we could not achieve since these kinds of seats are for children between 15-36 months (depending on how big they are). Since a 3D-CAD was done, we looked up the weight thereafter.

However, the results are valid compared to the theory; the standards are described, and the result is following the instructions of the dimensions from the standards. The product development has resulted in a child restraint system that is safe, light, easy to assemble and made of recyclable materials. The weight is lower than several seats on the market, the used material aluminum is recyclable and is thereby good for the environment, the assembling is easier because the product consists of only
few parts/assemblies and the manufacturing is unclear if it is easier than other seats on the market but there are enough aspects which contributes to a lower price. Also, since the belt have been an issue on today’s seats, this has been the priority. A belt collector will not be needed since the belt is developed in a way so that the caregivers will be able to fasten the child in a safe and easy way. Safety has been a very high priority throughout the project and has been a fulfilled criterion.

One of the remarkable things was that the brainstorming of possible concepts was done before finding standards about the dimensions. The different ideas from the brainstorming became instead useful at later stages when selecting the final concept for the product; including the seat belt.

Lastly, our goal was to have a prototype in real size, 1:1. We bought material and since none of us can weld, we asked some colleagues to do it for us but none of them had time; which we were told a week later. Instead, we agreed in taping the skeleton and sheet metal. Here, we encountered some problems... The tape held the skeleton, which took a couple of hours to tape together and we were excited. When we started to tape the sheet metal, the skeleton began to bend since the weight was too heavy for the tape to hold. Honestly, we got disappointed because we spent several hours doing this and we wanted to have a prototype to work with and see how it would really look alike. So, we agreed in making a prototype of the belt and use it instead. If we had made the seat in size 1:2, or even smaller, the above mentioned would not happen since the weight would have been lighter. Also, if some of us knew how to weld or if someone could have helped us with it (which was the plan), the skeleton would have been much more stable, and the prototype would not have bend. Anyhow, we faced this and continued with the work to at least make a prototype of the belt and have a good 3D CAD model.
6 Critical Review

The social, ethical and safety aspects are very important while developing a product, where even economy and regulations weighs in. Here, the caregiver must work together with the child. The child must be safely fastened, and the seat must be properly fastened in the car to make the first mentioned possible. According to the interviews, the high priority is safety and then the economic part. Also, installing the seat is a problem since this must be done with straps and the car’s seat belt. This seat will be forward-facing and have ISOFIX that will be fastened in ISOFIX anchorages in the car. To be ensured that the anchorages will stand the forces, a FEA-analysis have been made and the result is that they will be able to stand the forces during car accidents. The caregiver will have to attach the seat into the ISOFIX and then fasten the child with the belt that has been developed. The seat belt has been developed in a way so that the child will not be able to wiggle out but will sit comfortably. Due to the critical selection of material and manufacturing methods, we have succeeded to manage the criteria of safe, easy manufacturing, easy assembling and light. The child restraint system that has been developed considers the ISO standards. This means that it meets the standard requirements and makes it safe; the purpose of these standards is to secure child safety in vehicles. The first and most important criteria from the pairwise is safe and has been met. It also has good recyclability, this because it consists of mostly aluminum which can be recyclable a several times. The skeleton is welded with the purpose to be stable, the sheets of metal are cut and bend to fit and cover the skeleton and isolation material is placed between the sheets. The isolation material is also used on the inside where the child sit, together with Styrofoam, with the purpose to make it comfortable. The seat will at the end be covered with fabrics and designed according to customers wishes; such as different pattern.

We have used Google Docs. throughout the project, which we have experience from before. It has worked very well, and we have been able to divide the report writing evenly and read each other’s texts. Since we are both distance students, we have had meetings each week and talked through what we have done in the previous week, and how we would put up the work for the coming week. Since we divided the different parts of the report, we could work separately and contact each other if some problem occurred or if we just wanted to share ideas. If the situation would have been different and if we did not have to work on distance, we would have done the same work. Even though we were two persons who worked together, it was important that we both did the writing equal and that we had the chance to do all parts. At the beginning, we made a Gantt scheme which we have followed and even worked in advanced some weeks. Our goal was to have a good knowledge based
on different theories, and we were therefore almost completely done with the theory before we started with the concept evaluation.

However, to meet the ISO standards, the seat must be dimensioned in a certain way which limited us on making any developments on the seat’s dimensions (height, width etc.). Instead, we had to check for different factors on the seat such as the belt, head- and neck support, comfortability, price and material. Since we did not have the possibility to simulate car crashes by our own due to shortage of time and access to software, Swedish Standard Institute (SIS) contributed with forces during accidents. If we would have had the possibility to make a simulation, we could have shown were the forces acts and maybe receive a better result. Also, since an accident can happen in several ways, e.g. as frontal- and side collisions, the people and vehicle equipment are exposed to different forces and situations. This project has been based on a side collision which have been done and explained in SIS-ISO/TS 29062:2009.
References

Websites


**Scientific Articles**


Books


Standards

Appendix A

A.1 Questions for the interviews

- What brand is your car seat?
- Is the seat facing backward or forward?
- What age is your child?
- Advantages/disadvantages of the car seat you use for your child?
- When the problems occurred with the car seat at which age was your child? what length did your child have and what weight?
- What is the most difficult thing while installing the seat in the car?
- How do you fasten the seat? (car belt or ISOFIX etc.?)
- What do you perceive as unsafe with the car seat you have/use for your children?
- What changes would you like to make?
- Are the instructions for mounting the seat in the car clear? Is there a risk of accidentally making mistakes during mounting?
- Can the chair be angled, is it easy to adjust the headrest position?
- Does the seat meet your requirements?
- What is your thought about the price? High / low?

A.2 Results from the Interviews

The persons are anonymous and the purpose with the interviews is to understand what problems they have during the installation of the seat(s), and what advantages and disadvantages can occur in the daily use.

A.2.1 Person one

What brand is your car seat?

Interviewed person: The brands that we use are Britax (3 pcs.) and BeSafe (1 pcs.). Two of the Britax models are the same, and they are both placed in the front seat in two different cars. The third Britax and BeSafe are placed in the back seat in two different cars; this is because they are safer than the two other Britax.

Is the seat facing backward or forward?

Interviewed person: All seats are faced backwards.
How many children do you have? What age are they?

Interviewed person: Two children, one is 3.5 years old and the second one is 1.5 years old.

Advantages/disadvantages of the car seat you use for your child?

Interviewed person:

**Advantages:** Britax takes less place and is good placed in the care. According to tests, BeSafe is supposed to be the safest seat and was therefore purchased. Also, the children sit well in it.

The advantage with the Britax is that it is a simple seat and I have a better view while driving, with this seat beside me I can see the side mirror on the car, which is not possible with BeSafe since it is a big seat.

**Disadvantages:** Comparing Britax and BeSafe, Britax looks cheaper and is cheaper than BeSafe. An example is that the seat has plastic fasteners instead of metal.

BeSafe is big and takes much place in the backseat and because of this it is not possible to use two seats of this brand, therefore we bought Britax as an extra seat.

How do you fasten the seat? (car belt or ISOFIX etc.?)

Interviewed person: I fasten the seats with the car’s seat belt and straps that are attached to the children seat.

What is the most difficult thing while installing the seat in the car?

Interviewed person: The most difficult thing is to fasten the seat since this has to be done with the seat belt and straps. It is hard to adjust the seat; a balance must be found between these two fasteners. It is not possible to only fasten the seat belt or the strap separately.

What do you perceive as unsafe with the car seat you have/use for your children?

Interviewed person: Something that I think is unsafe is the car seat belt. One of my children is 3.5 years old and is capable to take of the belt from the shoulders.
What changes would you like to make?

Interviewed person: I would like to change the seat belt (which applies to all seats we use). The belt has to be applied in two steps, firstly the two straps, were the children puts its arms, has to been hold together with one hand (there is a little magnet but it is not enough to hold them together) and then these two straps needs to click into the strap which goes between the children’s legs. This is difficult since if I drop the first two straps, and don’t succeed to click them in together in the third strap, I have to do it all over again. Some of my relatives needs approx. 15 minutes to succeed with this. I would like to only make one step instead of two while fastening my children.

Are the instructions for mounting the seat in the car clear? Is there a risk of accidentally making mistakes during mounting?

Interviewed person: I think that they are clear.

But the instruction for the Britax seat that I use in the front seat didn’t agreed with the correct mounting. The instruction said that the seat ABSOLUTELY may not touch the front panel, so I went back to the store and a person that worked there told me that according to test that have been made for this seat, the seat must touch the panel due to safety. The manufacturer of the seat hasn’t changed this in the manual since it is a high cost to change all manuals that have been made.

Can the chair be angled, is it easy to adjust the headrest position?

Interviewed person: BeSafe can be angled and it has a headrest which is adjustable, together with the belt. In this case the children can grow together with the seat.

Britax has a wedge (kil) which comes together with the seat, and the support legs can then be adjusted. The two seats that are the same doesn’t have adjustable headrest. The other model has an adjustable headrest.

Does the seat meet your requirements?

Interviewed person: Yes, firstly safety.

What is your thought about the price? High / low?

Interviewed person: BeSafe is expensive and when several seats are needed, the price is not ok since one seat costs 5000 kr. Since we have two cars, this equals to four seats which is a very high cost.

Britax costs approx 1800 kr.
Other comments:

Interviewed person: The first seat we bought was BeSafe and we used it for our older child. There is no other specific reason why this brand was chosen, then that it has been tested and was the safest seat according to e.g. Folksam.

The problem is not the seats, it is the cars and they are not fully customized for having seats since they can be low, and some seats can be hard to fasten in the car, and it can be hard to put in the children in the seats due to low roof. Britax is one seat that is easier to mount in the front seat since if it is mounted in the back seat, the driver cannot adjust the chair backward and forward because the seat is in the way. A solution may be a rotating seat, which I have seen is available on the market, but I didn’t receive good criticism from Folksam, maybe due to lack of safety.
A.2.2 Person two

What brand is your car seat?

Interviewed person: Maxi Cosi backward facing

Is the seat facing backward or forward?

Interviewed person: Backward

How many children do you have? What age are they?

Interviewed person: One child, daughter 4 years old

Advantages/disadvantages of the car seat you use for your child?

Advantages:

Interviewed person: The seat height can be adjusted in several steps.

Disadvantages:

Interviewed person: The safety child seat takes too much space from the car seat. It is difficult to move it and it was difficult to install it. Now the daughter is in the age of four years and she can’t use the safety child seat because she is too big for it although the recommended age is up to 5 years from the manufacturer.

How do you fasten the seat? (car belt or ISOFIX etc.?)

Interviewed person: It is not equipped for ISOFIX.

What is the most difficult thing while installing the seat in the car?

Interviewed person: There are too many straps and it was difficult to install it.

What do you perceive as unsafe with the car seat you have/use for your children?

Interviewed person: It is alarming the fact that the child can’t use it and she is only four years old, although it is recommended to use it till the age of five.

What changes would you like to make?
Are the instructions for mounting the seat in the car clear? Is there a risk of accidentally making mistakes during mounting?

Can the chair be angled, is it easy to adjust the headrest position?

Interviewed person: No, the chair can’t be angled but it can be adjusted in height.

Does the seat meet your requirements?

Interviewed person: Yes partly, the first 2 years. After 2 years the seat was too small.

What is your thought about the price? High / low?

-
Appendix B - Observation

Figure B.1 Child seat Britax, Award Winning Kid-Family.

Figure B.2 Child seat Britax.
Figure B.3 Child seat Britax, Max-Way

Figure B.4 Child seat BeSafe, Design Winner; adapted to a new evolution of fasten the seat in the vehicle.
Appendix C - Concepts

First concept, figure C.1, is considered as safe, comfortable, adjustable seat belt but the clips might cause locking.

Figure C.1 The first concept, focus on helmet and belt.

Second concept, figure C.2, is considered as safe both for neck and head but uncomfortable, could be too warm, the child has not much space and limited size on child’s body.

Figure C.2 The second concept, focus on head protection and neck protection.
Third concept, figure C.3, is considered as safe, comfortable, can be used on different child’s body sizes but the clips for the belt might cause locking.

![Figure C.3 The third concept, two different kind of belts.](image1)

Fourth concept, figure C.4, is considered as uncomfortable, complicated to fasten the child, the neck is not safe, but the head and the body are safe, light and consist of few parts.

![Figure C.4 The fourth concept, a west and a helmet.](image2)
Figure C.5 Concept of the belt; able to fit both a right and left safety seat. Protects the chest/shoulders and the child cannot wriggle out of the belt.

Figure C.6 Another concept of the belt; able to fit both a right and left safety seat. The belt should be fastened in the middle.
Figure C.7 Concept of how to fasten the belt to the seat; an alternative was clips.
Figure C.8 Concept of how to fasten the shoulder belts with clips and connect with the strap between the legs.
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<tr>
<td><strong>Advantages</strong></td>
<td>*Approved ECE R44/04 *Adjustable headrest to different height positions *Removable and washable cover</td>
<td>Approved ECE R44/04</td>
<td>Approved ECE R44/04</td>
<td>Five point belt</td>
<td>*Adjustable *Backward facing</td>
<td>*Approved ECE R44/04 *Adjustable backrest</td>
<td>*Approved ECE R44/04 *Backward facing</td>
<td>*Backward facing *Approved by Folksam tests *Approved ECE R44/04</td>
</tr>
<tr>
<td><strong>Limitations</strong></td>
<td>Forward-facing seat</td>
<td>Forwards facing</td>
<td>Only the belt from the car can be used</td>
<td>Not approved</td>
<td>3 point-belts</td>
<td>Forward facing</td>
<td>Not tiltable</td>
<td>*Not Isofix), *Not i-Size</td>
</tr>
</tbody>
</table>
Appendix E - 3D-CAD model

Figure E.1 The skeleton of the safety child seat.

Figure E.2 Illustration of the seat when the first layer of sheet metal and isolation material is added.
Figure E.3 Added second layer of sheet metal, seen from behind.

Figure E.4 Illustration of the seat seen from the front.
Figure E.5 Added isolation material to the inside of the seat.

Figure E.6 Closer illustration of the ISOFIX solution.
Figure E.7 Final product with added Styrofoam and belt.
E.8 Drawing of the skeleton.
E.9 Drawing of the assembly.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>QTY</th>
<th>PART NUMBER</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>1</td>
<td>TSL-00003095</td>
<td>Sheet Metal Back</td>
</tr>
<tr>
<td>43</td>
<td>4</td>
<td>TSL-00003096</td>
<td>Sheet Metal Side Middle</td>
</tr>
<tr>
<td>44</td>
<td>2</td>
<td>TSL-00003097</td>
<td>Anchorage for DGFIX</td>
</tr>
<tr>
<td>45</td>
<td>2</td>
<td></td>
<td>Mounted Knobs ERK 35-SML-08 Mounted Knobs</td>
</tr>
<tr>
<td>46</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Bar Thread M8</td>
</tr>
<tr>
<td>47</td>
<td>1</td>
<td>TSL-00003020</td>
<td>Sheet Metal Inner Side Angled Down Outer</td>
</tr>
<tr>
<td>48</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Inner Side Angled Upper Outer</td>
</tr>
<tr>
<td>50</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Side Upper</td>
</tr>
<tr>
<td>51</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Side Back</td>
</tr>
<tr>
<td>52</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Side Down</td>
</tr>
<tr>
<td>53</td>
<td>1</td>
<td>TSL-00003020</td>
<td>Sheet Metal Back</td>
</tr>
<tr>
<td>53</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Inner Side Angled Down Inner</td>
</tr>
<tr>
<td>56</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Inner Side Angled Upper Inner</td>
</tr>
<tr>
<td>61</td>
<td>2</td>
<td>TSL-00003020</td>
<td>Sheet Metal Inner Side Upper Front</td>
</tr>
</tbody>
</table>

Materials: Welded Aluminium 5083
Appendix F - FEA of Anchorages

Table F.1 Physical Properties.

<table>
<thead>
<tr>
<th>Material</th>
<th>Aluminium 6061</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2.71 g/cm³</td>
</tr>
<tr>
<td>Mass</td>
<td>0.275784 kg</td>
</tr>
<tr>
<td>Area</td>
<td>17773.3 mm²</td>
</tr>
<tr>
<td>Volume</td>
<td>101765 mm³</td>
</tr>
<tr>
<td>Center of Gravity</td>
<td></td>
</tr>
<tr>
<td>x = 54.8 mm</td>
<td></td>
</tr>
<tr>
<td>y = 17.6 mm</td>
<td></td>
</tr>
<tr>
<td>z = 12.5 mm</td>
<td></td>
</tr>
</tbody>
</table>

F.1 Simulation:1

Table F.2 General objective and settings.

<table>
<thead>
<tr>
<th>Design Objective</th>
<th>Single Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Type</td>
<td>Static Analysis</td>
</tr>
<tr>
<td>Last Modification Date</td>
<td>2018-04-01, 17:02</td>
</tr>
<tr>
<td>Detect and Eliminate Rigid Body Modes</td>
<td>No</td>
</tr>
</tbody>
</table>

Table F.3 Mesh settings.

| Avg. Element Size (fraction of model diameter) | 0.1 |
| Min. Element Size (fraction of avg. size)     | 0.2 |
| Grading Factor                                | 1.5 |
| Max. Turn Angle                               | 60 deg. |
| Create Curved Mesh Elements                   | Yes |
Table F.4 Used material(s).

<table>
<thead>
<tr>
<th>Name</th>
<th>Aluminum 6061</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Density</td>
<td>2.71 g/cm³</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>275 MPa</td>
</tr>
<tr>
<td>Ultimate Tensile Strength</td>
<td>310 MPa</td>
</tr>
</tbody>
</table>

Stress

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's Modulus</td>
<td>68.9 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>25.9023 GPa</td>
</tr>
</tbody>
</table>

Part Name(s)

TS1-000000197

F.2 Operating conditions - Force:1

Table F.5 Force:1

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>400,000 N</td>
</tr>
<tr>
<td>Vector X</td>
<td>0.000 N</td>
</tr>
<tr>
<td>Vector Y</td>
<td>0.000 N</td>
</tr>
<tr>
<td>Vector Z</td>
<td>-400,000 N</td>
</tr>
</tbody>
</table>
F.3 Figures - Von Mises Stress

Figure F.1 Illustration of Von Mises Stress with a single point.

Figure F.2 Illustration of the back-side of the anchorage.
I have learned a lot through this project, and hereby I really want to thank Sonja Vuletic for a great collaboration! I would also like to thank our supervisor and examiner.

Natali Despotovski

Thank you Natali for a good collaboration!

Sonja Vuletic