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Child Restraint System for Shared Mobility

Development of a Mobile, Rear-facing and Safe Car Seat for the Car Travels of the Future

Master's Thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020
www.chalmers.se

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In collaboration with Axkid and ESSIQ
Master’s thesis in Industrial Design Engineering

Chalmers University of Technology SE-412 96 Göteborg
Print: Repro Service Chalmers

ACKNOWLEDGEMENTS

To begin this report, we want to thank everyone who made this project possible. Firstly, we want to thank the people at Axkid who initiated and supervised this project. A special thanks to Johan Andersson and Daniel Lundgren, our supervisors at Axkid, who shared a lot of time and expertise with us. Thanks to your engagement, the project reached a much higher quality level. Secondly, we want to thank AnnaLisa Osvalder, supervisor and examiner of this thesis, who shared a lot of insights about child traffic safety and provided us with guidance. We also want to thank Jonas Sohtell and the employees at ESSIQ, who enabled this project and provided us with an educational workplace.

During the project, we have gotten the opportunity to participate in meetings by the project team Assessment of Passenger Safety in Future Cars at SAFER. We want to give a special thanks to Lotta Jacobsson and Katarina Bohman who arranged these meetings, but also to the rest of the participants of these meetings for sharing their knowledge about traffic safety. Finally, thanks to Oscar Rexfelt, for information about product development for shared usage and to all the participants of the User Studies, for sharing experiences and valuable insights regarding Child Restraint Systems.

ABSTRACT

This report presents a product development project, where the preliminary aim was to develop a concept of a rear-facing Child Restraint System (CRS) adapted for shared mobility. The CRS was developed for children in the stature range 61-105cm for the main users; parents who do not own a car. The secondary aim of the project was to investigate different possible customer groups for this type of CRS solution.

More and more parents are estimated to live in cities without owning a car in the future. The development of CRSs have to keep up with this trend to guarantee children's safety in the future. This project is initiated and supervised by the CRS company Axkid, with the purpose to keep up with this trend and to simplify for parents who do not own a car to travel safely and comfortably with a toddler.

To accomplish the aims, User Studies were conducted to study the different customer groups, their needs and priorities related to CRSs. A new research method called *User Study via Social Media* was conducted to gain access to the main users since they were difficult to reach since this group is still quite small. In similar channels a Survey was published that got over 400 responses.

The result of the project is the CRS concept *Axkid Free* **-** a rear-facing, foldable and mobile CRS. The concept was developed for parents who do not own a car. This group, in addition to being the main user, was found to be the most favorable customer group during User Studies, since they displayed a need for a new type of CRS, an interest and purchasing power. To comply with this group's needs, the Axkid Free has backpack straps and a low weight for easy transport, offers better storing opportunities than the common CRS by being foldable and is quick and easy to install and uninstall thanks to the chosen attachment systems. The concept Axkid Free is developed according to the UN R129 regulation and has a rebound bar, support leg and ISOFIX attachments systems to secure optimal safety.

Keywords: Child Restraint System, Child Traffic Safety, Product Development

GLOSSARY

The following terminology is defined and explained in this glossary to enhance the understanding of the report for the reader. The glossary is sorted in an order regarding relevance, not alphabetically.

Child Restraint System (CRS) - Child restraint system will in this report be referred to by its abbreviation - CRS or CRSs in plural form. Child restraint system is an umbrella term for the different available options of car seats for children. Different common types of CRSs are:

- *Infant Carriers*, used in an age span of 0-9 months.
- *Child Safety Restraint,* used for toddlers.
- *Booster Seat* or *Cushion* used for young children.

Shared mobility - Shared mobility is an umbrella term for things such as public transit, car-sharing, taxi, and micro transit/shuttle services.

Child Safety Restraint - The type of CRS that is used for toddlers will be referred to as Child Safety Restraint.

Infant - Children in the age span of 0-9 months old.
That is the age span of children that uses the CRS category, *Infant Carrier*.

Toddler - Children in the age span of 9 months to 5 years old.
The more common definition of a toddler is a young child that has not yet learned to walk properly and therefore toddles. It is common to define the age of a toddler for children from 1-3 years of age. However, in this report, the definition will be expanded to include children in the age span of 9 months to 5 years old to fit the span of children that is recommended to travel in rear-facing *Child Safety Restraints*.

Young Children - Children older than 5 years. That is the age span of children that commonly uses the CRS category, *Booster Seat* or *Booster Cushion*.

Child and **Children** - The terms child and children will be used as an umbrella term for the different definitions, infant, toddler and young children, and refer to children in general.

Parent - The person that is currently accountable for the child's safety.

A Mobile CRS - The phrase “mobile” or “mobility” in relation to Child Restraint Systems means a product that is adapted to be transported and manageable to handle by a user.

UN R129 = UN Regulation No. 129.
UN Regulation No. R129 (UN-ECE R129) is the newest UN regulation for child car seats, often referred to as UN R129 or as i-Size. The regulation is adopted by the EU and was introduced in 2013. The UN R129 used children's height as a reference when determining what size of CRS that should be used.

ECE R44 = UN Regulation No. 44.
UN Regulation No. R44 (UN-ECE R44) or also referred to as ECE R44 or R44 is an UN regulation for child car seats that is older than UN R129. It has been in place for over 30 years and has a weight-based classification that classifies children into different groups depending on the weight span of the child.

ISOFIX - ISOFIX (ISO 13216-1) is a universal anchoring system for attaching CRSs to vehicles. The system is an international standard developed by ISO. The system is divided into two parts, where one part affects car manufacturers which consist of two defined metal loops that should be positioned in a car's backrest. The other part affects CRS manufacturers and consists of two clips called ISOFIX attachments which are positioned on the CRS. The clips and the metal loops correspond to each other and both these elements are required for the ISOFIX system to work.

Rear-facing travel - Traveling rearward-facing, with the body and face turned opposite to the driving direction.

Forward-facing travel - Traveling forward-facing, with the body and face turned in the driving direction.

TABLE OF CONTENT

1. INTRODUCTION

This chapter gives an introduction to the master thesis. It contains background, description of the project proposal, aim and purpose, research question, and demarcations of the master thesis.

1.1 Background

According to Trafikverket (2018), it only requires a collision at 40km/h with a car to injure a child. Children have a small and fragile body that requires extra protection during car travels. If an accident occurs, the head and neck of a child move with violent force (Trafikverket, 2018). That is why regulation in Sweden says that every child shorter than 135cm needs to use a CRS during drives and is recommended until the age of 12. (Transportstyrelsen, TSFS 2014:52; Trafikverket, 2018).

Despite the regulation, there is a misuse of CRSs, with the result that children get hurt or die every year in traffic accidents (Trafikverket, 2018). Correct usage of CRSs decreases the risk of injuries or deaths of children in traffic accidents (Brown et al., 2009). According to Lundgren. D, Safety and Compliance Manager at Axkid (personal communication, 28 January 2020) the overall knowledge about child traffic safety in Sweden and other northern European countries is high, compared to the knowledge in the world in general. What is considered to be safe or not differs between the southern and northern parts of Europe, as well as in other countries across the world. To have a clear and manageable target group for this project, the primary target group for this master thesis was chosen to be parents in Sweden and the northern European countries.

The trend of global urbanization enables sharing, due to improved access to shared economy platforms in smaller living areas (Jiang & O'Neill, 2017). According to the World Bank (2018), in 2050, two-thirds of the global population will live in urban areas and the estimated number of vehicles in the world will reach two billion. All these vehicles will stress the infrastructure and cause difficulties such as traffic jams and negative environmental impacts. Shared mobility might be one solution to these problems and could benefit the population's urban way of living (Machado et al., 2018). According to the Shared-Use Mobility Center (2020), Shared mobility refers to mobility solutions that can be shared among many people, such as public transit, car-sharing, taxi, and micro transit/shuttle services.

As the trend of shared mobility increases, a new type of use situation for CRSs appears, together with new user groups and user needs. This master thesis comprises a product development project that is initiated and supervised by Axkid, as an opportunity to explore this new market, customer group and product segment.

Axkid is a Swedish company that develops CRSs for children with a focus on child traffic safety. The company was founded in 2009 and their CRSs are currently, in 2020, sold in 23 countries. Axkid believes that rear-facing car seats should be used for as long as possible to guarantee child safety on the roads. Child traffic safety is of greatest importance throughout the whole process and to ensure this, education and communication with both parents and retailers are included in Axkid's business idea (Axkid, 2020).

Figure 1 presents a spider diagram with eight parameters that visualizes Axkid's priorities for the final concept of this master thesis and is based on a pre-study as well as their industry knowledge. The most important factors to consider are safety and correct and safe use of the CRS This diagram worked as a guideline during the product development process and as a template to measure the concepts against.

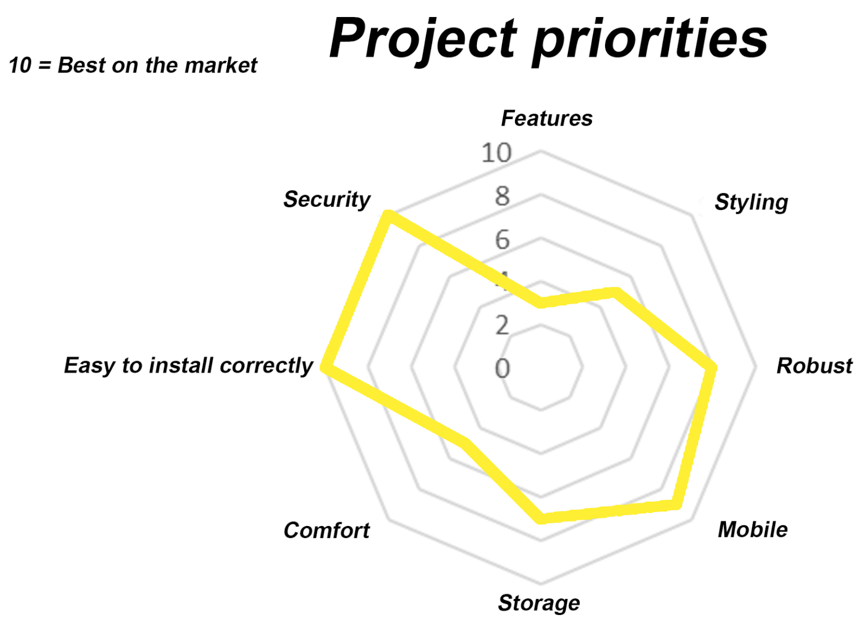


Figure 1: Priorities of the future concept.

1.2 Purpose

The purpose of this master thesis is to develop a CRS that enables and simplifies for parents, who do not own a car, to travel safely with a toddler. By inventing a CRS concept that is more mobile and offers better storing opportunities than the common CRSs on the market today, the needs and prerequisites to own a car as a parent can be lowered, as well as simplify the usage of shared mobility services for parents. To travel rear-faced is the safest position for children. The goal is to provide a rear-faced CRS concept that can be used more easily and, therefore, to a larger extent and in this way secure child traffic safety now and in the future.

1.3 Aim

The preliminary aim of this master thesis is to develop a product concept of a rear-facing CRS adapted for shared mobility. The goal is to end up with a CRS design that is mobile, rear-facing and safe. The concept should be developed for toddlers in the stature range of 61-105cm for the main users, parents who do not own a car.

The secondary aim is to investigate different possible customer groups for this type of CRS solution. Examples of possible future customers that have been considered are; parents or caregivers that do not own a car, guardians that transport children rarely, taxi companies and car rental companies that want to offer a safe journey for their young travellers.

1.4 Research Questions

- Which is the most favorable customer group for a CRS adapted for shared mobility?
- What needs and priorities of a CRS does the main customer group have?
- How will the new CRS be designed and constructed to fulfill the needs of the main customer group?

1.5 Demarcations

- Develop a rear-facing CRS for children with a stature in the range of 61-105cm.
- The demographic target group for the project is Sweden and the northern European countries.
- The developed CRS will be designed for usage in cars, and cars only.
- The CRS concept will comply with standards and the UN R129 regulation.

2. THEORETICAL FRAMEWORK

In this section, the theoretical background needed for this master thesis will be presented. The theoretical framework spans global trends, which is of importance for this project since it is a development project, the anatomy of children, and information about CRSs. Methodology description and tools and theories for product development related to the project are also outlined. The information in this theoretical framework was the result of the literature study as well as knowledge received from expert consultation.

2.1 Global Trends

In a product development project, it is important to keep the future and trends in mind to keep the concept up to date. This master thesis intends to develop a visionary concept for future use which makes analyzing global trends that could affect the CRS market important to study. Global trends such as urban growth and increased shared mobility justify the importance of developing a new category of CRS adapted for the constantly changing lifestyle.

2.1.1 Urban Growth

Urbanization refers to the proportion of a country that is urban. Urban growth is the increase in the number of people who live in cities (UNICEF, 2012). More than half of the human population lives in urban areas, and there is an annual increase in the number of people in the world that lives in urban areas compared to rural areas (Our World In Data, 2020). According to UNICEF (2012), an urban area can be defined by one or more of the following:

> “Administrative criteria or political boundaries (e.g., area within the jurisdiction of a municipality or town committee), a threshold population size (where the minimum for an urban settlement is typically in the region of 2,000 people, although this varies globally between 200 and 50,000), population density, economic function (e.g., where a significant majority of the population is not primarily engaged in agriculture, or where there is surplus employment) or the presence of urban characteristics (e.g., paved streets, electric lighting, sewerage).“

There is no global definition of threshold population size, which means when the United Nations presents statistics on urban and rural populations, they rely on definitions of rural and urban that vary between countries. In Sweden an urban settlement is 200 people but in Mali it is 40 000 people (McGranahan & Satterthwaite, 2014).

Living in Urban Environments

According to Kotulla et al. (2019) “High-density city development has become a key strategy for policy decision-makers to accommodate population growth and mitigate human impacts of the local and global environment”. The possible environmental benefits of living in high-density cities are reduced car use, the possibility of using shared facilities and land use (Kotullaet al., 2019).

A consequence of high-density cities is more compact housing (Kotulla et al., 2019). Micro living is an umbrella term for homes that do not conform to current minimum space standards and are divided into three categories; compact living (a smaller home), co-living (sharing rooms and facilities) and shared living (converted or divided houses) (BFF, 2019). According to the study of Kotulla et al., (2019) people who live in compact homes appreciate smart storage opportunities and multifunctional use of space.

2.1.2 Shared Mobility

According to the Shared-Use Mobility Center (2020), Shared mobility is an umbrella term for things such as public transit, car-sharing, taxi, and micro transit/shuttle services. There is a global trend toward a shared economy that can provide access to high-quality goods and services without using the traditional model of ownership. During the 21st century customers are more aware of the environmental and social concerns related to consuming new products and also the private economic gain in using underutilized assets. These things might be the reason why services such as Uber, Airbnb and other platforms that enable sharing resources have become popular in recent years (Machado et al., 2018).

2.2 Anatomy of Children

During a person's lifespan, the body undergoes major changes in strengths, physical traits and skills. From birth to adulthood, body dimensions change drastically, which is illustrated in figure 2. Length increases three- to four-fold while weight increases about twenty-fold during a person's first 20 years (Kroemer, 2006). At birth, a child's head is much bigger in proportion to an adult’s and 25 % of a child’s total body mass is in the head. For adults, the head composes 6% of the total body mass (Folksam, 2019). The trunk also undergoes major changes during a lifespan, in newborns the trunk composes 70% of the stature whereas for adults, the trunk is 50% of the stature. This affects the location of the center of mass of the body which, therefore, varies as the body develops (Kroemer, 2006). For anthropometric measures regarding children see Appendix A1.

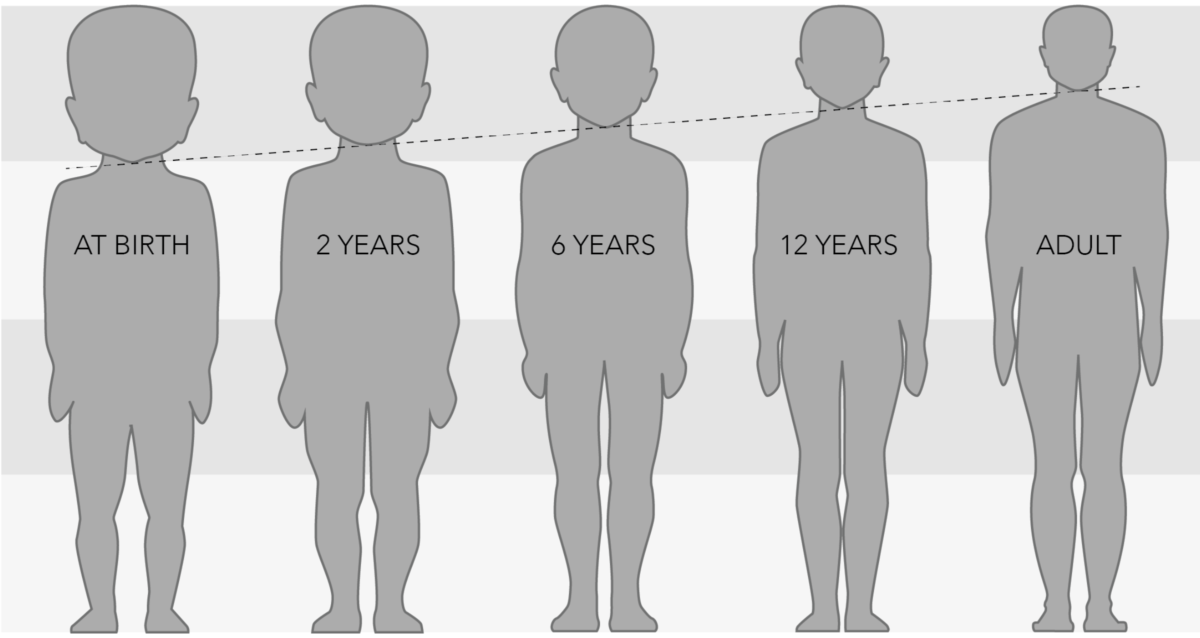


Figure 2: Body dimensions and the change in proportions from birth to adulthood.

At birth, children generally have a stature of about 50cm and weigh about 3.5 kg. Children's body size usually increases rapidly from birth up to 2 years of age. After 2 years, the growth slows down, until puberty strikes, where a growth spurt often occurs. Body changes during childhood and adolescence, however, vary much between individuals as well as rapid changes often occur quickly, in spurts, intraindividual. Development in body size depends on genetics, nutrition, health as well as activities and environmental factors (Kroemer, 2006).

Development in body mass is quite uniform between girls and boys before puberty. According to Kroemer (2006), the fact that interindividual variability is wide and the similarity in body mass development between genders makes it fatuous to arrange ergonomic information of children by gender or age. The similarity in mass development suggests that CRS designers do not need to differentiate children based on gender, according to Kroemer (2006).

There are some international differences in child anthropometry, this difference is small for young children, under the age of two however, the difference increases as children get older. According to Lueder and Berg Rice (2008), when comparing children from the United States, one of the tallest and heaviest populations, to children from Mexico, one of the shortest and lightest populations, the largest difference in average stature is 12mm at the age of 2 compared to 32mm at the age of seven. This difference continues to increase as children get older (Lueder & Berg Rice, 2008).

The difference between a child's body compared to an adult goes beyond visible changes. Bones, muscles and ligaments develop as a child grows. For children under the age of 8, the neck is more movable than an adult’s, due to that muscles are weaker, ligaments are more lax and the and the orientations of the shallow facet joints and cartilage have not yet been fully developed to bone. This also makes a child’s neck more vulnerable than an adult’s (Lueder & Berg Rice, 2008). The neck vertebrae development during childhood affects how vulnerable a child's neck is. At birth the cervical discs are rounded and the vertebral bodies are small. The cervical spine is also small in relation to the head. Between the age of 2 to 10 the cervical discs develop a flatter shape and the vertebral bodies grow and become more rectangular. After the age of 5 postural muscles and ligaments start to offer better support for the child's head. (Elowitz, 2017). The younger the child, the more at risk of injuries they are, due to that young children's bones are still developing. Younger children also have a thinner and softer skull. Also during a growth spurts the child's body can be more fragile (Lueder & Berg Rice, 2008).

Even though the development of children is often discussed based on age, age is a poor predictor of growth. How a child develops and grows is not based solely on age but on complex interactions between height, weight, growth rate, the onset of puberty and age. Children's development today also differs from previous generations. In general, children today are taller, heavier, less fit and enter puberty (especially girls) at an earlier age than previous generations (Lueder & Berg Rice, 2008).

It is important to consider children's physical development during product development of products for children. If an injury occurs during a child's development process the severity of the injury might be greater. Since bones and muscles are still developing together with their smaller size, makes children more susceptible to injury when big forces are active. For example in a car crash, if the child is not retained properly and appropriately. Children's injuries are therefore often more severe than adults’ (Lueder & Berg Rice, 2008).

2.3 CRSs - Child Restraint Systems

Cars as well as the safety systems active in cars, such as airbags and seatbelts, are designed with a “normal adult” in mind. Children who are smaller in size, have a different distribution of body mass and are more fragile due to their body composition, which is not as developed compared to an adult's body. Therefore, children are not protected by the car’s safety systems in the same way as an adult, which makes children more vulnerable during a car crash. Children, therefore, need additional protecting safety systems to be able to travel safely in cars (NTF, 2018), commonly referred to as child car seats. Child Restraint Systems (CRS for short) is an official term used in the child traffic safety industry and is an umbrella term for the different options of child car seats available like *Infant Carriers*, *Child Safety Restraints* and *Booster Seats* or *Cushions* (D. Lundgren, Safety and Compliance Manager at Axkid, Personal communication, 29 Jan 2020).

According to Swedish law, every passenger in a car must wear a seatbelt. It is also defined that children shorter than 135cm must use a CRS that is type-approved, suitable for the child, installed and used as intended. It is the driver, commonly the parent or guardian, that is responsible for the child's safety in traffic (NTF, 2018). According to NTF's website (2020b), children younger than 3 years old are not allowed to travel by taxi without using a CRS. The only exception is short temporary rides, in these situations the child is not allowed to travel in the front passenger seat. Children older than three are only required to use seat belts (NTF, 2020b).

A CRS is an expendable product similar to a typical bike helmet. If the CRS becomes harmed or fractured the CRS will not offer the same protection, therefore a CRS should be discarded if it has been involved in a collision (NTF, 2018).

2.3.1 Rear-faced Travel

To have a child traveling in a car in a rear-facing position, that is, with the body and face turned the opposite way from the driving direction, has many safety benefits for the child in case of a car crash. Sweden (Child safety experts and different instances) have a long tradition of advocating rear-facing car travel for children, going back to the first concept of a rear-facing car seat developed in Sweden in 1964 by Betril Adleman. Despite the many safety benefits, consumers, as well as CRS developers, choose, to a large extent, forward faced CRS for too small children (Jakobsson et al., 2013).

Safety Benefits

Due to a child’s anatomy, a rear-facing CRS should be used for as long as possible. In Sweden, it is recommended to use a rear-facing CRS for children up to the age of 4 to 5 years old (Folksam, 2019), in this report, referred to as toddlers. Although, Axkid’s recommendation is to use a rear-facing CRS for as long as possible, for children up to 25kg and 6 years of age since the protection effect is greater (Axkid, 2019). A rear-facing CRS is estimated to be more than five times safer than a forward-facing CRS (O'Neil et al., 2011).

Children are very vulnerable in a collision due to their large heads and the fact that the muscles and ligaments of the neck are not as developed as it is in adults. Children who are harmed in traffic accidents are therefore often affected by head injuries (Folksam, 2019). In a frontal collision, a rear-facing CRS gives support to the head and neck. The head and neck are slowed down together with the body and the forces of the motion are distributed evenly. Therefore, the rear-facing seat has a much lower strain on the spinal cord, neck and head than in a forward-facing CRS. In a forward-facing CRS, the child's body is restrained only with a belt and the heavy head is not supported in a frontal collision, which leads to a whiplash motion where the head is thrown forward and then back (NTF, 2018). These differences of distribution of forces during a frontal collision are illustrated in the illustrative figure 3. For children who travel in a rear-facing position 9 out of 10 are saved from injuries (Axkid, 2019).

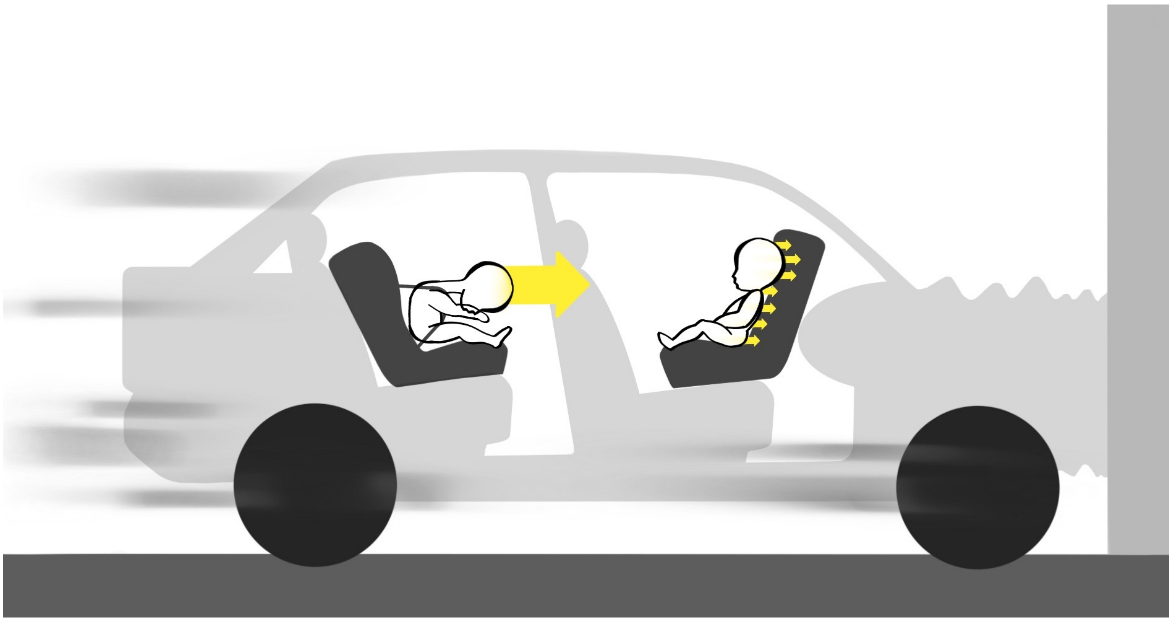


Figure 3: Illustration of how forces are distributed during a frontal collision in a forward-facing compared to a rear-facing car seat.

According to Folksam (2019), for toddlers the protective effect of traveling rear-facing in a car seat is 90-95% safer than traveling without any child restraint systems at all. As in a forward-facing car seat, the protection effect is 60-70% in relation to using no child safety restraint (Folksam, 2019).

There are CRSs on the market that can be used both in rear-facing and forward-facing positions, usually referred to as combi seats. According to Folksam (2019) the multiple adjustment options of turnable CRS increases the risk of misuse. That the combi seats are approved for forward-faced travel from a young age can be a temptation for parents to turn children into forward-facing positions too early and before the recommended age (Folksam, 2019).

History & Culture

In 1964 Bertil Aldman, a professor at Chalmers University of Technology in Gothenburg, Sweden, developed a prototype of a rear-facing child car seat. The prototype was the first of its kind to address the protection of children in cars and became a role model for the upcoming development of CRSs. Bertil Adelman's prototype was rear-facing, had a shell that aimed to distribute the loads, a rigid attachment system to the car and a harness that held the child in place within the shell. In 1967, Bertil Adelman's prototype was developed further and a rear-facing CRS was produced by Klippan (a Finnish company with a focus on car safety equipment) and sold in the Nordic countries (Jakobsson et al., 2013).

According to D. Lundgren, Safety and Compliance Manager at Axkid, there are big cultural differences when it comes to the usage of CRSs around the world (personal communication, 25 February 2020). Sweden and the other Nordic countries have a high awareness regarding the benefits of children traveling in rear-facing positions and use rear-facing solutions higher up in the ages (Jakobsson, 2017). In the rest of Europe, awareness is lower than in the Nordics and children are turning to travel forward-facing too early in relation to their physical development. In the south of Europe, forward-facing CRSs are mostly used for toddlers. In the United States rear-facing CRSs are used for toddlers but to a smaller extent than in the Nordic countries. Usage of rear-facing CRS and knowledge of child traffic safety is generally poor in developing countries (D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 25 February 2020)).

CRS's attractiveness and success rate are often discussed among experts around the world in the form of impact performance, child contentment, convenience and market appeal. This common view (outside of the nordic) results in that despite being convinced of the rear-facing CRSs superior protection and safety advances they are considered to be too inconvenient to be a good solution. This view, where the crash safety component only makes up a quarter of the important factors influences regulations and international recommendations and crash safety test scores (Jakobsson, 2017). The fact that UN regulations, adopted by the EU, do not measure neck loads, despite the fact that children who are harmed in traffic accidents are often affected by head injuries (Folksam, 2019), also results in that forward-facing CRSs can receive similar scores as rear-facing CRSs, which misleadingly makes them look equally safe (D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 25 February 2020).

The high level of awareness and usage of rear-facing CRSs in Sweden is, according to Jakobsson (2017), a combination of awareness, education and tradition which leads to social pressure on parents, as well as the unanimous in the message from Swedish expert during decades about the superiority of rear-facing CRSs. Another contributing factor is the Swedish *Plus approval*, a voluntary crash test focusing on neck forces during a car crash, which is widely accepted among Swedish parents. The *Plus approval* is also in unison with the message from authorities (Jakobsson, 2017).

Reluctance Against Rear-facing CRS

Despite the many safety advantages of a rear-facing compared to a forward-facing car seat, many parents turn their children earlier than what is recommended (which is 4 to 5 years). According to Folksam (2019), approximately six out of ten three-year-olds are placed in a forward-facing position during car rides. After outgrowing an *Infant Carrier,* it is easy for parents to be tempted to use a more convenient booster seat. Therefore, toddlers are the most important and challenging age group when it comes to CRSs (Jakobsson et al., 2013).

The reluctance against rear-facing CRS for toddlers is higher outside of the Nordic countries, although the same cons affect all parents. The common cons of using rear-facing CRS for toddlers are that they are difficult to install in a car, heavy and bulky as well as the lack of space for the child's legs in the car. Often the child as they grow older wants to travel like older children or adults and therefore travel forward-facing. Motion sickness and difficulties to have contact with the child that travels rear-facing in the backseat are also common cons described by parents (Jakobsson, 2017).

Gunilla Sörensen, researchers at VTI, described that the mounting of a rear-facing car seat is often perceived as difficult in comparison with other solutions. She also suspects that the complicated mounting increases the risk of not positioning the seat in a safer rear-facing position and chooses to mount the protection in a forward-facing position. Especially if the car seat should be used only during shorter journeys or temporarily in another car and that the risk of accidents during shorter drives is often neglected (Bergling, 2007).

Jakobsson (2017) describes that due to the many cons and the big reluctance against using rear-facing CRSs for toddlers, there is a need for a new CRS design solution. The new design should, according to Jakobsson (2017), target ease-of-use and future transportation needs, such as shared transportation, while applying the same protection principles as Bertil Aldman's initial concept of a shell for distributing loads, attachment system to the car and harness to position the child safely inside the shell.

2.3.2 Main Categories of CRSs

CRSs are an umbrella term for the different options of child car seats available and different variants included in this term are; *Infant Carrier*, *Child Safety Restraint* and *Booster Seat* or *Booster Cushion* which are illustrated in figure 4. These are the three main categories of CRSs, although there are more variants of CRS available on the market.

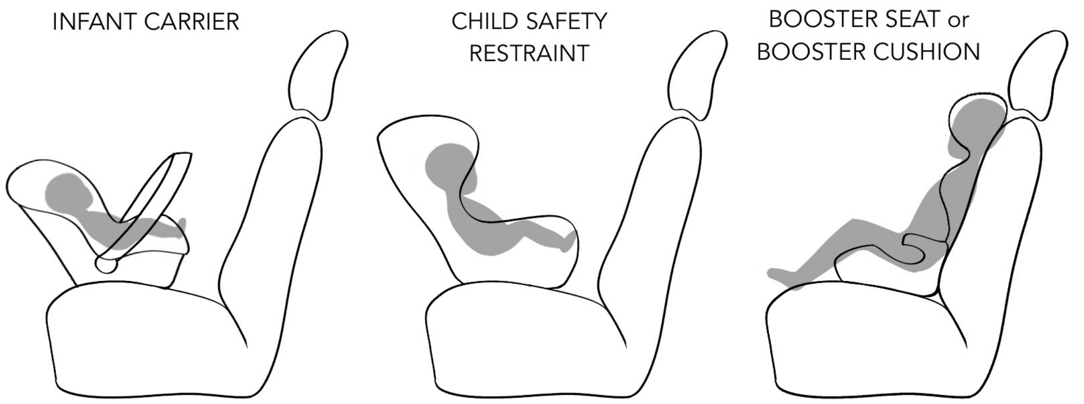


Figure 4: Illustration of the three main categories of CRS.

Infant Carrier

An *Infant Carrier*, also called a *Baby Seat,* is used for the smallest children, normally from birth up to nine months (NTF, 2018) or up to the child's stature is 75cm (United Nations, UN ECE R129 2018:3). The *Infant Carrier* is rear-facing and the child is held in place and secured by a harness connected to the *Infant Carrier*. This CRS option can be used until the weight or height limit of the *Infant Carrier* is reached or when the child's head is visible above the edge of the seat (NTF, 2018).

Child Safety Restraint

A *Child Safety Restraint* is a CRS that should be used as soon as the child is able to sit steadily without support. It is normally recommended from the age of 9 months to 4/5 years or for children with a stature between 61-105cm (United Nations, UN ECE R129 2018:3), as mentioned, this group will be referred to as toddlers in this report. There are both forward-facing and rear-facing options available, although it is recommended to use rear-facing seats for as long as possible since it is much more secure. The child is held in place and secured by a harness connected to the *Child Safety Restraint.* Once the weight or height limit of the seat is reached or when a third of a child's head is visible above the seat edge, the child has outgrown the *Child Safety Restraint* (NTF, 2018).

Booster Seat or Booster Cushion

Booster Seats and *Booster Cushions* are forward-facing CRSs. They have a seat cushion that aims to position the car's seat belt in a safe and correct way to fit children and the booster cushion can work with or without an integrated back support (see figure 4).

Booster seats or *Booster cushions* are recommended only when rear-facing car seats are no longer an option and not before the age of four or five, according to Swedish recommendations. It is also recommended that these CRSs will be used until the age of ten to twelve since the child's body and bones are not developed enough to keep the belt in place until puberty (NTF, 2018). According to D. Lundgren, Safety and Compliance Manager at Axkid, a booster seat and cushion is commonly used between the stature of 100cm and up to 150cm, however, D. Lundgren recommends rear-faced travel up to 125cm. (personal communication, 28 January 2020).

2.3.3 Terminology & Common Components of CRSs

A CRS is a complex product that consists of many different components. Depending on the design, model and main category, components vary. To enhance readability of this report the common components of a CRS have been illustrated in figure 5 on an existing CRS, of the model; *Axkid Modukid*, which uses an ISOFIX attachment system.

Figure 5: Terminology of common components of a CRS.
The CRS model in the picture is an Axkid Modukid that uses an ISOFIX-attachment system.

Additional components are present on a CRS that uses a seatbelt attachment system instead of an ISOFIX attachment system. These are visualized in figure 6 where the CRS Axkid Minikid is illustrated. The terminology used in the industry varies, however, the following phrases used in figure 5 and 6 is the chosen terminology of components that will be used continuously in this report.

Figure 6: Additional terminology of common components of a CRS. The CRS model in the picture is an Axkid Minikid that uses a seatbelt attachment system seen in front and side view, to best display functions.

A child safety restraint that uses ISOFIX-attachments commonly consists of two main parts, which are illustrated in figure 7, the chair part and the bottom plate, which is commonly called base. In an assembled CRS the chair part and the bottom plate are connected.

Figure 7: Illustration of common main parts of a CRS that uses ISOFIX attachments system.
The CRS model in the picture is an Axkid Modukid.

2.3.4 Regulations, Standards & Tests

There are many classifications and regulations regarding CRSs. Many regulations are active in parallel since when a new regulation is released it affects the CRSs that will be released from that on. However, the seats that are already on the market do not need to fulfill the new requirements of the new regulation and keep on being regulated by the regulation that was active during the CRS's release. In addition to UN regulations, there are many voluntary tests available that can influence customer purchases. The following regulations, standards and tests are of importance for this master thesis.

UN R129, i-Size

UN Regulation No. R129 (UN-ECE R129) is the newest UN regulation for child car seats and is often referred to as UN R129 or as i-Size. It came into force in July 2013 and is adopted by the EU. The goal of the regulation was to make CRSs easier to fit in cars and safer due to new safety tests from side impacts and keeping children in a rear-facing position longer. UN R129 CRSs are based on height rather than weight and require that children travel rear-facing up to 15 months old (RoSPA, 2020; Unece, 2016).

Changing the focus from children's weight to their height was an attempt to make it easier for parents since it was found difficult to know a child's weight and more common to know height due to the fact that children's clothing sizes correspond to height. However, according to D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 28 January 2020), since the ISOFIX attachment systems are only secure to manage a weight of 33kg of the seat and the child combined, the UN R129 regulated seats also need to be specified with a weight limit. To reduce the risk of misuse, the UN R129 regulation was originally focusing on use of ISOFIX-attachments, due to the fact that this attachment system is easier to install. However, from 2019 and forward belt attachments are allowed according to UN R129 (D. Lundgren, Safety and Compliance Manager at Axkid, personal communication, 16 Juni 2020).

ECE R44

UN Regulation No. R44 (UN-ECE R44) or also referred to as ECE R44 or R44 is an UN regulation for child car seats that is older than UN R129. ECE R44 will overtime be phased out and give way for R129 (RSA, 2016). ECE R44 has been in place for over 30 years and has a weight-based classification that classifies children into different groups depending on weight spans referred to as; G0, G0+, G1, G2 and G3, instead of UN R129 that uses the height of the child. In ECE R44 the minimum weight for the forward-facing seat is 9kg and the seat can be restrained by using the belt or the ISOFIX attachment system (UNECE, 2014).

ISOFIX (ISO 13216-1)

ISOFIX (ISO 13216-1) is a universal anchoring system for attaching CRSs to vehicles. The system is an international standard developed by ISO with the purpose of improving the safety performance of CRSs by reducing the risk of misuse and making installation of the system more convenient (ISO, 2020). The ISOFIX standard ISO 13216-1 provides requirements of geometry concerning anchorage points and for positioning of seat bight anchorages (ISO, 2018).

The ISOFIX system is divided into two parts, see figure 8. One part, the anchorage points, affects car manufacturers which consists of two metal loops that shall be positioned in a car seat’s backrest. The other part of the standard, affects CRS manufacturers and consists of clips called ISOFIX attachments which are positioned on a CRS and refers to by seat bight anchorages. The clips and the metal loops correspond to each other and both these elements are required for the ISOFIX system to work.

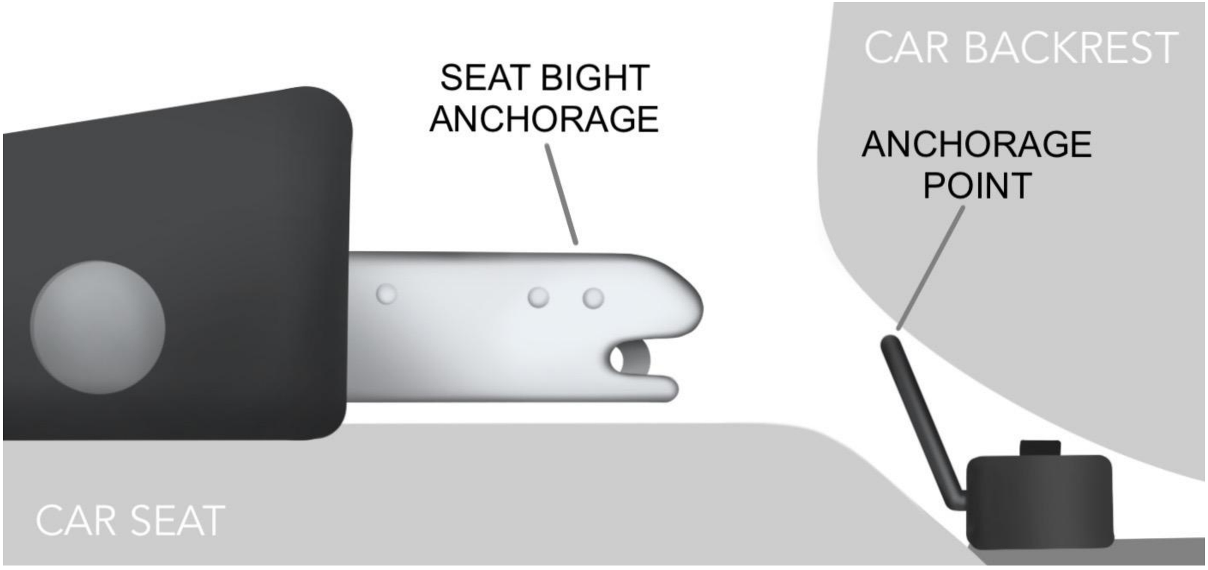


Figure 8: Illustration of the ISOFIX attachment system.

The car's ISOFIX system, the anchorage points, consist of two metal loops that are 6mm in diameter and at least 25mm long and are positioned in a line in the backrest of the car with a distance of 280mm between the two anchorage points. They are required to handle a force of 10 kN in strength in different directions (SIS, 2020). According to D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 28 January 2020), this corresponds to the fact that the ISOFIX system can secure a total weight of 33 kg. With a weight limit of 33 kg, both the weight of the child and the CRS are included in this weight limit. Due to the different spans of weight groups of test dummies that are used during crash tests, it is very common that child safety restraints that use ISOFIX are made for children of maximum 18 kg for ECE R44 and UN R129 regulated seats. Although, UN R129 regulations make it possible to have CRS with ISOFIX for children heavier than 18 kg as long as the total weight of seat and child combined is below 33 kg.

The ISOFIX attachments (seat bight anchorages) of CRSs have a lock mechanism and there are requirements that state that it should be clearly visualized for the user when the mechanism is properly looked, with a clear audible click or via color-coding. The ISOFIX attachments also have a predefined geometry to enable a correct match, independent of different manufacturers of cars and manufacturers of CRS (SIS, 2020). The standard also specifies that the attachments shall be rigid and enable easy installation of the system with a reassuring *click* feedback, this method is used in Sweden and Europe (ISO, 2020).

The ISOFIX standard was published in 1999 (ISO, 2020). The standard became a legal requirement in the United Statesand Canada during 2002 and 2004. The standard applies in Europe as well as in many countries outside of Europe. Therefore ISOFIX anchors are included in all new cars in the EU from 2014 (European Commission, 2012; ISO, 2020).

R2 Envelope (ISO 13216-3)

In addition to the ISOFIX standard ISO 13216-1, there is an additional standard, ISO 13216-3, that is relevant during development of a CRS. The International ISO Standard has the goal to ensure that the CRS will fit into cars (ISO, 2018). The classification should help consumers when choosing CRS to make sure that it is dimensionally suitable for their car. To ensure this, the interior of the car and the CRS have to correspond spatially. The ISO 13216-3, therefore, provides requirements both for car manufacturers regarding the space needed inside cars as well as to developers of CRS.

According to D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 17 Mars 2020), the category that is relevant for this project is the R2 envelope dimensions, which is for a reduced-size rear-facing toddler CRS, also referred to as ISOFIX size class D. See figure 9, for an illustration of the R2 envelope, to receive exact dimensions of the R2 envelope, the standard has to be bought.

The child restraint envelope simulates the dimensions of a CRS and is used to evaluate the space that is available in a car. Therefore, the CRS should be able to fit inside the child restraint envelope in at least one operational and crash secure position. However, it is accepted that the CRS is used in other positions where the CRS exceeds the boundaries of the child restraint envelope. An addition to the ISO 13216-3 regulated the support leg, which is allowed to be positioned outside of the R2 envelope during use (D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 29 January 2020)).

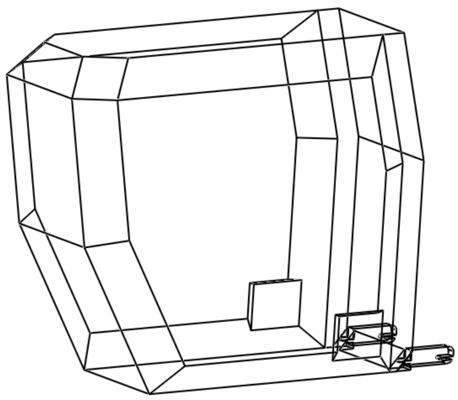


Figure 9: Appearance of ISO/R2 envelope for a reduced-size rear-facing toddler CRS

Plus Approval

In Sweden, a CRS can receive a Plus approval (in Swedish called *“Plustest”)*. Plus approval test is an additional, voluntary child safety test that investigates CRSs for children in the weight category of 18kg (for CRSs that use ISOFIX attachment systems) and 25kg (for CRSs that use seat belt attachment systems).

A Plus approval test measures the forces that the child's neck is exposed to in a frontal collision, something that ECE R44 or UN R129 do not. A Plus approval test investigates whether or not a child's neck can be subjected to forces that are life-threatening during a frontal collision (NTF, 2018). All CRSs that are for sale in Sweden are already approved and have passed UN R129 or ECE R44 requirements, but a car seat that receives a Plus approval gives a higher degree of security since the neck forces are not measured in UN R129 or the older ECE R44 test (NTF, 2020a). The Plus approval test is voluntary, however, it provides a competitive advantage on the Swedish CRS market and is widely accepted among Swedish parents (Jakobsson, 2017).

2.3.5 Design Guidelines for CRS

In addition to the regulation, standards and tests that influence the design and construction of a CRS, the product also has additional less formal guidelines that need to be followed in order for the CRS to fit in different car models, have good usability and offer a secure use situation for children. The following factors and guidelines have been used during the project's development process of a CRS.

Anchoring of Rear-facing CRS

Elements needed to anchor a rear-facing car seat in a secure way:

a. Main attachments: ISOFIX attachments or seat belt attachments.
b. Secondary attachments: a form of *Anti-rotation device*. This can be a *Support leg,* which is commonly used in Europe and Asia, or a *Top Tether* which is commonly used in the United States and Australia.
c. Third attachment: a *Rebound device*. It can be a *Rebound bar* or *Lower Tethers.*

These facts and expressions are given by D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 29 January 2020) and the information is also based on Folksams report from 2019.

In figure 10, the different anchoring elements are illustrated. The picture offers two possible alternative anchoring solutions, however, the elements can be combined in more alternative variations as long as main, secondary and third attachments, point a-c, are all included.

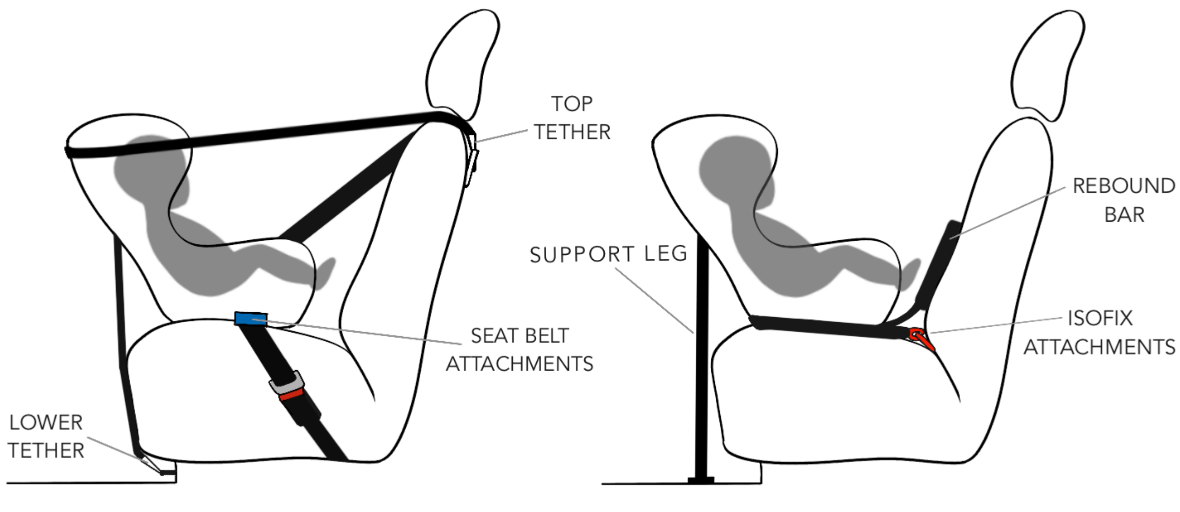


Figure 10: Elements needed to secure a rear-facing child restraint system in two alternative solutions.

To position the CRS in the car, main attachments (a), which is an ISOFIX attachment or a seat belt attachment, should be used. This to give the CRS support and secure the seat from rotating during a collision in a forward motion, like in a frontal collision, secondary attachments (b) are used. A rebound device, third attachments (c), should be used to prevent rotation of the CRS during a backward motion during a collision, which happens if the car is hit from behind or when the car bounces back after a frontal collision (Folksam, 2019).

A properly anchored child seat that uses a seat belt attachment system is just as safe as a car seat that is anchored with the ISOFIX attachments system. Although the chance of installing a child car seat correctly is higher when using the ISOFIX system (NTF, 2018).

According to the UN R129 regulation, it is not allowed to apply both an ISOFIX and a seat belt attachment system on the same child safety restraint (infant carriers are excluded from this regulation (D. Lundgren, Safety and Compliance Manager at Axkid, personal communication, 14 April 2020). If the CRS uses ISOFIX as main attachments a Rebound bar should be used and it is not allowed to use lower theaters as third attachments (D. Lundgren, Safety and Compliance Manager at Axkid, personal communication, 25 February 2020).

A child safety restraint that uses seat belt attachment systems can be used for children up to 125cm (UN R129), or 25 kg (ECE R44) (NTF, 2018). While a child safety restraint that uses ISOFIX attachment systems can carry a total weight of 33 kg, including both CRS and the weight of the child. This demand is commonly translated to that an ISOFIX CRS is used for toddlers up to 105cm (UN R129) or 18 kg (ECE R44), however, these boundaries are only commonly used and not regulations. As long as the total weight of 33 kg is not exceeded and the geometry of the child safety restraint complies with the requirement of the regulation, a CRS that uses ISOFIX attachments can be used for taller and heavier children than 105cm and 18 kg, according to D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 28 January 2020).

Slope Angle of Backrest of Child Safety Restraints

Depending on a child's age the slope angle of the backrest of a CRS should be different, the younger the child, the wider the angle. According to D. Lundgren, Safety and Compliance Manager at Axkid, the appropriate slope angle for a backrest of a CRS for children as they start using a child safety restraint (which is usually around 9 months) is approximately 30-35 degrees angle. As the child grows this angle can be narrower and when a child is 4 years old the child can usually sit at a 20 degree angle. For a CRS without an adjustable backrest slope should according to D. Lundgren be between 20-35 degrees. Since the car seat commonly has a pitch angle of 8 degrees, an additional 8 degrees has to be added to the angle of the backrest (personal communication, 24 Mars 2020). For a child safety restraint without an adjustable slope angle of the backrest should, therefore, have a slope angle in the span of 28-43 degrees.

2.4 Methodology Descriptions

In this section, general descriptions of the research, ideation and evaluation methods used during the master thesis project will be presented. The purpose of the section is to provide a general understanding of the methodology and to describe which methods were used.

2.4.1 Research Methods

Research methods are used to get an understanding of the problem and its background. The research methods can result in both primary and secondary data. Primary data can be collected through different research methods by researchers themselves within the project. Secondary data is collected by other researchers outside the project and maybe collected for other purposes, however, the information is useful for the project (Bligård, 2017).

Interviews

Interviews are a data collection method. Interviews can be structured, semi-structured or unstructured. A structured Interview often means that questions are formulated in advance, and the Interview follows a strictly planned order which is preferable if quantitative data is the goal. A semi-structured Interview can follow a preplanned plan on, for example, which areas to touch or which questions to ask, the difference is that there is more free talk about these areas than a structured Interview has. Semi-structured Interviews are useful to collect qualitative data while maintaining a structure for the interviewer during the Interview and analysis of answers. In an unstructured Interview, a free discussion takes place with the person that is being interviewed, which is preferred when qualitative data is requested (Lantz, 2013).

Self Observation

Self Observation is a research method to gather hidden information, restricted or subjective. The observer in Self Observation is the same as the observe. By trying to do the same things as the user, it gives a sense of how the user experience is. Self Observation can be a way to get a feeling of thoughts, emotion and other criteria that can be hard to ask about in an ordinary Interview or see in an observation (Rodriguez et al., 2002).

Survey

A Survey can be described as a kind of structured Interview where the interviewer is not present. Commonly a form over the internet or on paper containing a number of questions is provided to the interviewee who is able to answer them in writing text. A Survey is an indirect method, that means no personal contact exists between the person responsible for the Survey and those who answer it. A Survey is useful to gather data from a large number of people, people that might be hard or demanding to get to in person.

It is important to develop a survey with clear questions that is hard to misinterpret, that the questions in the form gives answers to the essentials underlying question the interviewer has and the Survey is conducted so it is possible to do wanted analysis afterwards. It is a good idea to do a pilot evaluation of the survey with some relevant people, before sending it to the large group of people. By doing that some easy mistakes can be corrected in an early stage (Bligård, 2017).

Benchmarking

Benchmarking is about examining how others have solved a problem and examining their results to learn about what they have succeeded with and finding areas of improvement. A Benchmark can be conducted on products in the same segment or in other industries with similar problems (NPD Associates, 2016).

Persona

One way to involve the user or stakeholder in development work is to create a Persona. The method is about creating fictitious descriptions of one or more people who belong to the desired target group. The purpose of creating a vivid and authentic description of the user is to get a better understanding of the user and have empathy for their wishes and needs during the development process (Wikberg et al., 2015).

User Journeys

User Journey is a visual way to present a process or path that the user goes through or does to accomplish a goal. In a User Journey, it is common to follow a persona through a scenario where specific actions, thoughts and emotions are highlighted. The purpose is to get designers and developers a picture of how users might behave while using a specific product or system to be able to improve the user experience (NASA, 2019).

Function Analysis

Functional Analysis is a way to map how the goal of the system can be transferred into functions that the system should contain. The starting point for the Functional Analysis is what is to be achieved and not how it is to be achieved. The Function Analysis can then be transformed into a system analysis by describing what constituent parts the whole system has and how they work together to make it work (Bligård, 2017).

KJ-Analysis

A KJ Analysis is used to obtain an overall picture of large amounts of data. This is done by dividing the data into constituents and then grouping them according to appropriate themes. It is a "bottom-up" strategy that is based on studying details first to add them together as a whole. The KJ-Analysis is named after the inventor Jiro Kawakita and is also called kinship charts or the “yellow patches method” after post-it patches are commonly used (Bligård, 2017).

Literature Study

One type of data collection method is literature studies. A literature study is a systematic, methodical and critical review of the literature with a scientific purpose (Bligård, 2017).

2.4.2 Ideation Methods

Ideation is an important part of a product development project. Ideation can be seen as an organized way of generating new ideas. In an Ideation process, it is important to think creatively rather than critically and work with quantity rather than quality in the beginning. The following section provides descriptions of the methods used to generate ideas and solutions to problems.

Brainstorming

The method was developed from the beginning by Axel Osborn and published in his book *Applied Imagination,* Osborn (1953). The idea with the method is that it should encourage ideas and thoughts that may at first appear a little crazy. Some of these ideas can lay the foundations for original and creative solutions to problems. It is therefore of great importance that ideas during brainstorming are not criticized or rejected. During the brainstorming session, ideas must be documented in some way so that they are not forgotten.

Morphological Matrix

When the main and sub-functions of the product are defined in Function Analysis, a Morphological matrix can be used to generate different sub-solutions to the different sub-functions. To generate as many solutions as possible on the identified sub-functions an Ideation method such as Brainstorming is advantageously used. When the number of different sub-solutions is considered enough for the progress of the development work, these are combined into different overall concepts. The advantage of a Morphological Matrix is that it generates a very large variety of different concepts (Wikberg et al., 2015).

2.4.3 Evaluation Method

After generating ideas and concepts, it is important to look back and see which of them fulfill the needs and requirements that were funded in the user research best.

Kesselring Matrix

Kesselring Matrix is an evaluation method where different concepts are compared with a reference, as in this case, which is the ideal solution. An assessment is then made of how well each concept meets the respective criteria. Finally, the points for each concept are summed up and a ranking is obtained (Bligård, 2017).

2.4.4 Visualizing Tools

It is important to visualize ideas during product development projects. To bring ideas to life for the project team or to a client. In this section visualisation tools or varied complexity will be described.

Sketches

Sketches are a visual tool for designers to visualize the thought process and are often used early in the design work. It can be a tool both for the designer himself/herself and a way to communicate and document how a product should look and function to other people (Wikberg et al., 2015).

Sketches can have different quality depending on the purpose and can range from simple idea sketches within the project group to color and material renderings to show to clients and other stakeholders more detail about functionality and purpose (Wikberg et al., 2015). The sketches can be used to describe the product at different levels, from the whole concept down to details (Österlin, 2003).

Physical Models & Mock-ups

Physical models and mock-ups are three-dimensional prototypes of products, where physical models have in general a simpler and more sketchy design, while mock-ups have a higher degree of functionality. Mock-ups are good for exploring human interaction with the current product (Wikberg et al., 2015), while physical models are good for internal communication within the project, as well as a quick, easy and inexpensive way to test and visualize form, function or structure (Österlin, 2003).

Virtual Prototyping

Virtual prototyping means building a prototype in a modeling and simulation program on a computer (Johannesson, Persson, & Pettersson, 2013). This can be done using various CAD/CAID programs, which are used to create virtual models in 3D (Wikberg et al., 2015).

2.5 Product Development Theory

In this section, some product development theories that have been of importance for the development during this master thesis will be explained. The goal is to provide a better general understanding of the product development process.

2.5.1 Usability

Informally, usability can be explained as, how easy the product is to use (Jordan, 2002). The formal definition by International Standardization Organization (ISO) defines usability as “the extent to which a product can be used by specified users to achieve specific goals with *effectiveness*, *efficiency* and *satisfaction* in a specified context of use.” (ISO 9241-11: 2018). *Effectiveness* in this definition refers to the extent a user can accomplish goals or tasks with accuracy and completeness. *Efficiency* refers to the effort required by users to achieve this goal and *satisfaction* to the absence of discomfort experienced by the user during use (Jordan, 2002).

Jordan (2002) complements the ISO standard definition with components which are *guessability, learnability, experienced user performance, system potential* and *reusability.* These can be usable to consider during a product development process to enhance usability and are described by Jordan (2002) as;

Guessability	The effectiveness, efficiency and satisfaction specific users to achieve specific goals with a specific product for the first time.
Learnability	The effectiveness, efficiency and satisfaction of specific users can achieve a good level of performance on specific goals with a product, when they have already achieved that goal once before.
Experienced user performance	The effectiveness, efficiency and satisfaction specific experienced users to achieve specific goals with a specific product.
System potential	The optimal level of effectiveness, efficiency and satisfaction to achieve specific goals with a product.
Re-usability	The effectiveness, efficiency and satisfaction specific users can achieve specific goals with a specific product after a comparatively long period of time away from these goals (Jordan, 2002).

2.5.2 Norman's Design Principles

There exists a number of design principles. Some are based on theory, experience or common sense. This section presents some of Norman's (1988) principles like visibility, feedback, constraints, mapping, consistency and affordance, described by Sharp, Preece and Rogers (2019).

Visibility	The more visible a function is, the more likely it is that the user finds it and interacts with it in an accurate way. If a function is positioned out of sight, it is harder for the user to find and know how to use it.
Feedback	Feedback is when the user receives information about what he/she has done or accomplished. The perceived feedback from the task generally allows the person to continue with an activity and provides the user with a sense of security that the task is executed. Products can give various kinds of feedback - tactile, audial, visual, verbal, or combinations of these. The most successful or best combination of feedback differs. The usage of feedback in an effective way can provide necessary understanding for user interaction and increase the success rate of the task.
Constraints	With constraints means restricting the number of interactions that can take place at a given time. By restricting different ways, ways that do not benefit the user, the number of ways to execute a task becomes less and the likelihood that the user makes the correct decision increases.
Mapping	Mapping refers to the relationship between controls and their real effects in the world. One example of mapping is up and down arrows that represent up and down movement of different objects.
Consistency	Consistency refers to designing functions that have similar operations and using similar elements to achieve similar tasks. It can be consistent within a system - then the same operations are applied many times for similar tasks. Or as consistency between systems - then operations follow rules that are common knowledge and many other objects are also using.
Affordance	Affordance refers to the intuitivity of a product. That is if the product gives clues on how to use it. For example, if a push-button encourages the user to push it. (Sharp, Preece and Rogers, 2019)

2.5.3 Product Semantics

Semiotics is the study of signs, and semantics is the study of their meaning. In product design, the product is the sign and the designer can, therefore, encode different meanings into the product, that the user then will decode. The designer can, for example, give the product attributes that express the purpose of the product, how it will be used, or encourage certain use behavior (Sunde, 2019). According to Sunde (2019) “Round shapes are considered ‘friendlier’ than angular ones. Studies also show that angular and sharp featured objects trigger the amygdala in the brain, which processes fear”.

3. IMPLEMENTATION

This chapter aims to illustrate the project's process, from start to end and should provide an understanding for the reader regarding the content of the reports chapters. The process is divided into four phases; Exploration, User Research, Ideation and Development. Each of these four phases is divided into four separate chapters of this report. The process used during the implementation of this project has been iterative and every phase starts broad and converges down to a result. All four phases have methodology, results and conclusion sections and are chronologically presented. The project process is described in figure 11.

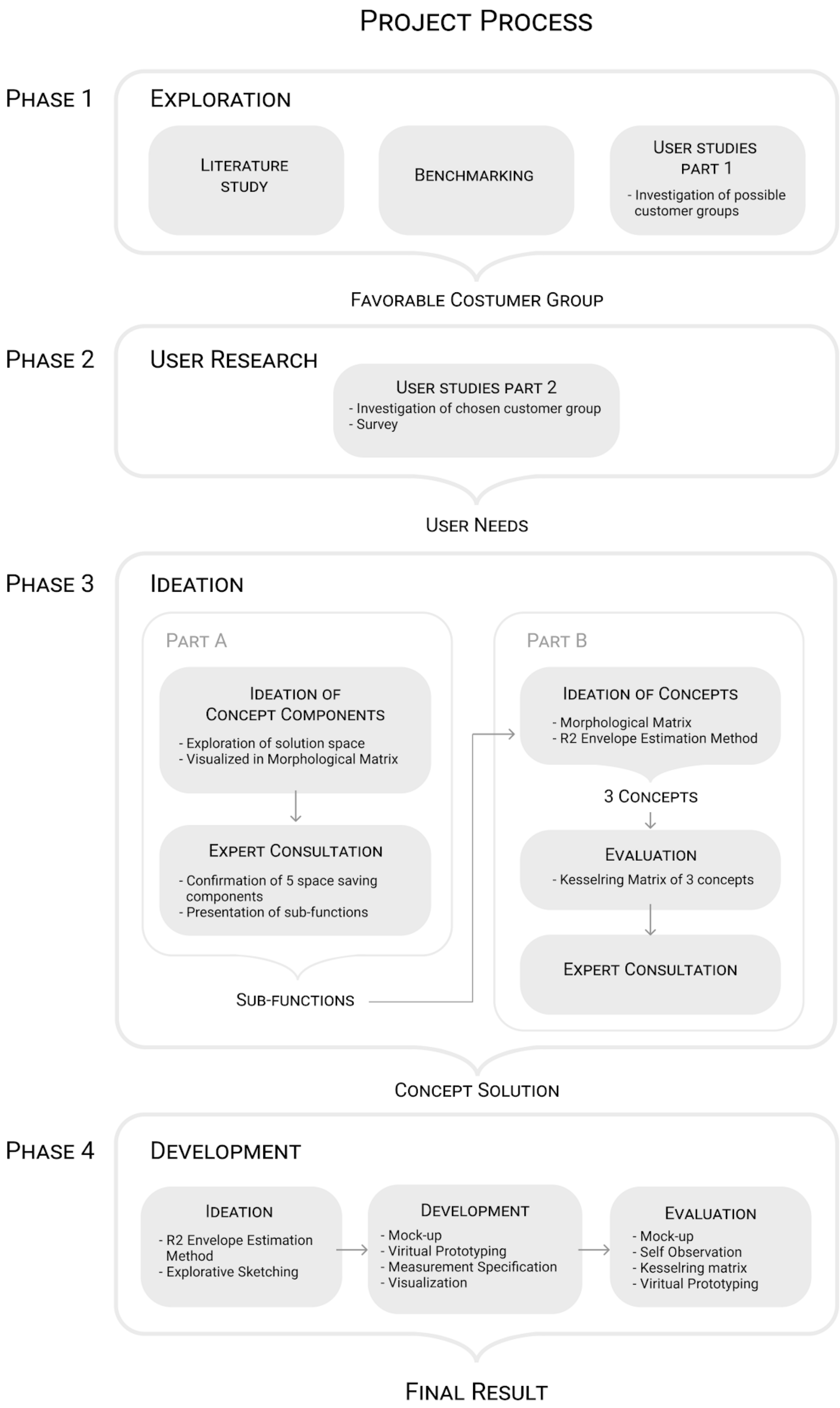


Figure 11: Schematic image of project process.

4. PHASE 1 - EXPLORATION

During phase 1, the main goal was to investigate possible customer groups for a mobile CRS. Parents will always to some extent be the main user of the CRS. Children will also be a user since they will sit in the CRS. However, since this project target is young children, 9 month to 4-5 years of age, the parents will be in charge and have been considered as the main user during this project. However, who the buyer and owner of a CRS are can be others than parents. The customer and owner of a CRS will also become a type of user and their needs will also have to be considered in development. The possible customer groups that were presented in the project brief from the client, Axkid. During the User Studies Part 1, a dialog has been kept with 58 persons in total from the various groups. The groups that have been considered and investigated are; Taxi companies, carpool companies, car rental companies, CRS rental companies, grandparents and parents. To gain an understanding and a theoretical background to the project and to the field of CRSs, a Literature study and Benchmarking was performed.

4.1 Methodology

In this section, the methodology of the User Studies Part 1 will be described. Methods used are; Literature study, Benchmarking, Interviews, and a method called User Studies via Social Media, which was developed during this thesis with the goal to gain information about inaccessible users. The findings were then analyzed by a KJ analysis and Funktion Analysis. In figure 12 Phase 1 is illustrated in a schematic image.

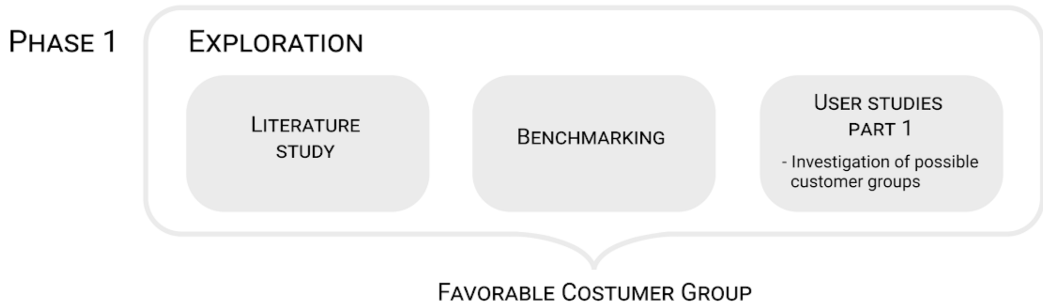


Figure 12: Schematic image of project process of Phase 1.

4.1.1 Literature Study

To be able to develop a rear-facing CRS adapted for shared mobility, a Literature study was conducted. The goal was to gain insight into areas of interest for this project such as; the CRS industry, standards, regulations, child anthropometry, and global trends. The literature that was used consisted mostly of scientific papers, popular scientific papers. This information was interpreted and analyzed.

4.1.2 Benchmarking

A Benchmarking of different CRS models was performed to get an overview of the CRS market and to gain inspiration. The Benchmarking was conducted both in different stores that sell CRSs and other equipment for children, at Axkid (who has a selection of CRSs available at their premises) and over the web. Over 20 different CRS models were examined physically in stores and at Axkid. The CRS models that were examined were from many different brands, including different models from the Axkid brand. Several CRS models were also examined via the internet.

The Benchmarking included both *classic* CRS models which do not have a mobility focus, as well as more *rare* models that were developed to be lighter and easier to transport. The Benchmark consisted both of studying CRS models as a whole, but also investigating different specific components and how different manufacturers have solved different problems. In the beginning, Benchmarking was used to simply gain an overall understanding regarding CRSs, how a CRS works, how it is anchored in a car, and what components that are necessary for safety reasons. After having learned the basics, the Benchmarking became more comprehensive by investigating design aspects, form factors, usability, and materials of some of the selected CRS models.

4.1.3 Function Analysis

To summarise what functions and goals that a CRS has to fulfill, a Function Analysis was conducted. The Function Analysis was mainly based on findings from Benchmarking and Literature study.

4.1.4 Interviews

To gain an understanding of the possible customer groups and their needs, a series of Interviews were conducted. The interviewees are described in table 1. The Interviews were both semi-structured and unstructured to receive qualitative data and gain a deeper understanding of different target groups. See section 2.4.1 - Interviews for methodology description.

Table 1: Interviewees of User studies Part 1, with description and Interview type.

Interviewee object number	**Trade or title**	**Company name and type**	**Interview type**
1	Store Employee	Big Baby - children store	Unstructured Interview in store
2	Taxi driver	Taxi Jönköping AB	Semi structured Interview via telephone
3	Taxi administrator	Taxi Göteborg	Semi structured Interview via telephone
4	Business developer	Move About - Carpool company	Semi structured Interview via telephone
5	Product developer	M - Carpool company	Semi structured Interview via telephone
6	Operator	Avis - Car rental company	Unstructured Interview at location
7-9	Parents who owns their car		Semi structured Interview via telephone and at location
10-12	Grandparents who owns their car		Semi structured Interview via telephone
13-58	Parents		Unstructured Interviews in written dialogs on Social Media *

* For methodology description see section 4.1.5.

4.1.5 User Studies via Social Media - Creating a Dialogue with Inaccessible Users

The customer group of this User Study was parents, who have or who have had toddlers, who do not own a car. This group, who according to forecasts will get larger in the future, is still a small group and therefore harder to reach than parents who own a car. To gain access to the specific customer group; parents without cars, a new method of data collection was developed and performed. This method consisted of creating a dialogue with these users, in the commentator's field of a post inside Facebook groups. The Facebook groups that were chosen had topics that related to and were of interest to the project.

During this user study, posts were published into two different Facebook groups. One of the Facebook groups had a topic regarding CRSs (called “Bilbarnstolar”) which had approximately 28 000 members at the time where the post was published. The other Facebook group had a focus towards sustainability issues and aimed to share tips and questions on the topic of a more environmentally friendly everyday life (called “Miljövänligare vardagsliv”). This group had approximately 21 000 members at the time of the publication of the post. The Facebook group with a sustainability focus was chosen based on the assumption that many of the parents have actively made a choice of not owning a car, which could be based on an interest towards sustainability and environmental concerns. Swedish Facebook groups were chosen during this project due to time efficiency since these groups were more accessible.

The posts that were published had a picture, both to create a larger post and to draw attention to the post and the topic, to increase the chance that the post was noticed and read by Facebook users. The picture had an illustration of a rear-facing CRS, to clarify the topic of the post and a Chalmers logotype to gain credibility and draw attention to the academic purpose, see figure 13.

Figure 13: Appearance of the Facebook posts. To the left is the post that was posted in the group with a sustainability focus. To the right is the post that was published in the group with a topic of CRSs.

The post was written in the same language as the Facebook group members used, in an accessible language, not too formal or academic, to make the text easy and to make people feel safe. To be successful, one would have to make sure that the post is appropriate for the chosen Facebook group and are in line with the rules of what can be posted in the group. Otherwise, the post will most likely be removed by administrators. The text was slightly adapted to fit the topic of the Facebook group, to be in line with the group's rules, and to reach the members in the best way. In the post, open questions were asked to avoid directed answers and inspire members to write about all sorts of stories and experiences.

When a member of the Facebook groups responded in the comment section of the post, it was important to answer to create a dialogue. By starting a dialogue - where comments from Facebook members were followed by answers with new questions, a type of unstructured Interview was created in chat format. In this way, the data collection provided a deeper understanding and more qualitative answers. Since the dialogue is open for others to see, comment and like, other users can be a part of the dialogue between the person that first left a comment and the “interviewer”. In this way, others can agree or disagree and share their similar experiences, which provides a deeper level of understanding for the users as a group compared to ordinary Interviews. It is important to be polite in the comments and thank the respondents for their participation. The company name, of which this thesis is created in association with, was left out of the post to avoid biased answers and stories in relation only to the CRSs from Axkid.

4.1.6 KJ Analysis

To collect, organize, and analyze the answers which were collected from the user studies via social media, a digital KJ analysis was created in a spreadsheet. See 2.4.1 Research methods - KJ-analysis for more information about the methodology. The answers from the Facebook posts comment section were all read, analyzed, and then organized within the KJ-spreadsheet.

4.2 Results

In this section, the results from Phase 1 will be presented. This includes findings from User Studies Part 1, which builds the foundation for the choice of customer group for the project. The findings from the different interviews during User Studies Part 1, were analyses with a KJ analysis. The result from the Benchmarking, including an Analysis of Semiotics and Design Language and a Function Analysis will also be presented.

4.2.1 Literature Study

The main part of the result from the literature study is the foundation for the theoretical framework of this report, see Chapter 2 - Theoretical framework. Parts of the literature also became an inspiration for the development of the new CRS.

4.2.2 Benchmarking

The Benchmark gave many valuable findings in the early stages of the project. From how a CRS works, degrees of usability, and user experience of handling different CRSs as well as an overview of the market.

A finding during the Benchmarking was that, few CRS models, similar to the one this project has the aim to develop, on the market. The closest one that was found, which could be considered both mobile and safe (it has an ECE R44 regulation), is Nachfolger HY5. Nachfolger HY5 is a rear-facing CRS for toddlers up to 105cm that is inflatable and becomes stiff when the CRS is inflated to its maximum. Without any air inside the Nachfolger HY5 it becomes smaller and flexible and can be folded into a bag with dimension, length 45cm, width 35cm, height 27cm. Nachfolger HY5 weighs 4.9kg and has an electric pump to inflate the CRS and anchors with a seat belt attachment, lower and upper tethers.

Nachfolger HY5 was used and investigated during the project. Findings from these investigations were that it took quite a long time to press out the air from the CRS, after using Nachfolger HY5. It was also difficult to fold the CRS when uninflated, info the original size and shape which made the bag difficult to carry. The installation and uninstallation were unintuitive and took a long time compared to a CRS that used ISOFIX attachments. The installation of the top tether was tricky and the installed CRS appeared to not be very stable in the car. Many factors were impressive and inspirational, like the low total weight and the small size and manageable package it becomes to when folded.

Another CRS model that inspired the development of this project was *Axkid Modukid*. A rear-facing CRS from Axkid for toddlers up to 105cm with an ISOFIX, support leg and rebound bar as an attachment system, approved by the UN R129 regulation. Axkid Modukid has a bottom plate where all the anchoring components are located. The chair part, where the toddler is placed during a car drive, can be connected to the bottom plate, see section 2.3.3 Terminology and Common Components of CRSs for a picture of the Axkid Modukid.

Axkid Modukid is developed for the same length span of children as the Nachfolger HY5 (61-105cm) and has many clever features. The Axkid Modukid is not developed with a focus towards mobility and is big and heavy (14.5 kg). The model is well tested and proven to be safe, it is also approved according to the Plus Approval. By knowing that, Axkid Modukid influenced the project beyond Benchmarking because many principles of necessary safety components, etc. were used during the product development of the new CRS. Due to the fact that this project is initiated and supervised by Axkid, there are no intellectual property conflicts of reusing parts and design components from the Axkid Modukid in the new CRS concept. To do this could even create a stronger connection to the brand identity and previous models of Axkid CRSs.

4.2.3 Function Analysis of CRS

The result of the function analysis is summarized in table 2.

Table 2: Function analysis of CRS.

System goal:	Enable that toddlers 61 up to 105cm travel safely in cars
Main functions:	1. Distribute forces during a car crash to protect the child from harm 2. The product is movable and not permanently bound in cars
Sub functions:	• Keep child in place in a safe position in the car • Are adjustable to fit different sizes of children • Be confirmed according to UN R-129 regulation • Be applicable in many cars (Cars of newer models in the EU)
Support functions: *(optimize main function but are not absolute necessary)*	• Are manageable • Are intuitive to install to minimize use errors and optimize safety • Enable a comfortable seating position for the child to travel in cars awake and asleep
Extra functions for a CRS adapted for shared mobility	• Mobile • Storable

4.2.4 Results - User Study Part 1

Findings from User Studies Part 1, will be presented in this section. Firstly the possible customer groups are presented one after one. Followed by a summary of the findings together with an analysis of how suitable the group is, as a good customer group, for a rear-facing CRS adapted for shared mobility.

CRSs Store & Rental Place

Interviewee object number 1 provided information both about CRS buyers and CRS renters since the store both sells and rents out CRSs. The store employee also provided information about their need regarding CRS-products from a rental place’s perspective.

Findings Concerning Buyers of CRSs:

- Buyers of CRS ask a lot about crash tests and safety regarding the products.
- Many buyers believe that bulky, rounded chairs are safer.
- Buyers are generally attracted to soft and padded fabrics.
- Buyers ask a lot about the slope angle of CRSs and want to make sure that the product will offer good comfort for the child while sleeping.

Findings Concerning Renters of CRSs:

- Renters generally were less informed about safety tests and different CRSs models than buyers, who often came prepared and had read up before coming to the store.
- Trust salespeople about what is a safe CRS.

Findings Concerning CRS Rental Places as a Customer Group for Project:

- Store employees could, for safety or legal reasons, not install the rented CRS in a customer's car, unless the customer specifically asked for help. This, according to this store's procedures.
- The CRS model that they had chosen to rent out was a Britax Römer with a seat belt attachment system. This CRS was chosen since it was quite small and therefore could fit into many different car models and because it was not too heavy.
- The salesperson did not think that the CRS had to be adapted to be appropriate to rent out and that the models available were good options.

Taxi Companies

Two different taxi companies were contacted. Interviewee number 2 described that when they received a booking that required a CRS, a detour was taken and a CRS was picked up at the taxi companies locals. This led to longer wait and a higher price for the customer, who had to pay a fee for the extra time it required to pick up a CRS. Interviewee number 3, described a different work methodology from his company. At this taxi company, some of the larger taxi cars were equipped with a CRS in the car. The CRS was not mounted but stored in the trunk. When a booking came that required a CRS, these larger and prepared cars got the booking. A special fee for borrowing the CRS was taken and the customer sometimes had to wait a long time since the cars with CRSs could be occupied.

Both of the interviewees described that families with children traveled via their taxi companies every day but said that they were not their main customer group. The main problem that they described with the CRSs, is that they take up such a large space in the taxi car and that this storage space is needed for customer's baggage, wheelchairs, and walkers. In order for all the taxi cars to be fully equipped, the cars would have to have a selection of CRSs stored in the car to fit all ages of children. When asked how a CRS should be designed to fit into a taxi drivers work situation a taxi driver said:

> "It is important that it is easy to install.
> And also that it does not take up space."
> - Taxidriver

Carpools

Two different carpool companies were contacted during User Studies Part 1. Neither of the companies had currently CRSs in their assortments. The carpool system consists of cars that are bookable through an app and most commonly the cars are used for shorter rental periods like a couple of hours. The cars are positioned outside, not in garages, to enhance accessibility. Therefore, there are no storage areas in relation to the cars where CRSs can be stored and protected from outside conditions, like weather and people. According to interviewee object number 4, the problem of CRSs for carpools where storage. He said:

> "We can't store ten different seats for different children and different statutes all the time. We can't do that since families with kids are not a big customer group."
>
> - Carpool Business Developer

This interviewee also described that they were open to offering CRS solutions in the future if the market would demand it - which is not the case today. In the future, he predicted that some of the cars in their carpool would be special "family cars" with CRSs mounted inside, which could be booked by those who demand them. This was not an alternative today since the carpool had too few cars. A storage and rental solution with CRSs in specialized cabinets was also an option but required collaborations with other companies that could deliver these cabinets. Overall both of the carpool companies were reluctant against including CRSs into their assortments and referred to that families with children were not a big or a desirable customer group. Interviewee number 4 said this regarding families as a customer group:

> "We are not marketing ourselves towards the group that is potentially the most difficult group to handle."
>
> - Carpool Business Developer

Car Rental Companies

The car rental company that was contacted had a selection of CRSs in their assortments. According to interviewee number 6 the current design of CRS works well for them since they have a local where the storage of CRSs is possible. Parents and families with children were not a big customer group and therefore, their needs were not a big priority for the car rental company.

Parents with Cars

Interviewee number 8, 9 and 10 were parents who owned their own cars and CRSs. These people gave almost identical answers. Even though the current CRSs for toddlers are bulky, heavy and take up a lot of space, the product solution is well adapted for users that own a car, who can store the CRS in the car and does not need to move or uninstall it often. They were reluctant against renting or buying second hand CRSs and wanted to buy their CRSs new. Only on travels, where the own car could not be used, there was an expressed need for a mobile CRS solution.

Grandparents with Cars

Interviewees number 11, 12, and 13 were grandparents and each of them had several grandchildren. These persons lived in houses and owned their own cars. Interviewee number 11 lives in the same city as his grandparents and owns his own CRSs since it was more convenient, for example, to make picking up grandchildren from kindergarten easier. Interviewee number 12 and 13 lived in another city than their grandchildren and therefore, the children were dropped off via car when they were visiting and at that occasion the CRS and the child was transferred to the grandparent's cars. They were open to owning their own CRS in the future, but did not think that it was of importance that the CRS took up less space to store or in other ways different from current CRS.

Parents with a Car-free Lifestyle

During the User Studies via Social Media, unstructured Interviews took place in the commentator's section of the Facebook post that was published in two different closed Facebook groups by the project group. This resulted in a dialogue with 45 persons in total. The interviewees are all parents that both own and do not own a car. They all had in common that they, to various extent, had reflected over their usage of cars and therefore had the type of lifestyle that was of interest for this project. Some of the interviewees even stated that it was the lack of good solutions that were the reason that they, reluctantly, owned a car. They meant that life with children was very difficult without a car, especially when the children had outgrown an infant carrier CRS or if a family had several children.

General Findings:

- The answer from these users differed from previous Interviews with parents. Both of the users with and without cars demonstrated a need for a new type of CRS solution.
- Parents that did not own a car - still wanted to own a CRS. This was due to convenience, that a good and safe solution was always available when the family got access to a car without any additional hustle. Also due to a fear that rented or borrowed CRS could be unsafe.
- It was a great engagement from women in the comments of the Facebook post. Only 2 of 45 interviewees were men.

Rent, Borrow or Second Hand:

The interviewees demonstrated strong feelings against renting, borrowing, or buying CRSs secondhand and showed a great reluctance for all options. The main reason was the fear that the CRS would not be safe by having invisible damages. This was the general presumption and involved users who had a strong sustainability drive.
An interviewee said:

> “We own our own child car seat. I wouldn't dare to buy one second hand since I don’t know if it has any damages. I could imagine renting as long as it would be well tested between every user. I like the idea of not owning short term products and I am very environmentally conscious (I eat plant based food, almost only buy things second hand, like to rent etc). But when it comes to my child's safety, there is nothing more important and I want to be able to feel secure with the car seat.“
>
> - Mother who owns a car

The general concern was that a second hand CRS would be unsafe due to hidden damages, for example, caused in a car crash. Other fears were that the CRS would be old, which could mean that the plastic would be damaged or that the model was not as safe as newer models.

> "It is not a chance that I am going to take with my child."
> - Mother who owns a CRS but not a car

There was also a fear of inconvenience of not knowing what to expect when borrowing or renting CRS. Hygiene issues were also mentioned as discouraging. There was a great mistrust of people or businesses that would earn money on renting out CRS, feeling that it would not be safe if money was involved. Some could imagine trusting businesses that were considered as reliable - like the non-profitable Swedish organization NTF, to rent CRSs from. If a CRS should be borrowed, people want to know and trust the person that owned the product and that this person could pledge that the CRS was safe.

A Child Safety Restraint (a CRS for toddlers), which should be used for approximately 4 years, was considered to be a worthwhile purchase due to the long use time. Something that speaks against a Child Safety Restraint customized for shared usage

Mobility
The mobility problems of owning a child safety restraint and not a car was a topic that engaged the interviewees and that appeared to be the greatest problem for users without cars. Horror stories about trips and the difficult use situations were shared in the comments. People had also taken matters into their own hands and tied CRS to carts with wheels among other creative solutions to enhance mobility. Many expressed that they missed the more mobile infant carrier that could be carried more easily or connected to a stroller. As a single parent or if a family had several children, the mobility issue was described as even greater.

> "I have dragged rear-facing car seats at busses and trains. It is demanding and results in a booster cushion too early. A flexible (smaller, low weight and easy to install) and safe child seat is missing from the market. This is a strong contributing factor to why our family bought a car when our second child came."
> - Mother of two, who owns a car

Storage
How users thought about the storage of CRS were of interest during the user studies. The storage was not often brought up spontaneously, which indicates that it was not a big problem. When asked, users responded that the CRS is stored in storage rooms or closets and that they took up a lot of space. In comparison to the mentioned mobility issues, the parents without cars thought that storage problems were minor.

Favorable Customer Groups for a CRS Adapted for Shared Mobility

In table 3, findings concerning how favorable and appropriate the different investigated groups were, as customer groups for a CRS adapted for shared mobility, are summarized. In this table, the different motives the groups have for buying a CRS of this type are listed. The third column refers to the success status of the customer groups.

Table 3: The possible customer groups of a CRS adapted for shared mobility, their motives and if they are considered to be a good customer group or not.

Possible customer groups	**Motives for buying a CRS adapted for shared mobility**	**Success status**
CRS rental companies	+ Have a need for CRSs that are easy to handle (transport to cars and install). - Do not have a problem with storing existing CRS. - Does not express a demand for a new CRS model adapted to renting.	Low
Taxi	+ Have a need for a space efficient solution because of lack of storage space in taxi cars. + A new solution could increase the clientele, to include families with children to a larger extent. - To be a sufficient solution, many CRSs that are appropriate for children, 0-12 years, are needed in one taxi. Which is difficult due to lack of storage space in taxis. - A CRS for 0-12 lies outside the scope of this project. - Low demand. Lack of interest since families with children are not a big customer.	Low
Carpools	+ Shows an interest for a similar solution. - Low demand. Lack of interest since families with children are not a big customer. - Express that they are not ready to invest in these types of solutions or towards families with children. - Could use existing CRS that are always installed in a car in the future. - Are reluctant to take responsibility over safety issues connected to CRS and have a problem on how to guarantee safety between users.	Low
Car rental companies	- Low demand. Lack of interest since families with children are not a big customer. - Do not have a problem with storing existing CRSs. - Do not have a problem with transporting existing CRSs to the cars.	Low
Grandparents	+ In the future, the group of grandparents that live in the cities and do not own a car will increase and then they will have a need for a new CRS solution. - Do not have a problem with storing existing CRS. Have much storage space in general. - Do not have a problem with transporting existing CRS. - Existing solutions of CRS work well today.	Medium

Parents with cars	+ Have a need for a more mobile and flexible CRS for travel - Existing solutions of CRS work well.	Medium

Parents without cars	+ Express a demand for a new solution of CRS.
	+ Want to own the CRS themselves and therefore have purchasing power. Because of:
	    + Safety first
	    + Mistrust of people/companies that rent out CRSs
	    + Hygienic issues
	    + Convenience
		High

Findings indicated that parents without cars, is the customer group with the highest need, interest, and demand for a CRS for shared mobility. Therefore, in addition to being the main user, parents who do not own a car should be the main customer group and intended buyer of the concept. Other potential successful customer groups are parents who own cars but need a mobile CRS for traveling. As well as grandparents who live in smaller housings, perhaps in the cities, or do not own a car. This is a group that probably will increase in numbers in the future. The other investigated groups were found to have a low success rate as a customer group.

4.2.5 Semiotics & Design Language of Existing CRSs

When investigating the different models of rear-facing CRSs on the market during the different stages of the Benchmarking, different striking features related to semiotic and design language were noted. These main differences in design language are related to how rounded and enclosed the CRSs appear to be. In figure 14, these variations are illustrated by a set of axes, in which some of the CRSs from the Benchmarking is deployed. The vertical axis represents how enclosed the CRS is by how much side protection that the CRS has. The horizontal axis represents how rounded back the CRS has, where much rounded appears C-shaped and a less rounded back with an L-shaped appearance.

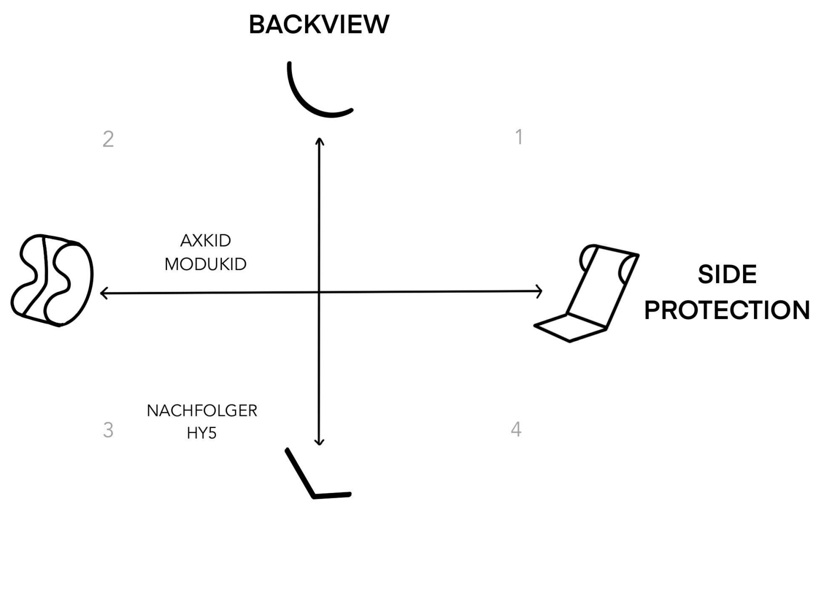


Figure 14: Exploration of design Design language of CRSs according to a rounded and enclosed appearance.

According to people in the CRS business - experts at Axkid and the sales personnel at the CRS-store, parents, and buyers of CRSs preferred products that could be positioned in the second quadrant where the C-shaped back and large, bulky side protections created an enclosed and protective look. These CRS were generally more expensive and extravagant. Another design factor that CRS buyers value while in the store, according to these experts, was a soft, smooth, and well-padded fabric. Black and neutral colors were also what parents generally wanted to buy.

A child's head is most vulnerable in a car crash. A child's legs, on the other hand, are not so vulnerable during a car crash and do not require protection from a CRS. Therefore side protections on a CRS are very important high up, close to the head, and further down the CRS, the side protections are of less importance. The rounded C-shaped back and large side protections help to create nesting and enclosed feeling that parents value for their child. However, these also enlarge the CRS which takes up a bigger space both in the car and while stored. Since this project aims to develop a CRS that is mobile and has better storage opportunities, it was decided that the fourth quadrant, noted with a 4 in figure 14, where the side protections are not larger than necessary for safety and an L-shaped back is the aim. This to avoid motion sickness as well as be space-efficient. Although it is important to keep nesting and enclosing feelings through semiotics and material choices.

After analysing the existing CRS and their design language and discovering new needs from a new type of customer from User Studies Part 1, the following semiotic value words were chosen for the

- Caring
- Protectable
- Robustness
- Trustworthy
- Mobile

4.3 Conclusions

It has been confirmed that there is a need for a CRS adapted for shared mobility. Both User Studies and Benchmarking confirm that there is lacking a rear-facing solution that is both mobile and safe in a car crash on the CRS market.

The secondary aim of this thesis; to investigate different possible customer groups for a product concept of a rear-facing CRS adapted for shared mobility have been fulfilled. During this process, many findings were provided concerning CRSs that will be a foundation during the continuous work of this project. The conclusion of this investigation was that in addition to being the main user, parents who do not own cars should also be the main customer group of the concept. This conclusion was presented and approved by the client, Axkid.

The developed method, where social media was used to reach an inaccessible user group, was found successful during this project and provided a good understanding for the desirable user group - parents who do not own a car.

4.3.1 Decisions

- Parents who do not own a car are the main customer group and the main intended buyer of the CRS concept.
- To incorporate shared usage opportunities of the CRS is not a goal, since it was not found to be desirable from users.

4.3.2 Issues to be Further Investigated

The chosen customer group needs to be further and deeper investigated.

- Findings from User study 1 needs to be validated by finding a larger group of people, including “more common users”.
- When do parents, who do not own a car, use a car and how often?
- How important is mobility, respectively storage opportunities, regarding CRS for parents that do not own a car?

5. PHASE 2 - USER RESEARCH

In Phase 2 of the project, user studies were conducted in the form of a Survey. The primary customer group was identified after User Studies Part 1 during Phase 1 and defined to be parents who do not own a car. The main goal of the User Studies Part 2 was to investigate this chosen customer group further to discover their needs, motives and requirements. The aim was also to validate findings from User Studies Part 1 during Part 2.

5.1 Methodology

In this section, the methods used during the User Studies Part 2 will be described, in figure 15 a schematic image of the process is presented. These are; Survey and User Journeys. The findings from these were then analyzed in a spreadsheet, graphs and KJ analysis.

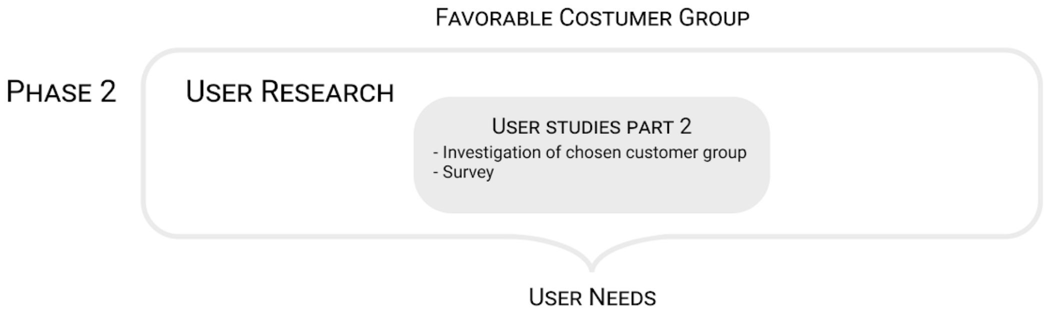


Figure 15: Schematic image of project process of Phase 1.

5.1.1 Survey

A digital Survey was conducted to complement and validate the qualitative data from User Studies via Social Media with more quantitative data. Even though the User Study Part 1 provided a lot of insight concerning the user group, there were still some question marks and a need for complementing answers regarding some user needs and habits related to CRS usage. The main aim of the Survey was to find answers to the questions:

- How do parents prioritize regarding a CRS´s various factors - what factors are considered to be most important?
- How important are the factors of storage and mobility considered to be?
- Where and how does the customer group live?
- How do these people, who do not own a car, gain access to a car and what errands do they need a car for?
- Which is the best way to anchor a CRS that is adapted for the customer group that was found in User Studies Part 1- ISOFIX attachment system or a seat belt attachment system.

The aim was also to try to receive answers from male CRS users as well since there were few findings from the User Studies via Social Media that came from men. There was also a concern that findings from User Studies via Social Media could be directed since the interviewees were reached through social media groups with special topics - CRSs and environment focus. Therefore, an aim during the Survey was to reach out to parents without cars who could be considered to be more “ordinary people”, that is the most average user. As well as to validate it these “ordinary people” had different views on CRSs than the interviewees from the User Studies via Social Media from Phase. A hypothesis was that people who are members of a Facebook group regarding CRSs might have other opinions about child traffic safety than a person that is not and could be more advanced in their knowledge of CRS.

Publishing Place

The Survey was posted in over 30 different Facebook groups both closed and open and in the project group members' LinkedIn feeds. The post attracted a varied amount of respondents. Some posts were deleted by the administrators, since they considered the post to not be in line with the theme of the group, which inhibited the number of respondents. After all, 19 Facebook groups provided data through the Survey

The groups were categorized into three different main categories according to the theme of the group. The categories were made as an effort to try to distinguish answers from “ordinary people” from people within the CRS group or groups that had an environmental focus. The Facebook groups that were chosen had topics that related to and were of interest to the project, but to reach “ordinary people” also large groups with topics outside the interest to the project were selected. The names of the Facebook groups, and into which of the three main categories it was sorted in can be seen in table 4, together with the number of the respondents.

Table 4: The Social Media groups, main categories,
their Swedish names and number of respondents from User Study part 2.

Categories	Name of Social Media Group	Number of Respondents
Environment	Miljövänligt vardagsliv Medveten konsumtion	127
“Ordinary People”	Bilfritt Malmö Cykla i Göteborg Pappisar Pappagruppen - för pappor och blivande pappor Dela byta Låna DELLEN Samåkning Resa med barn Vad händer i - Båstad/Göteborg/Uppsala/Östersund/Trollhättan Köp och sälj barnprodukter Vi som älskar att resa Mammor united Ekonomitips föräldrar LinkedIn	233
Child Traffic Safety	Bilbarnstolar	44

Publishing the Post

All the contacted groups were Swedish, therefore, the Survey and the posted message, which was posted in the Facebook group together with a link to the Survey, were written in Swedish, to fit the feed and the native language of the majority of the group members. That only Swedish groups were chosen was due to the difficulty of finding and joining appropriate groups.

The text of the posts was different from group to group depending on the theme of the group and different internal posting rules within the groups. The message alongside the Survey was always welcoming and followed the same style and tone as the post in User Studies via Social Media. It was clearly stated that it was a survey for a Master Thesis at Chalmers, both in written text and in the preview window of the linked Survey, where the Chalmers logotype was used as a heading of the survey for increased credibility. The text in every post had:

- A short explanation about the purpose of the study
- Motivation why today's models of CRS are not adopted for shared mobility
- Question if anyone wishes for a more mobile CRS model on the market.
- At the end of the post, it was written that the most wanted participants were parents without a car and that the survey took about 8 minutes to complete.

Construction of Survey

The Survey was an online Survey created in Google forms and consisted of 19 questions. The Survey is found in Appendix A2. The questions were a combination of open-ended questions, multi-choices, select one answer, and rankings on a scale. The questions were conducted to be as clear as possible and have a minimal chance of misinterpretation. After that a pilot test of the Survey was conducted to see that everything was clear and that the online link worked. The Survey was divided into different sections. There were sections about questions related to:

- GDPR rights
- About the participants
- CRS ownership
- CRS requirements in the future
- Storage and transportation
- Access to a car
- How to transport children
- Wishes regarding CRSs

Analysis of Survey

The answers were transferred to a spreadsheet to get an overview and enable an analysis of the results, to make a comparison between relevant groupings, and to draw conclusions. Tools within a spreadsheet were used to create charts and visualize the data. There were also qualitative answers from two questions in the survey that were analyzed with KJ analysis. The qualitative answers were also summarized into different categories and summed.

5.1.2 User Journeys & Persona

After the survey, two User Journeys were made to summarize and visualize the findings from Phase 2. The User Journeys include both a description of the users, their life situation and the use situation that was described.

The trip was divided into different moments to enable a better understanding of every action and operation. A moment can for example be what interactions with the CRS occurs at home or in the car. The User Journeys also tries to clarify how the experience is during every moment, the emotional state of the character and if there are any product development opportunities related to each moment.

The two different User Journeys describe two common car trips, according to findings in the User Study Part 1 and 2. The people that will execute the trips are representative users for this project and have different life situations to paint a bigger picture of the possible users of a CRS adapted for shared mobility.

5.2 Results

Following sections present the results from User Studies Part 2. This includes quantitative and qualitative results from the Survey. This information was summarized in the User Journeys, Expressed requirements from users list and resulted in findings and decisions regarding the anchoring system.

5.2.1 Quantitative Results from Survey

The survey got 404 valid answers that approved the GDPR agreement. The division of the number of answers from each group is visualized in Appendix A3. In the three divided main categories regarding themes of Facebook groups - around 31% of the answers came from groups with an environmental focus, 11% from the CRS group, and 58% from other groups that were referred to as “ordinary people”. The proportion of male participants was 18%. Which was far from the goal of 50%, but a better percentage than the User Study Part 1.

Owning a Car or not & the Difference of Priorities

The main users of this project are parents who do not own a car, therefore these users were the main intended respondents from the survey. However, insight from parents with a car-free lifestyle provided much valuable information from User Study Part 1 and therefore, the answers from parents who owned cars were also of interest in this survey. All 404 respondents were parents (to be a parent or guardian was a request for filling out the survey). 251 of them did own a car and 142 respondents did not own a car. 7 respondents answered that they neither owned or did not own a car. These 7 answers were included into the group of parents who do not own a car since their situation was estimated to fit best in this group. Thereby, 149 answers of the survey were from parents who did not own a car.

Since the Survey had answers from both car owners and people who did not own a car, interesting comparisons between the groups could be made. Comparisons regarding different lifestyles, needs, and priorities. One finding that was confirmed through the Survey, was that of the group of parents who do not own a car, a majority lived in larger cities (metropolitan municipality with at least 200,000 inhabitants) and in apartments, compared to those with cars who lived in cities or municipalities of different sizes, and mostly in houses (see Appendix A3).

How different factors regarding a CRS was prioritized was another question where participants who owned cars answered differently compared to the group who did not own a car. On Question 9 - “On a new rear-facing child car seat, which factors would you prioritize? Choose the 5 factors that you think are of the most importance.”. The factors that were available is displayed on the x-axis in figure 16. Figure 16 displays the answers from respondents with a car and figure 17 displays the answers from respondents that do not own a car. Both groups prioritize security highest, followed by the comfort of the child and then the fact that a CRS can be installed quickly. When it comes to the fourth factor, the two groups were not unanimous. As the fourth most important factor the respondents without a car choose “easy to bring along/mobility”. While parents with a car ranked “easy to bring along/mobility” as number 5 and intuitively to install correctly as number four. The mobility factor was rated higher by respondents without cars.

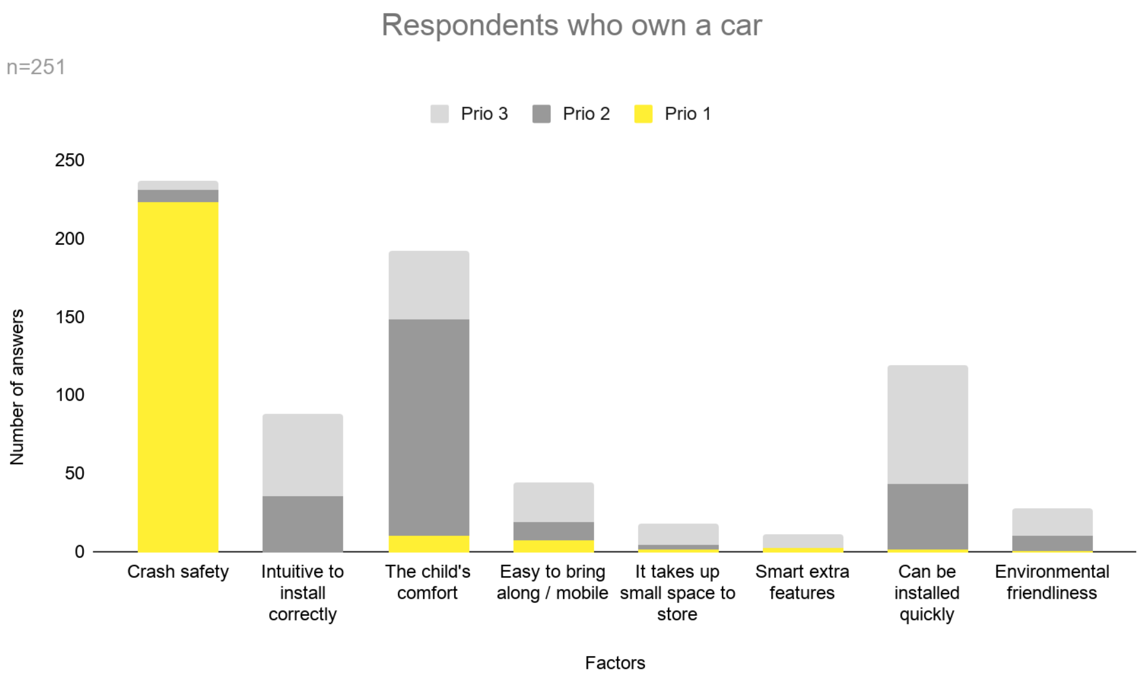


Figure 16: Results from question 9, regarding prioritization of factors of a new mobile CRS, for parents who own a car.

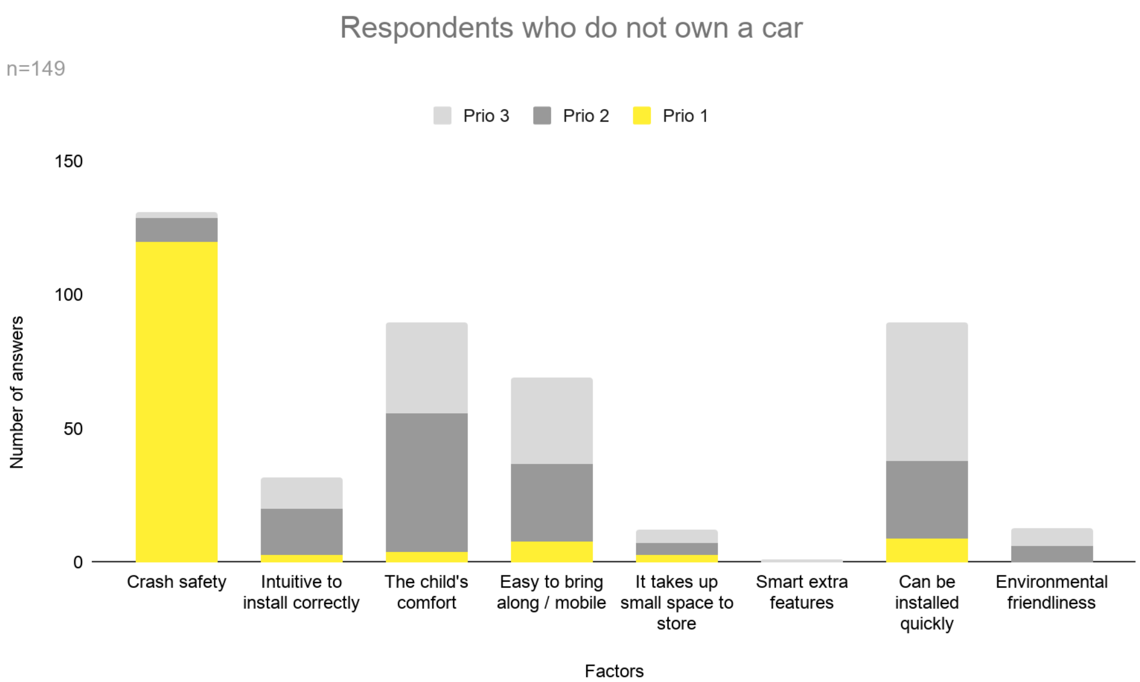


Figure 17: Results from question 9, regarding prioritization of factors of a new mobile CRS, for parents who do not own a car.

“Ordinary People”

The answers of the survey from the three different main categories of Facebook groups, Environment, “Ordinary People” and Child Traffic Safety (see table 4) were separated to enable an analysis between answers from environmental groups, the CRS group, and the rest of the participants. This was done due to the hypothesis that the topics of interest - the environment and CRSs, could affect the answers from the respondent and that these users might not be the “ordinary user”. The result, when analyzing how the three different groups had responded in the Survey - showed that the three groups were surprisingly unanimous. The CRS group ranked security higher than the other groups did on question 9, but had answers similar to the other groups in other questions. The groups’ with an environmental focus, however, answers were almost the same as the groups that were referred to as “ordinary people”. Therefore, there was no need to keep the answers from different Facebook groups with different topics separated.

Parents Who do not Own a Car

A goal of the Survey was to find out how parents who do not own a car, gain access to a car and what type of errands that they need a car for. According to the answer to multichoice Survey question 14; “In which of these circumstances and how often, do you have a need for a car (when children should be traveling in the car)?“, see appendix A2, the most common thing to use a car for was shopping for larger or bulky items (Food, IKEA, etc) and for visiting friends and family, see figure 18.

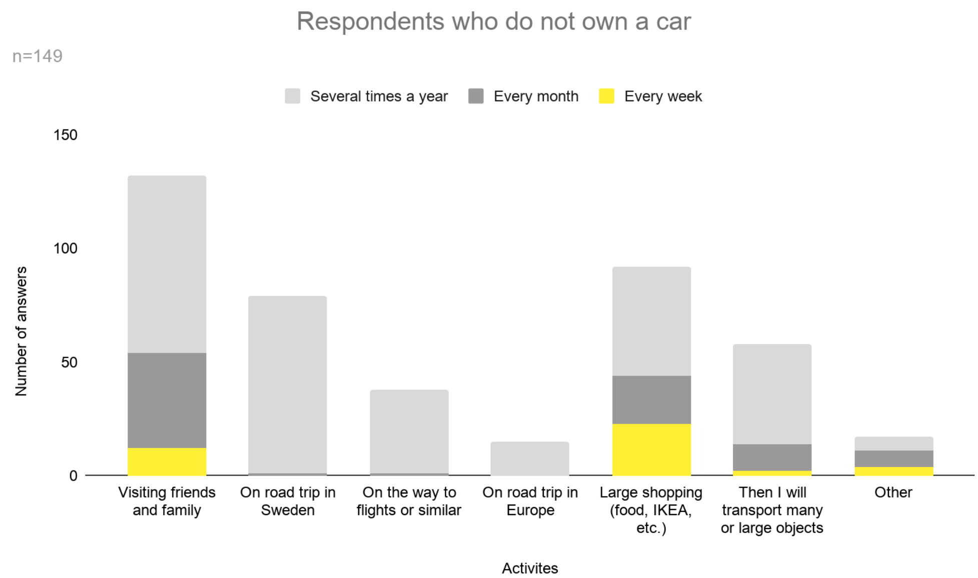


Figure 18: Answers to question 14. Display which activities and how often parents that not own a car use a car.

The result from the multi-choice question 16 - “Which types of transportations do you use together with children”, see Appendix A2, displays in which ways parents who do not own a car travel together with a child. The most common methods of transport are public transport, and cars borrowed from family or friends (see figure 19). Not so common was regional busses, flying, renting cars from carpools or car renting companies.

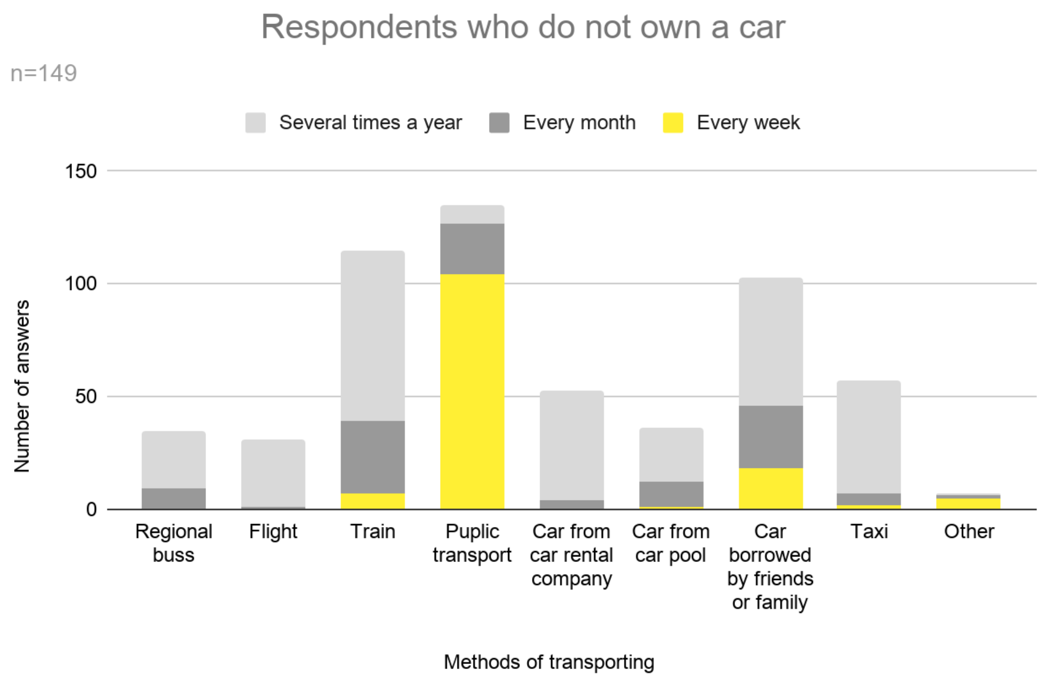


Figure 19: Answers to question number 16, illustration methods of traveling with children, answers from parents who do not own a car.

Important Factors - Storage in Relation to Mobility

During the User Studies via Social Media it was found that many interviewees talked about the problems of mobility regarding CRSs but very few about the problems of storing the bulky CRSs without owning a car. Therefore, a question that came up after analysing the User Study Part 1 was how important storage was for users and if this factor should be a high priority during the development. To gain insights about how important the two factors were for users, the Survey aimed to compare storage to the importance of mobility.

Two questions of the Survey investigated this question, question number 9 and question number 12. In question 9 where the respondents should prioritize between important factors regarding a new CRS, see figure 17, for construction of the question see Appendix A2. The results was that mobility (the factor “easy to bring along/mobility”) was prioritised as number four for users that did not own a car and “it takes small space to store” received lower scores and was rated as number seven out of the eight factors.

In questions 12 and 13 in the survey the participants were asked to rank the factors of the storage and the transportation of a CRS. In figure 20, the questions and the results are displayed. The result showed that both factors, storing and transporting a CRS, is a bigger problem for parents who do not own a car than for those who own a car. Both groups answered that the transportation of the CRS to the car was a bigger problem than storing it between usage, for detailed information see Appendix A3.

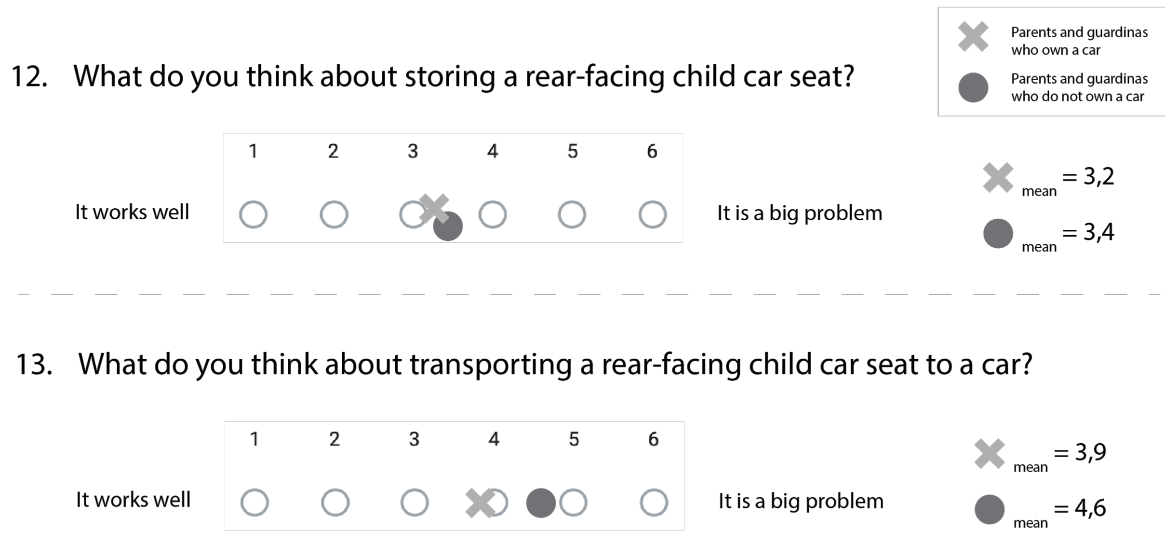


Figure 20: Question 12 and 13 of the Survey and the mean results from the two groups.

5.2.2 Qualitative Results from Survey

Two questions in the survey were open ended to provide qualitative data from the survey as well. These answers were analysed, categorised and counted. The two most common answers to the open survey question number 10; “What is the biggest problem regarding existing rear-facing child car seats?”, was different combinations of saying that the CRS was “Bulky and difficult to handle” and “Difficult to install”. The second open question, number 17, where the participants were given the opportunity to wishful thinking on how a CRS can be better adapted to fit their lives better, the two most common answers were “a more mobile CRS” and “that it would be easier to install”.

The analysis of the qualitative answer from the survey confirmed many of the findings from the User Study Part 1, like the importance and need of a more mobile CRS. After summarizing the qualitative answers from both Part 1 and 2 of the User Studies, a stagnation and saturation in the results was evident.

5.2.3 User Journeys & Persona

The findings from User Study Part 1 and 2 and what was discovered about user needs and the users - people who have children and do not own a car, were summarised in two User Journeys. This helped to visualize the findings and to make them memorable for the project group during the development process. The result from the User Journeys was that they provided a deeper understanding, an overview of problems and user needs related to traveling with a CRS. It also gave insight during the development phase of the user journey, because dividing the trip into different moments helped to understand that there are many situations where the new CRS needs to be adapted to give a great overall product experience.

In User Journey 1, The Persona - Kristina, who is a single mother will travel with her child and CRS to friend with public transport. Single parents have other needs than couples since they have to carry and be in control of everything themselves while on a journey with children and to bring the CRS on public transits a common method of traveling according to the user's studies. See figure 21. to see the whole User Journey number 1. In User Journey number 2, a couple of parents will rent a car in a carpool to visit IKEA with their child, which is a very common use context according to the Survey answers. Their experiences are described in User Journey number 2, see figure 22.

User Journey 1

Kristina and her daughter Mio are going to visit her friends outside the city center. They will stay from Friday to Saturday and spend the night there. They will travel from their apartment with public transport and train before Kristina's friends will pick them up with car. Mio and Kristina has one large backpack with all their packing, a stroller and a rearward facing car seat (using ISOFIX) with them on their trip.

Kristina, 32

- Child: Mio 3 years old
- Single Mother
- Lives in an apartment in Stockholm
- Does not own a car
- Likes to play tennis and do pottery

	Home	Public transport	Train	Install	Car	Arrived
Interaction with car seat	Retrieves CRS from storage area in basement. Carries CRS in elevator and to apartment. Packs CRS in the stroller seat and anchors it with straps. She put on the backpack and holds Mio in the hand before she locks the door.	Bring the stroller with the CRS, the backpack and Mio to and onto the buss. She puts Mio on a seat nearby but has to stand with the belongings in the passageway. She tries to not take up the whole space as well as keep Mio in her seat.	Bring the stroller with the CRS, the backpack and Mio to and onto the train. Kristina folds the stroller and places it and the backpack on the baggage stands. The CRS is put in the entrance of the train wagon.	Carry the CRS to her friend's car. Install the CRS by using the ISOFIX attachment points in the car.	Mio travels in the CRS and are happy.	Takes Mio out of the car seat. Uninstall the car seat since the car should be used to drive other people too and they need the room. Packs the CRS to the stroller again. her friends helped by her to carry all the stuff inside.
Experience	Has to bring Mio to the basement, and she is afraid of the basement. Kristina finds it uncomfortable and demanding to retrieve the bulky CRS among the varied belongings. Gets annoyed at the disorder of all her things in the storage room.	All the stuff is heavy to carry around. Kristina is tired and sweaty. Feel like she is in the way with all her stuff in the buss passage way. Mio is overexcited from being on a trip and yells in the buss. The other passengers look at them and Kristina feels uncomfortable.	Stressed to get onto the train with Mio and all the stuff in short time and safely. Difficult to find a place for all the belongings. Feels uncomfortable that her stuff take up such a big room and could get in the way of others. Since she can not see the CRS, the stroller and the packing she is a worried that something will be stolen or taken by mistake. When everything is in place Kristina enjoys the train journey.	She is relieved that Kristina's friends pick them up. The installation whent quite smooth, similar to other cars with ISOFIX. Took some time to find ISOFIX anchoring points in the car and unfold the support leg.	Kristina enjoys talking to her friend and Mio enjoy the ride.	Are happy to have arrived.
Opportunities	Better storage opportunities. Option to make packing easier.	Lighter and more mobile CRS.	Possibility to place the CRS on the hattrack or on the baggage shelf. Easy to carry CRS onto the train.			Option to make packing easier.

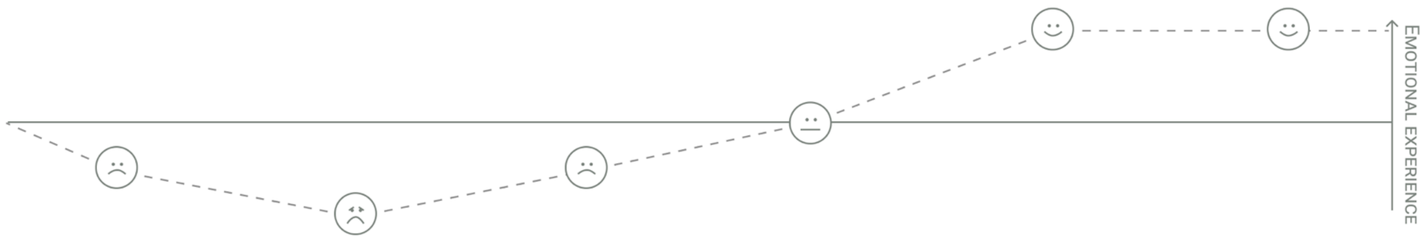


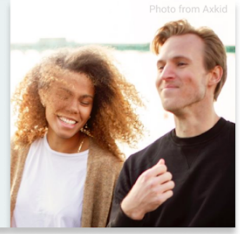
Figure 21: User Journey number 1.
Single mother traveling by bus and train to her friends who has a car, with her child.

User Journey 2

Lucas and Robyn are going to IKEA to buy furniture to Emma's new room. They are planning to buy her a bed and some kids furniture. For this occasion they are going to rent a car in a carpool that is close to their apartment, 200m. It will be a long day, so they have brought the stroller for Emma as well as a diaper bag. They also have a rear-facing car seat with ISOFIX with them on the trip.

Lucas, 37 & Robyn, 38

- Child: Emma 1 years old
- Lives in an apartment in Malmö
- Does not own a car
- They both like cooking and to travel



	Home	To car pool	Install	Car	Arrived	From carpool to home with shopping
Interaction with car seat	Retrieves CRS from wardrobe in the apartment.	Lucas carries the car seat in his arms while Robyn drives Emma in the stroller.	Install the CRS by using the ISOFIX attachment points in the car. Regulates the rebound bar. Forgets to fold the support leg out first and has to remove the CRS from the car seat, fold out support leg and install CRS again. He puts Emma in the CRS and adjust the harness to fit her.	Emma travels in CRS and falls asleep.	Lucas carries Emma from CRS to stroller.	Robyn takes Emma from CRS to stroller. They carry their shopping and the CRS and puts it outside the house. Lucas drives the car to the car pool and walks back home. At home he carries shopping and CRS back to the apartment.
Experience	Since the CRS is used rarely, much stuff is stored inside the bulky car seat and things fall out and has to be put back in the wardrobe, which makes Lucas annoyed. Carrying the CRS is uncomfortable and heavy.	Lucas's back starts to ache as soon as they have left the building. The CRS is both difficult to handle as well as heavy. He also has to stop and take several breaks before they arrive to the car pool.	Happy to have reached the car so the heavy lifting is done. Annoyed about the inconvenient of needing to fold out the support leg first. Annoyed that he always forget how to install it. Lucas's back ache when he lifts Emma in her seat,	Are happy that Emma travels safely and was comfortable enough to sleep. Emma's head tip forward when she is sleeping which Lucas thinks look unsafe and uncomfortable.	Emma wake up when she is lifted out of the CRS and starts to cry.	Tired from the shopping and all the carrying but happy with a successful and effective shopping trip.
Opportunities	Better storage opportunities. Easier to carry and handle.	Lighter and more mobile CRS.	Opportunity to fold out support leg inside the car. Make it more ergonomic to position child in CRS.	Better head position for sleeping child or possibility to fold seat backwards.	Easy to carry child out of CRS.	Option to make packing easier.

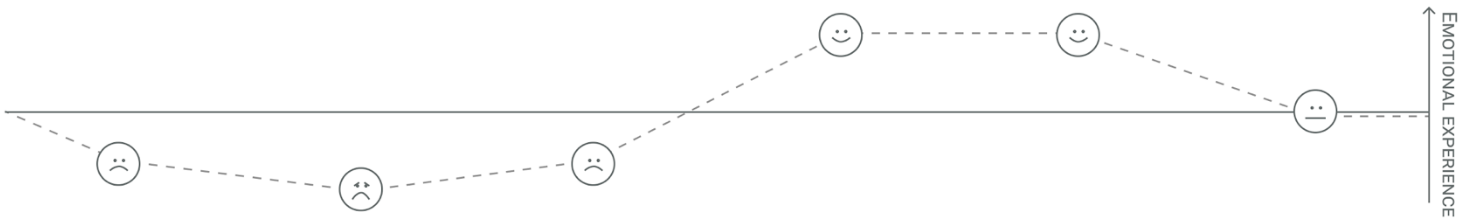


Figure 22: User Journey 2. A couple of parents rent a car in a carpool and travel to IKEA with their child.

5.2.4 Expressed Requirements from Users

To summary discoverings from User Study Part 1 and 2 a list of requirements, needs, and wishes were made. The list contains the described needs that a mobile CRS needs to have, be like or enabled, from a user's perspective. The list worked like a summary of requirements from users, to lower the risk of missing expressed user needs during the development phase. The full list of expressed requirements from users can be found in Appendix A4.

5.2.5 Findings Regarding CRS's Anchoring Systems

In table 5 the different pros and cons in relation to the different attachment systems are presented. These findings are based on User studies Part 1 and Part 2, Literature Studies and expert consultations. For more information about the attachment systems see section 2.3.5 Design Guidelines for CRS. The information in relation to the attachment systems are regarding rear facing child safety restraints.

Table 5: Pros and cons with different attachment systems.

Attachment system	**Pros**	**Cons**
ISOFIX attachments	+ Fast installation time + Intuitive to install correctly + Makes use of indicators, which is safer	- Has a weight limit (33kg in total) - Only works in cars who uses the ISOFIX system - Heavy weight
Seat belt attachments	+ Has a higher weight limit and can be used for a longer time (up to the child is 25 kg). + Compatible with all cars (even older cars without ISOFIX)	- Take a longer time to install - Difficult to use indicators to illustrate correct installation and therefore not as safe - Not as Intuitive to install correctly
Support Leg	+ Fast installation (time) + Intuitive to install correctly + It is possible to illustrate a correct position with indicators, which is safer + Comfortable installation + Same Installation in all cars	- Heavy weight - Large
Top tether	+ Light weight + Take up small space	Installation is: - Time consuming - Uncomfortable - Unintuitive - Difficult to use indicators to illustrate correct installation and therefore not as safe - Different installation depending on car model
Rebound bar	+ Fast installation time + Intuitive to install correctly	- Heavy weight - Large
Lower tether	+ Light weight + Take up small space	Installation is: - Time consuming - Uncomfortable

Choice of Main Attachments - ISOFIX Attachment System

According to regulations (UN R129) it is not allowed to apply both ISOFIX and seat belt attachment systems on the same Child safety restraint product. Therefore, this was not an option. There were both pros and cons of the two systems (see table 5). A fast installation was rated to be a very important factor in the survey, speaks in favor of the ISOFIX attachment systems. That the CRS would be easier to install was the most common wish and answer to the open survey question number 17 which also speaks in ISOFIX favor. As to the improved safety thanks to the intuitive installation which makes use of indicators.

The pro - *Compatible with all cars*, of the seat belt attachment system, can be ignored since this project aims to create a concept for future use, all newly produced cars have ISOFIX, and cars without will be phased out. The pro - *Has a higher weight limit and can be used for a longer time (up to the child is 25 kg)*, lies outside the demarcations of this project who only aims to create a CRS for children between 61-105cm, which corresponds to approximately 18kg. When these factors are weighed in, the ISOFIX system is estimated to be the best choice for this product concept.

Choice of Secondary Attachment - Support Leg

A top theater is smaller and lighter which is better from a mobility perspective. When it comes to usability for the user and safety in regards to a safe installation the support leg is the clear winner, see table 5. Therefore a support leg was chosen to be the most suitable secondary attachment for the CRS concept.

Choice of Third Attachments - Rebound Bar

When a support leg is used as a secondary attachment; a Rebound bar has to be used. Lower theaters as third attachments are not allowed in combination with a support leg. The rebound bar also gives a better user experience for the users according to the table 5, and therefore a rebound bar is chosen as the third attachment for this CRS system.

5.3 Conclusions

The Survey validated findings from User Study - Part 1 and confirmed that there is a need for CRS models that are more mobile, easier and faster to install and that offers better storage opportunities. The result from the Survey displayed the difference in needs and requirements of parents who do not own a car, compared to parents who own a car. The fact if the respondents owned a car or not influenced the answers. Which category of Facebook group the respondents were from, did not have a big effect on the answers. The factors factors for parents without cars got the following score:

1. Crash safety
2. The child's comfort
3. Can be installed quickly
4. Easy to bring along / mobile
5. Intuitive to install correctly
6. It takes up a small space to store
7. Environmental friendliness
8. Smart extra features

When comparing the need for mobility and need of better storage opportunities, improved mobility concerning CRS was the factor that was of most importance for users in both User Studies Part 1 and in Part 2. Therefore, improving mobility has been the highest priority during development.

After investigating the chosen customer group in User Study Part 2, increased understanding of the target user was gained. The target user has been defined to be:

- A parent or guardian
- Do not own a car
- Own a CRS
- Lives in an apartment
- Uses a car quite often - every week or every month

This definition and the two User Journeys have been used during the ideation and development of the concept.

5.3.1 Decisions

The result from the Survey in combination with findings from User Study - Part 1 and by consulting with Axkid provided information regarding the different anchoring methods. This resulted in a decision of which anchoring methods that this CRS concept will make use of, in order to be best suited for the user. This selection was approved by the client, Axkid. These chosen attachment systems are;

- Main attachments: ISOFIX attachment system
- Secondary attachment: Support leg
- Third attachments: Rebound bar

5.3.2 Issues to be Further Investigated

The target group and customer group have now been investigated as well as CRSs have been explored. The next step and the topics to be further investigated is how to turn the user needs that were found during these User Studies to ideas and develop CRS concepts.

6. PHASE 3 - IDEATION

During Phase 3, Ideation and Evaluations have been made in iterations. Expert consulting sessions, as well as evaluation methods, have been used to narrow the scope and finally to choose a fundamental concept that was further developed in Phase 4.

Phase 3 is divided into Part A and B, due to different aims of the ideation development process. Part A had a strong focus on exploring the solution space and coming up with different solutions that could solve known problems from User Study Part 1 and 2. During Part B, the development and analysis of whole concepts were done. The Methodology section presents methods that were used during both Part A and B while the Result section is divided into Results Part A and Results Part B to simplify the reading.

6.1 Methodology

In this section, methods from Phase 3, Part A and B, are presented. Phase 3 is described in figure 23. The methods that were used in Part A and B were; Ideation of parts and concepts, Morphological Matrix, Kesselring Matrix, and R2 Envelope Estimation Method. R2 Envelope Estimation Method was a method that was used and developed in this project that aimed to evaluate if the ideas fitted within the R2 envelope (ISO 13216-3).

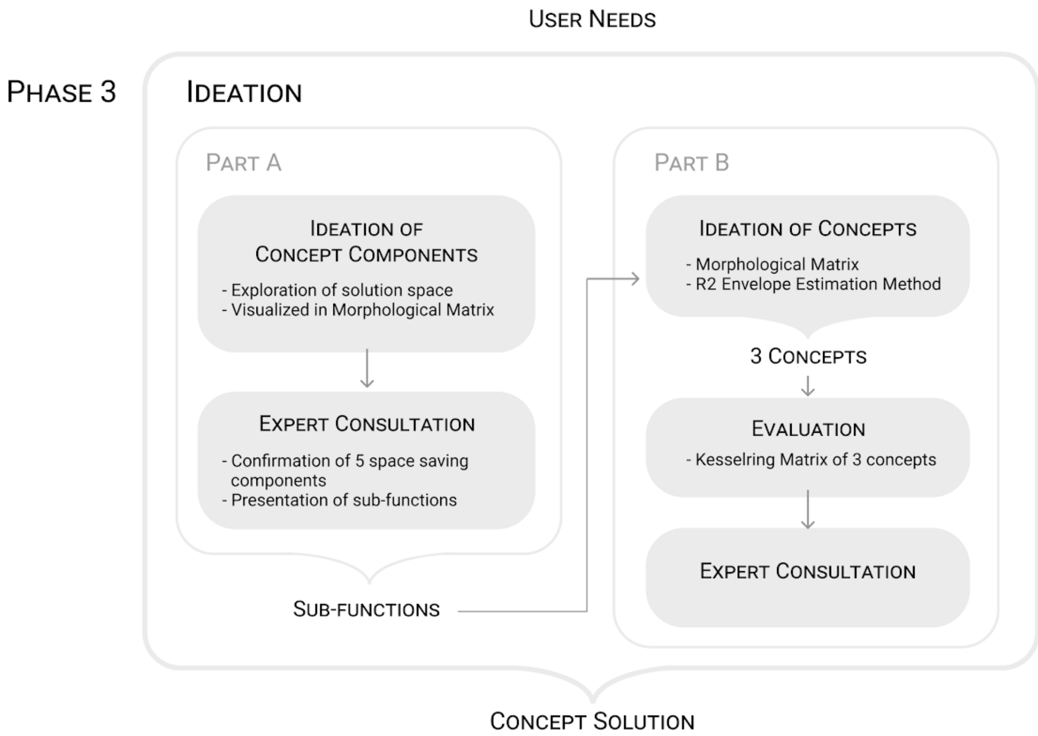


Figure 23: Schematic image of project process of Phase 1.

6.1.1 Ideation

Ideation has been performed continuously during the project in Phase 1 and 2. During Phase 3 more structured Ideation sessions were performed. Methods used during these sessions were Brainstorming and Morphological Matrix (further description see 2.4.2 Ideations methods). Explorative sketching was also used to investigate and explore solution space. The Ideation was performed in iterations where an Ideation phase was followed by a summary and a presentation for the client, Axkid, which involved Expert Consultation. The Ideation during Part A and B were of different characters:

Ideation Part A: Broad Ideation - Exploring solution space, where the focus was to develop solutions to sub-functions, these were mapped in a Morphological Matrix which provided structure.

Ideation Part B: The aim was to come up with fundamental holistic concepts with the goal to be different but applicable. They were constructed by using sub-functions from the Morphological Matrix.

6.1.2 Morphological Matrix

A Morphological Matrix was performed in two steps and developed after analyzing the Function Analysis (see 4.2.3 Function Analysis of CRS). In Part A the sub-functions of the CRS become a way to find problem areas for ideation sessions. The sub-solution that was developed in Part A was combined in Part B to three fundamental holistic concepts.

6.1.3 R2 Envelope Estimation Method

The R2 Envelope Estimation Method was a method that was developed just for this project to get an understanding and make estimations of the developed concept's size and dimensions. The R2 Envelope was sketched up in profile in scale 1:10 with a guideline grid for measurements and lines in appropriate backrest angles which created a R2 Envelope Estimation worksheet, see figure 24. The R2 Envelope was positioned in a 10 degrees angle to a sketched car seat, which is a common angle in cars. The concept ideas were sketched in the R2 Envelope on the worksheet and if any parts of the CRS could not fit approximately inside, without finding any way to fix it, the concept was removed. By using the R2 Envelope in this way it became like a filter to analyze the feasibility of early concepts.

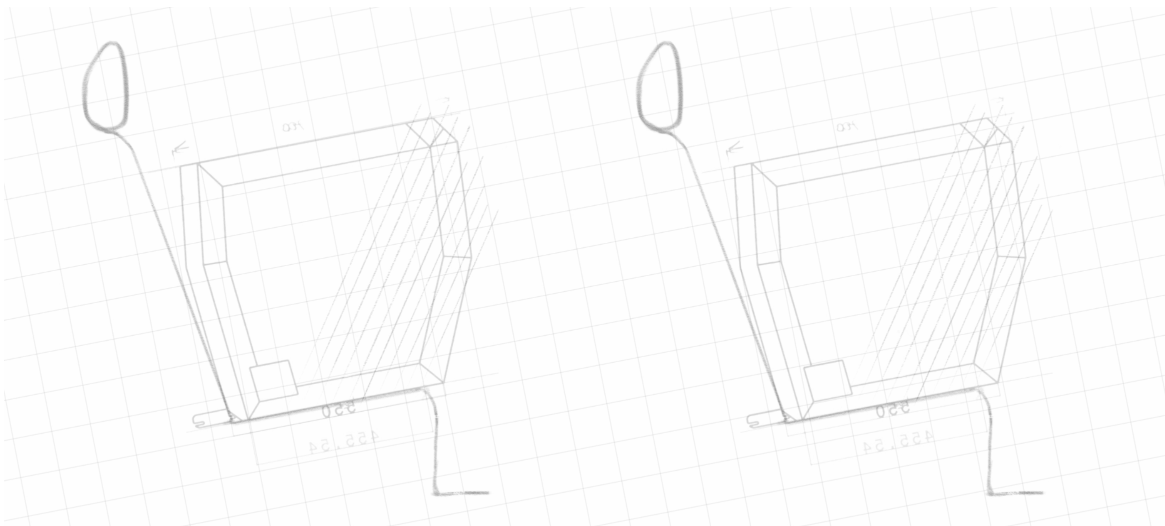


Figure 24: R2 Envelope Estimation Method worksheet.

6.1.4 Kesselring Matrix

To evaluate the three fundamental concepts and to choose a final concept, a Kesselring Matrix was used. The selection criteria and how the different criteria were weighted is described in Appendix A7 together with comments describing the weight grades. The weight score 5 is the highest and 1 is the lowest. The weighting of the score is motivated and based on the preliminary scope from the client Axkid and user findings from Phase 1 and 2. The gray areas in Appendix A7 are selection criterias that are important for the project (e.g. easy to clean, semiotics etc) However, due to the fundamental development level of the basic concepts during Phase 3, these selection criterias has not been investigated in this phase and in these selection criterias in concept 1, 2 and 3 have been graded equally. These selection criterias need to be integrated during the concept development of Phase 4.

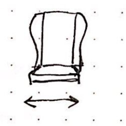
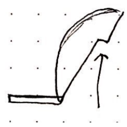
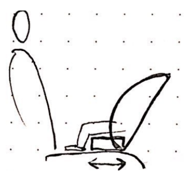
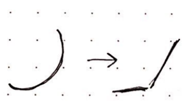
6.2 Results Part A

The result from Part A includes; Five Space Saving Components, Ideation of Sub-functions and Morphological Matrix. For further results of Phase 3, see section 6.3 Results Part B.

6.2.1 Five Space Saving Components

In consultation with Axkid and from findings in Phase 1 and 2. Five space-saving components were developed as fundamental principles on how to develop a CRS that is not as large and bulky as many CRSs models are today. The space-saving components can be applied to all concepts during the product development phase. The space-saving components are described with pictures and text in table 6.

Table 6: Five space saving components.

Component	Pictures	Explanation
1		Small lower side impact protections.
2		A CRS that has a slim width provides more space in a backseat. Possibly room for up to three CRSs in the back seat.
3		By having an offset of 1cm between the headrest and the backrest, the head of the toddler leans back in place. This prevents the head from falling forward during sleep without adding more slope angle to the back.
4		Shorter cushion saves space and gives the toddler more leg space.
5		A straighter L-shaped back instead of C-shaped takes away the bulkiness and provides more space in the car.

6.2.2 Ideation of Sub-functions in Morphological Matrix

With findings from Five Space Saving Components and Phase 1 and 2, Ideation of sub-functions for the Morphological Matrix was conducted. The sub-functions were divided into Mobility, Storage, Extra functions, Support leg, Rebound bar, and ISOFIX attachment. Each sub-function was explored and several different ideas on how to design the sub-function were summarized on post-its, see Appendix A5 for a visual presentation of the Morphological Matrix.

The ideas in the Morphological Matrix were developed through Brainstorming and exploratory sketching sessions (see figure 25) which resulted in ideas of different sub-functions of a CRS and whole CRS concepts. To fit the format of the Morphological Matrix some of the concepts ideas were split to fit the division of the Morphological Matrix's sub-functions.

Figure 25: Brainstorming and Explorative Sketching sessions.

6.2.3 Expert Consultation

After Ideation in Part A a presentation to the client, Axkid was made. The experts provided feedback on the 5 space-saving components and on the first part of the Morphological Matrix of CRS components. A selection of components in the Morphological Matrix was made with help from the experts and non-feasible components were removed.

6.3 Results Part B

In this section, the results from Part B are described. This includes the output of the Morphological Matrix and how the R2 Envelope Estimation Method was used to reduce the many concepts from the Morphological Matrix down three fundamental concepts. The three fundamental concepts will be described as well as how the Kesselring Matrix and Expert Consulting from Axkid led to a selection of these three concepts, where one was chosen for further investigations and development.

6.3.1 Morphological Matrix

The output of doing the Morphological Matrix were different holistic concepts based on the different sub-functions ideas. This concept was further evaluated in the R2 Envelope Estimation Method.

6.3.2 R2 Envelope Estimation Method

A variety of concepts were produced by creating the Morphological Matrix but several of them were found to not be feasible. Some concepts were removed since they were found to be not successful according to the *Expressed Requirements from Users* list or because they were outside the limits of the R2 Envelope. In figure 26, a concept is sketched into the R2 Envelope Estimation Worksheet, to explain the evaluation process. The concepts that were outside the R2 Envelope were first iterated one more time in an Ideation session to try to solve why part of the concept was outside the R2 Envelope and try to make the concept fit. If they still could not fit inside the box, concepts were removed. R2 Envelope Estimation Method resulted in three feasible concepts, which theoretically fitted in the R2 Envelope and obtained many necessary properties discovered in Phase 1 and 2.

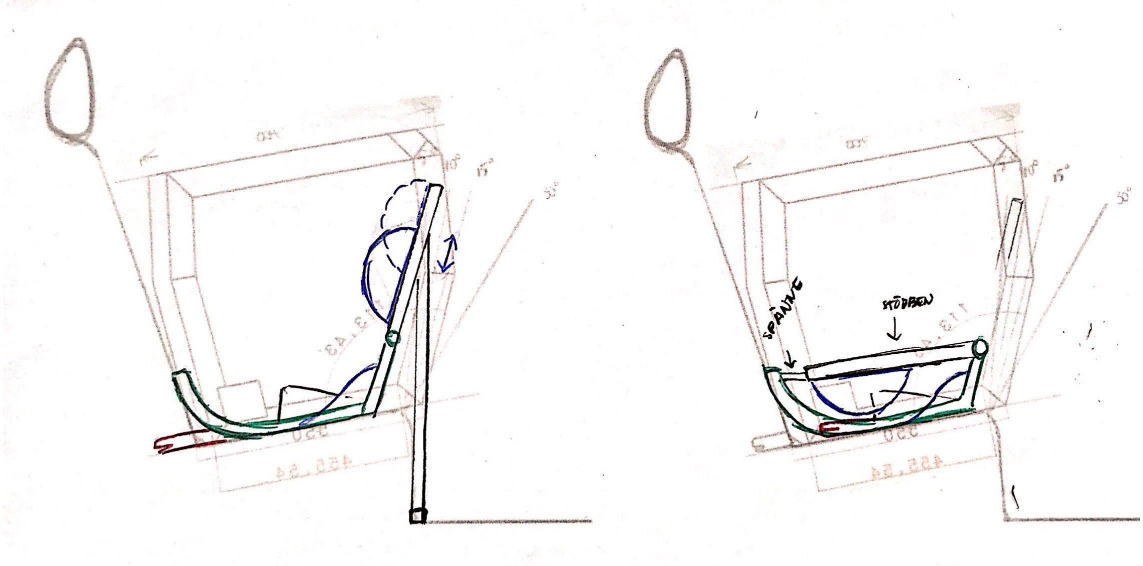
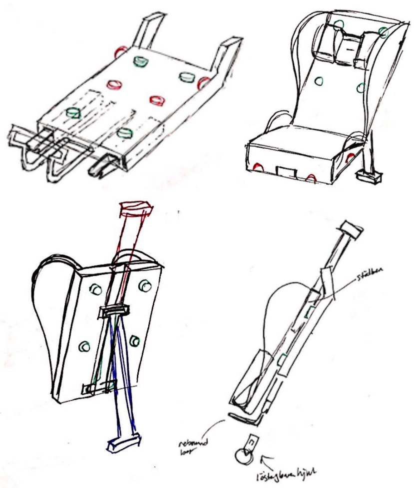
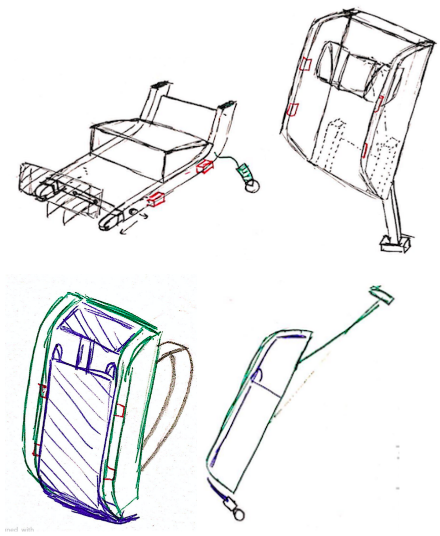
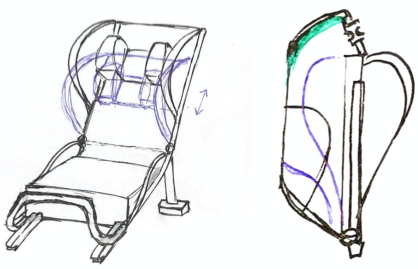


Figure 26: R2 Envelope Estimation Method - Concept that were inside the R2 Envelope.

6.3.3 Three Fundamental Concepts

This section describes the three fundamental concepts that were the result of Ideation Part 2, Morphological Matrix and after the R2 Envelope Estimation Method sorting out process. The concept is briefly described in table 7, for a more comprehensive description see Appendix A6.

Table 7: Three Fundamental Concepts described.

Concept	Pictures	Description
Lego		● Divided into parts: bottom plate and back part + wheels. ● Attachments (red) face each other - in the car. Connect bottom to back part in seat mode. ● Attachments (green) face each other - outside the car. Connect bottom to back part in mobility mode. ● Can be pulled as a suitcase or carried as a backpack ● Stored in backpack mode and have protruding objects
Box		● Divided into parts, bottom plate and back part + wheels ● Attachments (red) at each other - Outside the car. ● Two bars at the bottom plate attaches to the cavities of the back part - In the car. ● Can be pulled as a suitcase or carried as a backpack. ● Stored in backpack mode and have a uniformed shape.
Small Fold		● A single part that is foldable, due to a joint. ● Can be unfolded in the car ● Can be carried as a backpack ● Stored in backpack mode and have a uniformed shape, some protruding objects.

6.3.4 Kesselring Matrix

To see the complete Kesselring Matrix 1 - see Appendix A8. According to the Kesselring Matrix, the concept that got the highest total score of 66 was concept 3: Small Fold. The second best was Concept 2: Box with a score of 62 and last place came Concept 1: Lego, score 57.

Concept 3: Small fold got a lower point than the other concepts in selection criteria *mechanics* due to the joint in the middle of the backrest that needs to handle a lot of force in a car crash. However concept 3: Small fold was better in other selection criterias as *fast and easy to store*, *preventing misplacing of components* and *storage* that resulted in the highest score, see Appendix A7 for selection criterias, and Appendix A8 for the total Kesselring Matrix.

6.3.5 Expert Consultation

The expert consultation, with the client Axkid, in Part B resulted in a ranking of the three fundamental concepts with motivations. Axkid’s favorite was the concept: Small fold. Their motivation was that this concept had high potential due to its small size in folded mode and that consisting of only one part made it easy and intuitive to install. In second place,Axkid rated the concept: Box. The motivation was that the concept Box became more uniform while folded than the concept: Lego, that Axkid ranked last.

6.4 Conclusions

Phase 3 consisted of ideation in iterations. It started wide, with various ideas of both whole concepts and components, which was narrowed in three fundamental holistic concepts. At the end of Phase 3 one fundamental concept was chosen to be further developed, the Small Fold concept. The Small Fold concept was chosen based on being the concept that provided the highest rating both in the Kesselring Matrix and in the Expert Consultation.

6.4.1 Decisions

Important decisions were made during Phase 3. At the Expert Consultation during Part A, the client, Axkid confirmed that the five space-saving components were useful principles for this project. The five space-saving components were core principles that the three fundamental concepts made use of. Another decision was that the concept Small fold was the best of the three fundamental concepts and therefore should be further developed in Phase 4. Both the Kesselring Matrix and Axkid ranked the concept Small fold highest.

6.4.2 Issues to be Further Investigated

The Small Fold concept should be developed further in Phase 4. Some important issues that needs to be further investigated were:

- Configuration of rebound bar - what is the minimum height possible that is safe?
- Size and measurements of different parts
- Hinch design
- Material selection
- Semiotics
- Usability
- Cleaning options

7. PHASE 4 - DEVELOPMENT

During this last Phase of the project, the chosen concept solution from Phase 3, Small fold, was developed into an applicable concept. The Small fold concept was further developed and ideated in many iterations where measurements of different parts, usage of the concept and usability were investigated. The concept was visualized by a prototype and also as a 3D model in a CAD program. This provided understanding of how the concept’s parts should interact, which were very helpful during the development process. The final concept; a CRS developed for shared mobility, was then evaluated by a Kesselring Matrix where the new concept was evaluated compared to two existing CRSs, Axkid Modukid and Nachfolger HY5.

7.1 Methodology

The methodology of Phase 4, the development process, was an iterative process. Ideation was used continuously to improve and develop parts as well as the whole CRS concept. Mock-ups and virtual prototyping were used to improve and visualize the concept stages. The CRS Axkid Modukid was analyzed. The final concept was evaluated by a Kesselring Matrix. Phase 4 is illustrated in figure 27.

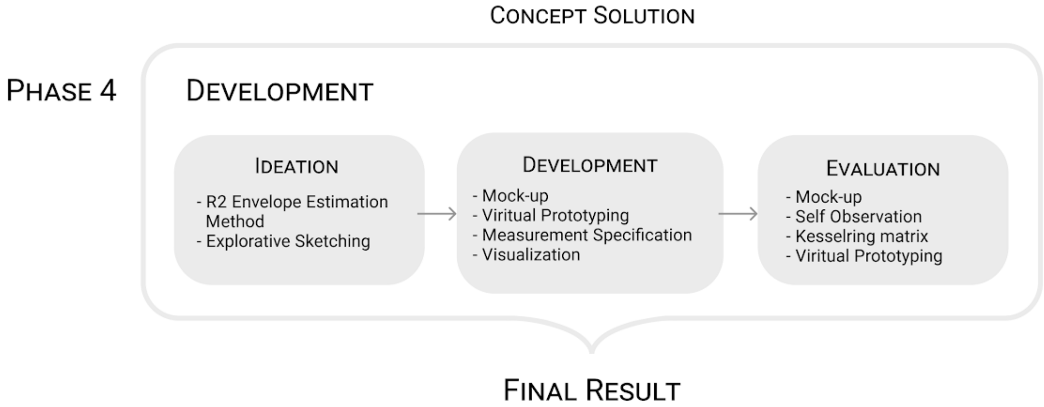


Figure 27: Schematic image of project process of Phase 4.

7.1.1 Ideation

The small fold concept was developed during Phase 4 via an iterated Ideation process. The Ideation made use of Brainstorming (See section 2.4.2 Ideation Methods - Brainstorming) and explorative sketching.

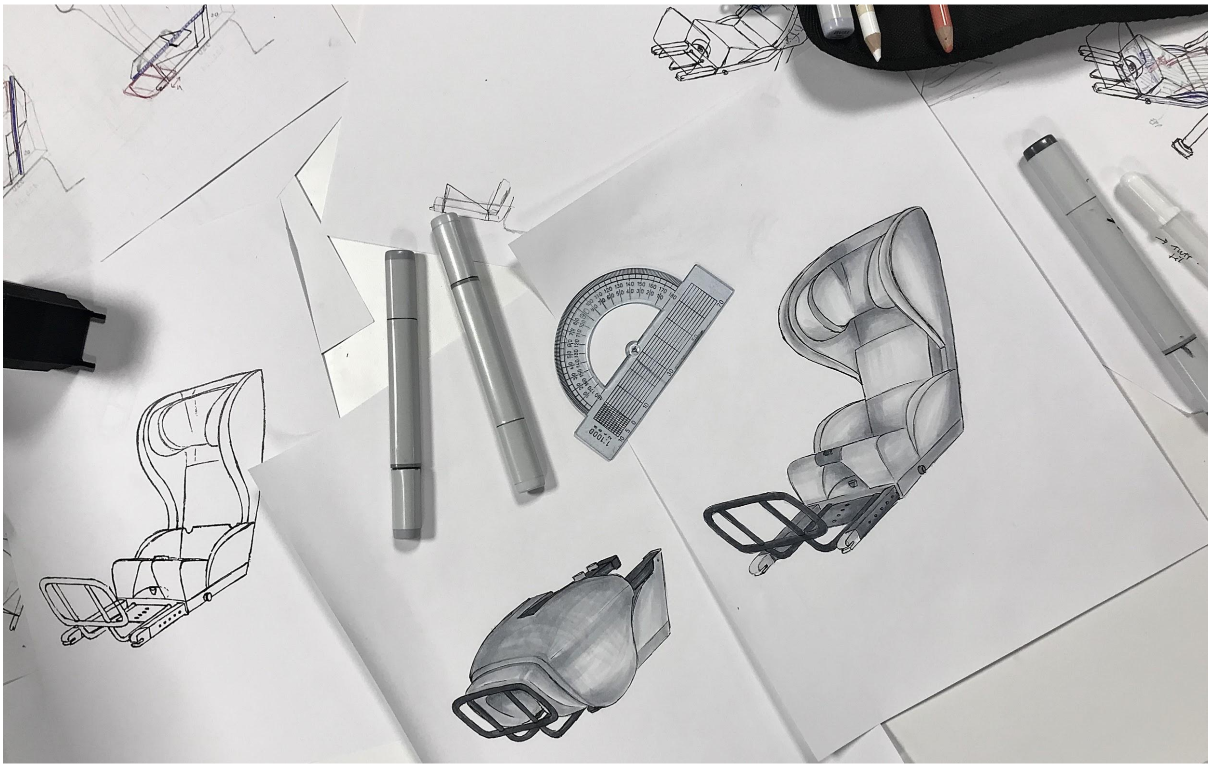


Figure 28: Explorative sketches of different stages during the Ideation process of Phase 4.

Ideas were communicated verbally and via rough sketches. The R2 Envelope Estimation Method was once again used to estimate possible space of different parts. See section 6.1.3 R2 Envelope Estimation Method for a more detailed description of the methodology. The different concept ideas were drawn in scale into the R2 Envelope Estimation worksheet both in the folded position and in the seat mode to understand how the different parts could interact and fit into both use modes. Ideation was applied during different stages of the development process during Phase 4, in figure 28 examples of explorative sketches are shown.

7.1.2 Mock-up

To visualize and gain a better understanding of the Small fold concept, a Mock-up made of foam board was built. The Mock-up was in scale 1:1 to provide an understanding of the usage of the concept and to enable the prototype to be tested and evaluated in context during Self Observations. The Mock-up had several interaction moments built-in, for example, foldable back, adjustable headrest, movable ISOFIX-arms among other things, which allowed the use situation to be tested. The Mock-up was iterated and developed continuously during the development process of Phase 4 and worked both as an ideation method and as an evaluation method. The measurements that were estimated during ideation were tested in the Mock-up and the result of measurement from the Mock-up worked as a foundation in the 3D modeling.

7.1.3 Analysis of Axkid Modukid

A CRS of the model; Axkid Modukid, has been at the project group's disposal during the whole project. Axkid Modukid has been analyzed in detail and used to; receive measurements and properties of a CRS, analyze possible solutions of components and worked like crash safety reference during the development phase of the new CRS. The CRS has also been used during Self Observations.

7.1.4 Self Observation

Self Observation, where the project group members reenacted as users, were used during the development process. Since the prototype was of low fidelity and it was hard to gain access to the main target group, parents with a car-free lifestyle, Self Observation was used to gain a user perspective and evaluation of the concept in different common use situations. To get in the right mindset and think like the target users, the two User Journeys were used as inspiration during these reenactments. The User Journeys were based on the findings from User Studies Part 1 and 2 and worked as a summary of common answers. In this way, the use situations, the Personas and their life situations from the User Journeys, could be used during the Self Observation sessions to more easily recall user findings and provide more accurate evaluations. See section 5.2.3 User journeys, where the result from the User Journeys can be found. The reenactments were done in context to provide the most accurate result. Therefore, the object that was to be observed, that is, the prototype, was observed in a car. The car was a BMW i3, which is a smaller car model, which was chosen since a smaller car puts higher demands on the CRS, that was accessible to the project group and borrowed from the company ESSIQ.

7.1.5 Virtual Prototyping

To develop the concept in detail a virtual 3D model was built. The program that was used was CATIA V5. The modeling was an iterated process where CRS components were evaluated and adapted to fit into the CRS concept as a whole during the Virtual Prototyping process.

7.1.6 Kesselring Matrix

To evaluate if the final result would be a better alternative for parents who do not own a car than existing CRSs, the concept was evaluated in a Kesselring Matrix to two comparing CRSs - Axkid Modukid and Nachfolger HY5. Axkid Modukid was chosen since it is a safe CRS that uses the same attachment systems of ISOFIX, rebound bar and support leg, as the new concept. Nachfolger HY5 was chosen since it is the most mobile CRS on the market today and developed for a similar market that was the aim of this project. Both of the two comparing CRSs are developed for toddlers in the same stature span of 61-105cm as the new concept. The same evaluation criterias and grading that was used during the Kessel ring evaluation during phase 3 was used, see Appendix A7 for selection criteria and how the different criteria were weighted. For more information about the methodology, see section 6.1.4 Kesselring Matrix.

7.2 Results

Phase 4 involved many iterations and the concept was continuously developed and improved. Firstly the ideation led to an improvement of the Small Fold concept, which was illustrated by hand and presented to and approved by the client, Axkid. This concept was translated into a life-sized prototype. The information from the prototype and the findings from using the prototype and the CRS Axkid Modukid during Self Observations in context helped to develop the concept further and were a foundation for the 3D modeling process. During the 3D modeling the components were developed in detail and a whole CRS was built up in CATIA V5. This iterated development of the Small Fold concept eventually led to the final result of this project - the Axkid Free CRS concept. A foldable and mobile CRS concept designed for shared mobility.

7.2.1 Development of Small Fold Concept

After Phase 3, new information was received that affected the development of the Small fold concept. For instance, information about how large the slope angle a CRS for toddlers needs to be impacted the Small fold concept. The joint of the Small fold concept also needed development and the use situation, further investigations. The concept was therefore developed further with ideation methods and the R2 Envelope Estimation worksheet. The result of this is the concept is illustrated in figure 29.

Figure 29: The Small Fold concept further developed in its 4 different use stages.

This concept is in one piece, has a folding mechanism instead of a joint. This folding mechanism provides support through metal bars, figure 29 illustrates the folding mechanism of the concept. The back slope is 35 degrees and the back has a thicker rounded upper part that covers the lock mechanism of the support leg. This new concept should be carried as a backpack, however, with the seat part towards the users back instead of the back part, which was the case in the Small fold concept. This concept was presented to the client, Axkid, that provided feedback that the concept could be promising. This concept was further developed by developing a Mock-up and further worked with a Virtual Prototype.

7.2.2 Mock-up

The Mock-up aimed to provide an understanding of the concept as a whole. By building the mock-up in scale 1:1 the size of the concept could be used during evaluations and Self Observations to test the concept in the right context - in a car. In figure 30 the Mock-up is shown.

Figure 30: Mock-up of CRS concept.

The Mock-up had several movable elements that allowed it to be interacted with in similar ways as in the intended use situation. The prototype was iterated and developed continuously during the development process of Phase 4 and worked as an evaluation of how well the concept could be constructed and used. During the first iteration during Self Observation in a car, it was found that the back was too long for the CRS to be unfolded inside a car without hitting the roof. Also, the width of the rebound bar was too wide to provide a good support to a car seat backrest and that the holder for the support leg took up too much valuable space in the car. These findings resulted in a new ideation iteration, the Mock-up was then moderated and tested in a car again. In figure 31, the newer version of the Mock-up can be seen when it is tested in a car. This time the backrest has been altered and is now possible to fold and unfold inside of the car. In this way, findings from using the prototype enabled the development and worked as a foundation for 3D modeling.


Figure 31: Mockup during Self Observation in a car.

The Mock-up was also used to evaluate the folded mobility-mode of the CRS concept in regards to size and contact towards the back. In figure 32 the folded Mock-up is evaluated as a backpack. The size of the folded concept and the surface that is in contact with the back of a user was estimated to be good. This must however, be further evaluated during future work by a prototype that has the correct weight distribution.


Figure 32: Folded Mock-up used as a backpack.

7.2.3 Analysis of Axkid Modukid

The CRS Axkid Modukid was used as inspiration during the development process, see figure 33. This CRS model was chosen since it is developed for the same range of children, uses the same attachment systems and is developed by the same client as the concepts that will be developed in this project. The CRS was used during Self Observations to gain an understanding for the users and investigate and evaluate the product and different components. By testing to install, uninstall, carry the CRS around and have the CRS back in the car and reflect about leg space for front passengers, it resulted in a personal experience of using a CRS and an opportunity to observe a “user” (a member of the project group) while handling the CRS in context.

By carrying the CRS to a car and for longer distances, displayed the need for better mobility. It became very clear how the bulkiness of the chair further worsened the bad use situation from a mobility perspective. Installing the CRS in a car also provided valuable insights, for example, how dark it is inside a car while installing the product. In this way, usability issues were discovered. For instance that it was difficult to see some of the indicators of the Modukid during installation or that the design of some actuators were hard to understand.

By investigating the different components of this CRS an increased understanding of the different parts and their interactions with each other could be gained. The Axkid Modukid was used as a reference for measurements during the virtual prototyping. In this way estimations about how components could be designed in a crash-safe way could be made.

Figure 33: The Axkid Modukid was evaluated both with Self Observations and by investigating the CRSs components and design in detail.

7.2.4 The Final Concept - Axkid Free

The final result of this project is a CRS concept named Axkid Free. This is a rear-facing CRS developed for toddlers between 61-105cm and for parents that travel with shared mobility options. It is designed to fit users who do not own a car, by being mobile and manageable to bring along, easy to install and uninstall, as well as easy to store between use situations. The concept is foldable and can be carried as a backpack, the weight of approximately 10 kg, which makes it lighter than most rear-facing CRSs. The concept is visualized in figure 34, to the right the concept is covered in its fabric cover and to the left without fabric, where the different components are more visible. The final concept is visualized with 3D modeling in CATIA V5 and with the rendering program KeyShot and with digital sketches. The concept is described in detail in Chapter 8. *Final Result*.

Figure 34: The Axkid Free CRS concept. To the left without fabric cover and to the left with fabric cover on.

7.3 Evaluation of Final Concept

To enable quick evaluations during the many iterations of the development process evaluation methods that could be used by the project group was used. These methods were; Mock-up in scale 1:1, virtual prototyping, User Journeys and Self observations. Finally a Kesselring Matrix was done to investigate if the concept could deliver and get a higher score than the CRSs Axkid Modukid and Nachfolger HY5. Due to a low fidelity Mock-Up, that was difficult to understand as a user, which could have caused misleading answers, a difficulty to gain access to desirable users - parents with a car-free lifestyle, as well as due to the time frame of this project, evaluations with users were not performed.

7.3.1 Mock-up

The Mock-up was used for evaluation of the concept. By being constructed in scale 1:1, it was possible to test the functionality of the concept, for instance making sure that it could be managed as intended and still fit inside a car. That the size of the folded Mock-up was possible to carry on the back as a backpack etc. By iterating and developing the Mock-up, it was used to evaluate several concept ideas.

7.3.2 Virtual Prototyping

During the 3D modeling, measurements of different parts were adjusted and tuned. During Virtual Prototyping, the concept's appearance could be designed and altered according to what appearance that was desirable. By being able to move the different 3D parts - like moving the headrest to its maximum and minimum, the size of the parts could be evaluated and be confirmed that they could fit together and the concept would work. Another example was that the back part could be folded to reassure that the back and seat part could fit together while the CRS is folded. In this way, the Virtual Prototyping worked as an evaluation method as well.

7.3.3 User Journeys & Self Observations

By reenactments and walking through the different use steps from the User Journeys as the character of the Personas of the User Journeys, the information from User Studies could be remembered and used to evaluate how successful the concept could be to the Personas. This was helpful to evaluate the Use Situation of the concept. According to estimations, the Personas would have had a much better user experience from using the new CRS concept.

7.3.4 Kesselring Matrix

To evaluate if the final concept was successful and could provide the chosen target user with a better use situation than the CRSs available on the market today, a Kesselring Matrix was made. In the new Kesselring Matrix, the existing CRSs Axkid Modukid and Nachfolger HY5 were used to evaluate the Axkid Free concept according to similar evaluation criterias that were used in previous Kesselring evaluations.

The result was that Axkid Free received the highest score, 69 compared to Nachfolger HY5 which received the score 56 and Axkid Modukid a score of 36. See Appendix A9 for the full Kesselring Matrix. The high score was due to the fact that the Axkid Free concept received good marks on both safety and mobility. While Axkid Modukid received high marks in safety but poor marks in mobility and Nachfolger HY5 high marks on mobility but low points regarding safety. According to the results from the Kesselring Matrix, the Axkid Free concept covers a new market segment and would improve the use situation for parents who do not own a car.

7.4 Conclusions

During the project's fourth and final phase the development of the chosen applicable concept from Phase 3 was developed through many iterations with the final result - the Axkid Free concept. The final result - the new concept will be described and discussed in Chapter 8-11.

The methods that were used during Phase 4 to develop and evaluate the different concepts provided different insights. The Mock-up provided valuable information about the size and use situation inside a car and the Virtual Prototyping was good to develop different components and evaluations that the parts could fit and work as a whole. The User Journeys was helpful to evaluate the project based on user needs and findings from User Studies. However, to have had the opportunity to evaluate the concept towards real users would have provided much valuable insight that could have improved the concept further. The Kesselring Matrix evaluation indicated that the new concept was better for the chosen main user since it received higher marks than existing CRSs. The evaluation also showed that the concept is better than the options available on the market today and indicates that the new concept could provide a better use situation for parents who do not own a car.

8. FINAL RESULT

This chapter presents the final result of the project. It contains information about material selection, measurements and explanation of the different components of the final concept. This chapter also presents the intended usage of the concept.

8.1 Introduction

The final result of the project is the CRS concept *Axkid Free* **-** a rear-facing, foldable and mobile CRS for toddlers with a stature range between 61-105cm. Axkid Free is visualized in figure 35. The concept is developed for parents who do not own a car and, therefore, have other needs for a CRS, such as being easy to bring along, easy to install and uninstall and offer better store opportunities than the common CRS. In this chapter the Axkid Free concept will be described in detail. The concepts, composition, the different parts and the use situation.

Figure 35: The CRS concept - Axkid Free. With its fabric cover.

The concept is foldable by a folding mechanism that allows the CRS backrest to fold over the seat part, see figure 35. When folded, the CRS can be carried as a backpack or as a suitcase through straps positioned under the CRS seat. In this way the CRS is designed to be transferred and easy to bring as well as takes up smaller space both at home and on travels. Since the CRS should be carried on the back, the user's hands are free to do other things such as carry bags, drag a stroller or hold a child's hand.

The CRS is rear-facing, developed according to the UN R129 regulation and has rebound devices to secure optimal safety. The CRS offers a comfortable backslope angle and has a soft headrest which is designed to provide a good sleep position for the child and keep the head in an ergonomic position. The seat is short and together with the adjustable rebound bar and ISOFIX-arms this offers optimal space for the child's feets and legs.


Figure 36 : Axkid Free in its 4 different positions. Seat position, outfolded, folded and in mobile position.

In addition to developing a CRS concept for shared mobility, the secondary aim of the project was to investigate which customer group that was most favorable for such a product. During the project's User Studies Part 1 it was found that parents who do not own a car, are the most favorable customer group for a CRS adapted for shared mobility. Parents wanted to be able to guarantee the safety of the CRS by knowing that it had not been harmed in a car crash, in order to trust that it was safe to use for their child. Therefore, many parents expressed a strong willingness to own their own CRS rather than to share, borrow or rent. Other investigated target groups such as taxi companies, carpool services etc. were disregarded as target groups for this concept, due to findings that indicated a lack of need for such a system. The cause was partly a concern about being responsible for safety and management regarding CRSs as well as carpool, car-rental and taxi companies referred to that parents were not a preferred customer group for them. Hence, parents were found to be the best possible customer group for this project.

8.2 Material & Weight

Each component of a CRS has to be carefully evaluated and calculated to make sure that the material composition and the design of the part make the CRS durable in a car crash. Since the Axkid Free concept has not been produced and crash tested, assumptions about which materials which are best suited for creating a prototype, have been made and are presented in this section. The assumptions about material choices are based on materials commonly used in CRSs and on expert consultations. An overview of the materials that build up the Axkid Free concept and motivations to why they are chosen is illustrated in figure 37 and described in table 8.

Since the concepts exact material compositions of each component lies outside of the scope for this master thesis, an approximation of the concepts total weight have been made by expert consultation with D. Lundgren, Safety and Compliance Manager at Axkid (personal communication, 5 May 2020). After consultation with D. Lundgren, a possible and reasonable weight of the Axkid Free concepts has been estimated to be approximately 10 kg. This is based on D. Lundgrens experience of how lightweight different components are able to be within a reasonable price range from the company's perspective.

Figure 37: Description of the different materials in the concept.

Table 8: The materials of the Axkid Free in relation to which part the material is used on and the materials qualifications and properties.

Material	**Parts**	**Qualifications**
Hard plastic *Polyethylene (PE)*	Back Seat Pull buttons Key actuator Seat belt buckle ASIP holders Support leg rings Headrest plate Harness adjustment nest	High ductility and high impact strength. A plastic which is commonly used in CRSs.
Metal *The metal used is a mixture of different steels and aluminium.*	Support leg Support leg holder Rebound bar ISOFIX arms Bars and plate of back part Metal core of seat part	The metal composition of each part is chosen based on durability, strength, weight and price. Since Axkid Free is a mobile concept, low weight is an important factor.
Expanded Polypropylene (EPP)	Backplate	Good energy absorption. Lightweight and high strength.
Styrofoam *Expanded polystyrene foam (EPS)*	ASIP	Good energy absorption. Lightweight material.
Polymeric foam with high density *Polyurethane Foam (PUR)*	Headrest Lumbar pads	The polymeric foam is flexible which allows the headrest to be compressed to fit into the space between the back part and the seat part within the folded CRS. The foam should provide support for the child’s head both in a car crash and to provide comfort during regular use, sitting and sleeping. The foam should be of high density to provide the support needed and only has to be compressed a few centimeters while stored in the CRS’s folded mode.
Woven Straps *Polyester*	Five-point-harness Strap to quick-release buckle Backpack handle Backpack shoulder straps Sternum straps	Woven polyester, used in seatbelts, have very high tensile strength to withstand the forces active in a collision. It has a smooth surface and attractive look. Straps connected to the backpack part need to be durable but not as the same quality as the harness.
Fabric - Soft	Headrest Cover of Rebound bar	To give a soft and inviting feeling soft fabric is chosen on the headrest. This is the part of the CRS that is in direct contact with a child's skin and should be smooth and cozy. The fabric is removable and washable.

Fabric - Durable	Upper part Lower part ASIP	A durable fabric covers the main part of the CRS. The fabric has fibers that creates a surface that repels dirt. The fabric is lightly padded to be soft and comfortable for children and to provide a cushion-like appearance that attracts parents. In chosen parts - on the seat and back, where the child leans on, extra padding is used. The fabric is removable by a zipper and washable.
Fabric - Mesh	Lumbar pads	Mesh fabric allows the material under to breath, which will keep the lumbar pads fresh.
Rubber	Support leg block end part	Provides friction in relation to the car's floor.

8.3 Measurements

During the Virtual Prototyping development, each of the components of Axkid Free has been moduled in CATIA V5. During this process measurements of each part were evaluated and decided. Measurements of the concept are of great importance since a CRS has to be able to fit into the R2 Envelope, fit inside a car and be appropriate for a wide range of toddlers. Some of these measurements are visualized in figure 38 and 39. Additional descriptions of measurements of the Axkid Free concept is described in Appendix A10.

8.3.1 Seat Mode Measurements

In figure 38 the measurements of the Axkid Free concept in seat mode are listed. When the back is out folded and the folding mechanisms metal bars are extended, the length of the CRS is increased with 80mm from 580 to 660.

Figure 38: Measurements of Axkid Free concept in seat mode.

8.3.2 Mobility Mode Measurements

When the CRS concept Axkid Free is folded its approximate size is 590 x 410 x 290mm. These measurements are the maximum size since the concept is not folded into a perpendicular box but has a wedge shape. The measurements of the folded concept are illustrated in figure 39.

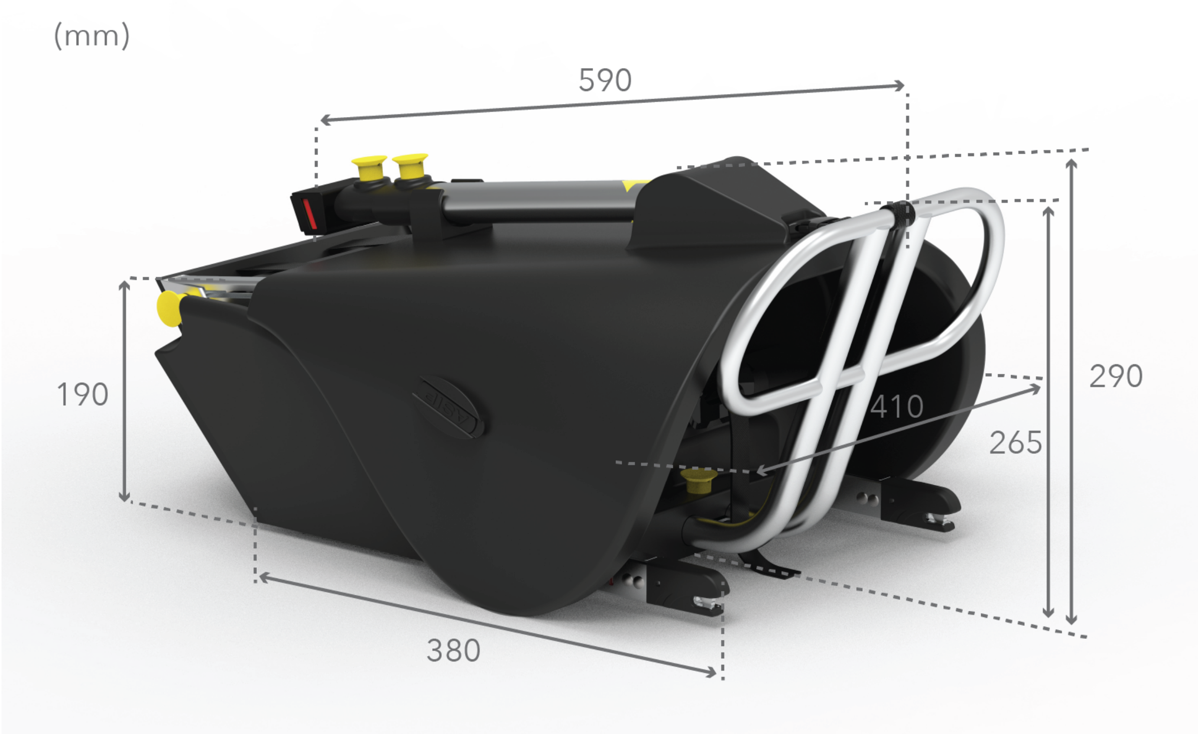


Figure 39: Axkid Free concepts measurements in folded mobility mode.

8.4 Parts

A CRS is a complex product and has many different parts. This section will explain the different parts in detail to provide a better understanding of the CRS concept's composition and functions. Firstly, the lower part and the upper part of the CRS will be described separately. However, these two parts can never be separated by a user, the CRS's different parts can never be removed and the CRS will always be a single unit. The different parts are separated, illustrated and described one by one in this chapter for the reader to gain an understanding of the different parts.

8.4.1 Lower Part

The Axkid Free's lower part is illustrated in figure 40 and makes out the seat of the CRS. The lower part has a hard plastic structure that covers a metal core. The metal core, which is illustrated in figure 41, has two metal bars that run from the two ISOFIX arms up to where the folding mechanism connects the lower part to the upper part starts. The plastic structure of the lower part is formed as a seat cushion with a 25 degree angle. The seat cushion creates a 100 degree angle between the seat and back, which gives a 35 degree back slope angle of the CRS. The two wings on the plastic structure work as side protection for the toddler's hips and create an embracing expression by the large and soft roundings. The lower part is a container for parts like the rebound bar, ISOFIX, and harness and the pull-bottoms that operate different parts. (The lower part can also be seen as a container for the upper part, since these are connected.) On the bottom of the lower part, shoulder straps, four lumbar pads and a backpack handle are located, see figure 42. The lower part is covered by a fabric cover that is padded for comfort and can be removed and washed.

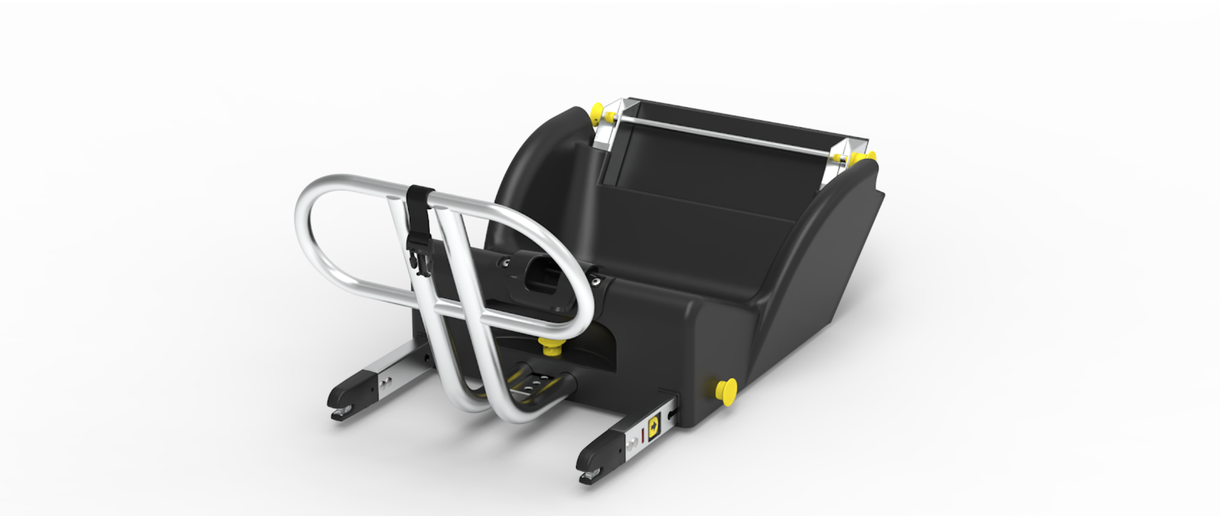


Figure 40: Lower part of Axkid Free.

Figure 41: Metal core of the Axkid Free's lower part.

Figure 42: Bottom side of the lower part where the backpack straps can be seen.

8.4.2 Upper Part

The upper part is connected to the lower part by the folding mechanism, which connects the metal bars in the metal core of the lower part with the metal bars of the upper part (More pictures and descriptions in section 8.4.3 - Folding Mechanism). In figure 43, the upper part is visualized. The upper part has a plastic structure that is attached to a metal plate with two metal bars. An EPP plate is positioned inside the plastic structure that creates a flat back surface which gives back support and shock absorption for the toddler. The backrest position in seat mode creates a slope angle of 35 degrees in relation to the ground, which is an appropriate slope angle for a CRS for toddlers between 61-105cm. The upper part has cavities for the seat belt and the adjustment mechanism for the headrest.

The support leg is connected to the back by a metal holder that is kept inside the upper part plastic structure. The leg can also be held in place when the support leg is unfolded in the plastic holder on the upper parts back. On the upper part, two side wings and two ASIP attachments are positioned. To the ASIP attachments, an ASIP block can be connected. ASIP is a type of side impact protection that Axkid uses on many of their CRSs, like on Modukid. The ASIP block is made of styrofoam with a plastic back side that can connect to one of the attachments, depending on which side the CRS is placed in the car.

The headrest and the headrest plate fits inside the upper part. The shape of the upper part has enclosing side protection wings to provide side protection for the toddler, and an embracing and caring expression. The upper part has a fabric cover that is soft and padded. This cover can be removed by a zipper which allows the fabric to be cleaned.

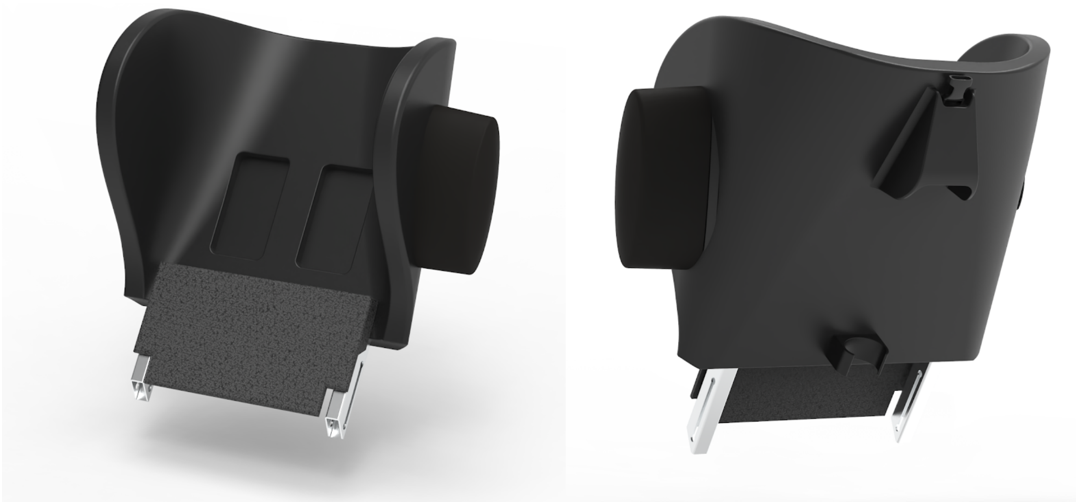


Figure 43: Upper part of CRS front view and back view.

8.4.3 Folding Mechanism

A factor that distinguishes Axkid Free from other CRS models on the market is the ability to be folded. A folding mechanism allows the upper part to be folded on top of the lower part, which reduces the CRS's size and makes it more manageable. The different parts active in the folding mechanism are visualized with the corresponding terminology in figure 44.

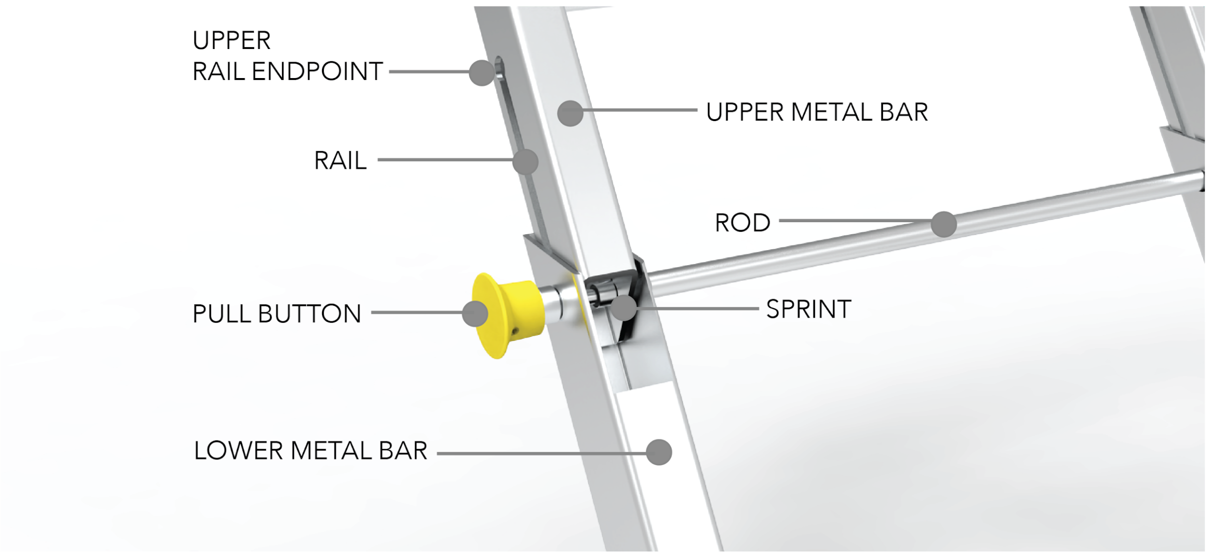


Figure 44: Folding mechanism and its parts, with terminology.

The folding mechanism consists of a long metal rod. Each end of the rod is connected to a pull button, with a spring and a sprint. The rod spans across the CRSs backside and connects the upper metal bars and to the lower metal bars. The upper metal bars have milled rails in which the rod and sprints of the folding mechanism can slide. This enables the upper metal bars to slide up and down the rail between two circular endpoints in the rail - which either submerge or extend the upper metal bars into/from the lower metal bars.

When the sprints of the rod go through the circular endpoints in the rail, the sprints fill the circular endpoint, which locks the rod and stops the upper metal bars from submerging or extending. When the upper endpoint of the rail is locked by the sprints, the CRS is in seat mode and the upper metal bars are submerged 120mm into the lower metal bars which give the CRS stability and strength, see figure 45. When the lower rail endpoint is locked by the sprints the upper metal bar is extruded from the lower metal bar and the upper part can be rotated forward, this allows the upper part of the CRS to be folded over the lower part.

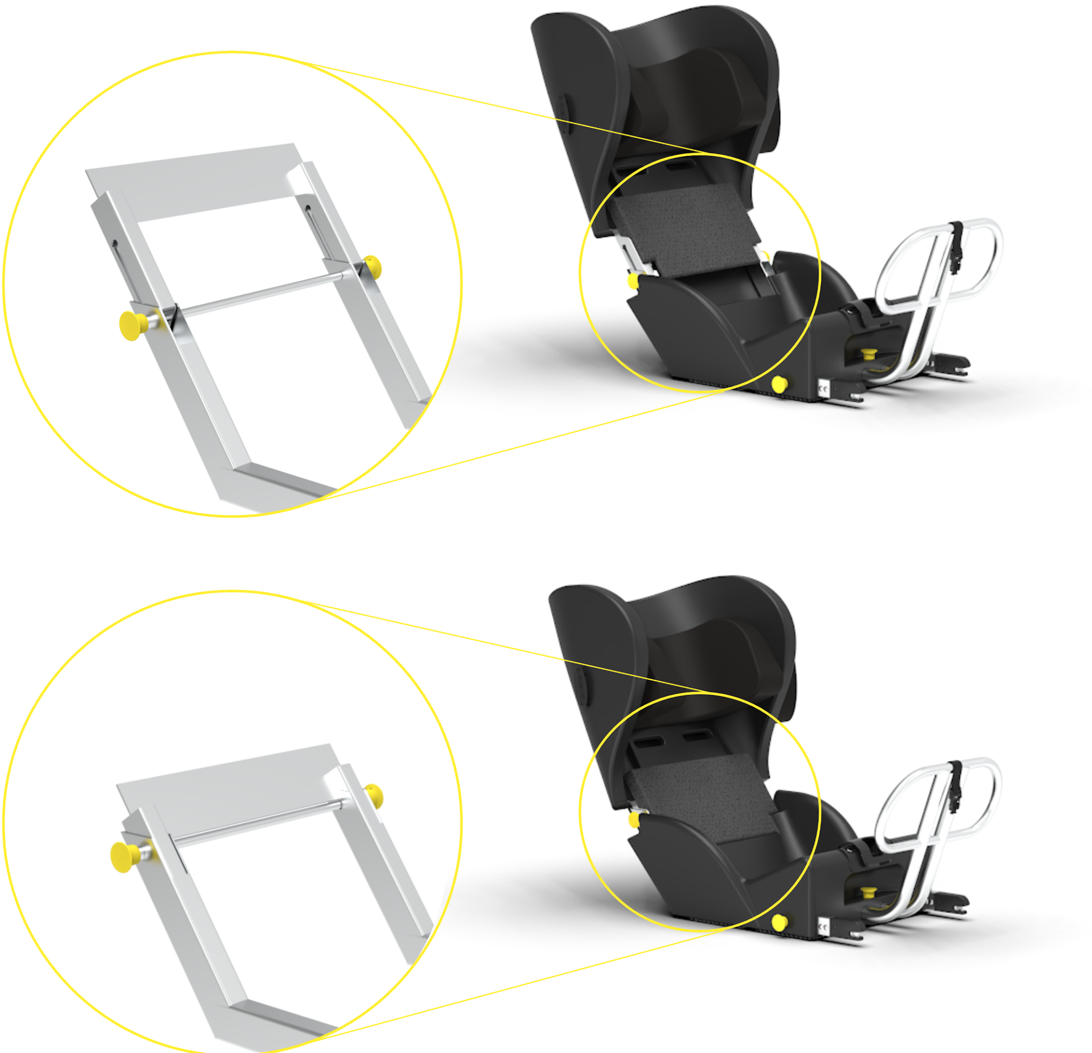


Figure 45: Folding mechanism, at the top is the folding mechanism extended and to the bottom is the folding mechanism submerged.

The folding mechanism in detail - from mobility mode to seat mode:

1. The sprints fill the lower circular endpoint of the upper metal bars. This locks the folding mechanism and the upper part of the CRS can be folded over the lower part. To enable the folding of the upper part, the lower metal bar has no front side at the top, see figure 46.

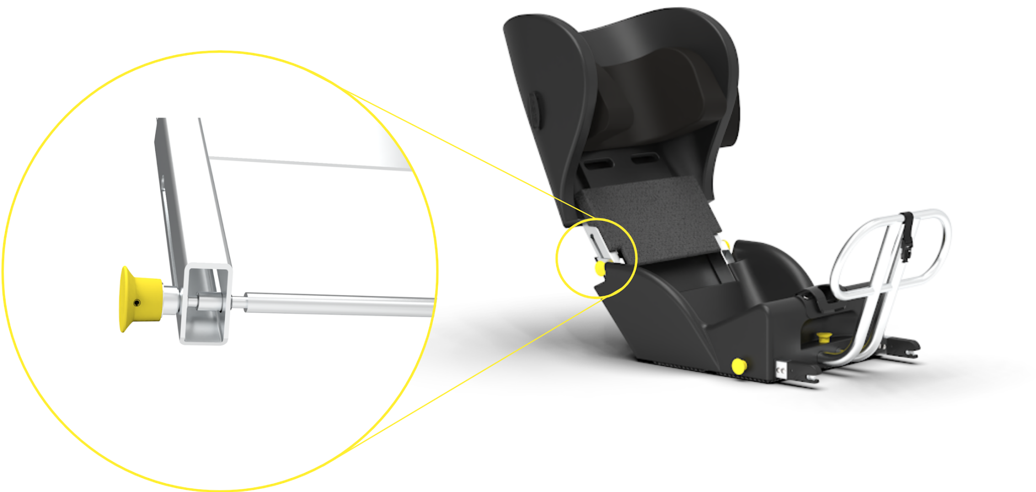


Figure 46: Step 1 folding mechanism.

2. To turn the CRS from mobility mode to seat mode the upper part of the CRS needs to be raised. To submerge the upper metal bar into the lower metal bars, the user pulls one of the two yellow pull buttons that are located and anchored at each side of the rod (either of the two pull buttons will work). By pulling one of the pull buttons the rod moves in the same direction and the sprints are disconnected from the upper rail endpoint, figure 47. This allows the rod to be moved along the rail of the upper metal bar, see figure 48. This allows the upper metal bar to be submerged into the lower metal bar.

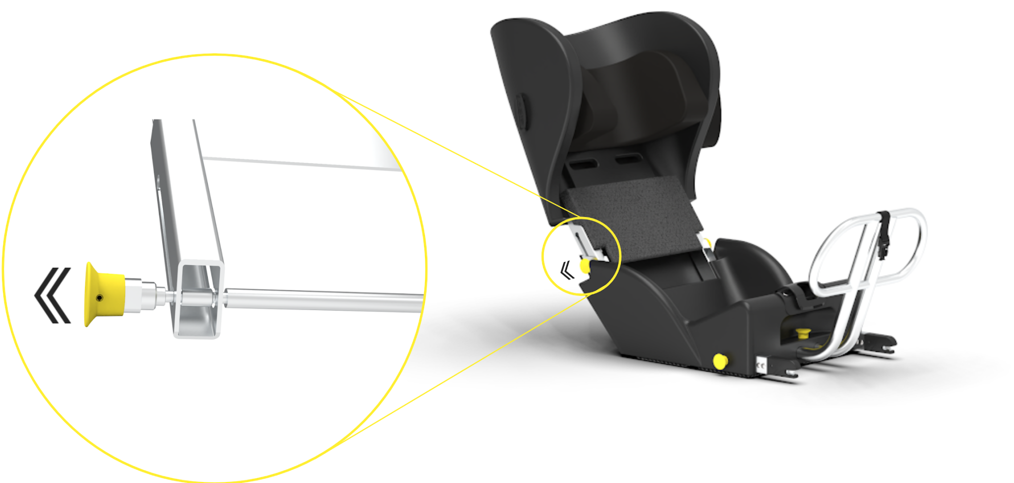


Figure 47: Step 2 of folding mechanism, when pull button is pulled.

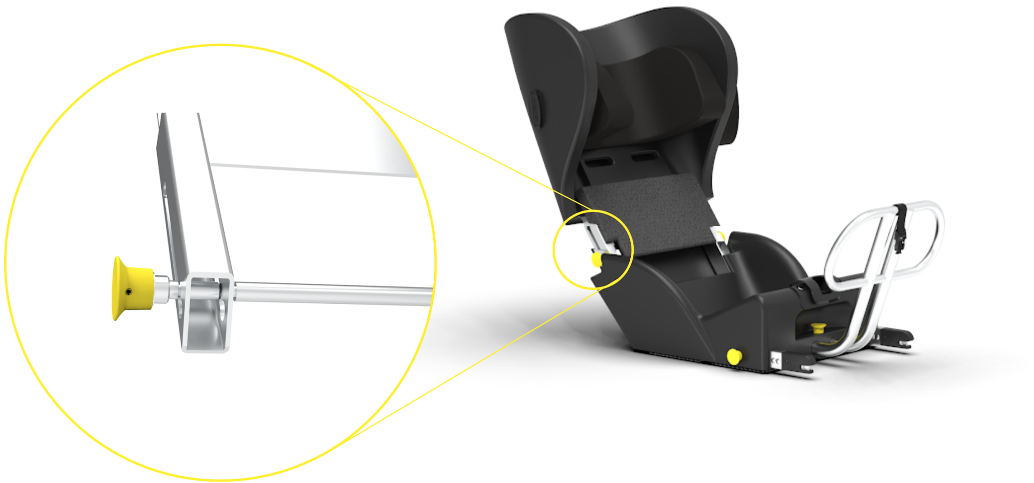


Figure 48: Step 2 of folding mechanism, when rod moves inside the rail.

3. By pulling on the pull button a spring inside the button is pressed together (the spring in the opposite pull button is extended). When a user releases the pull button the springs put pressure on the sprint and the rod. If the rod is positioned by the more narrow rail, the upper and lower metal bars can slide along each other. If the rod is positioned by the upper or lower rail endpoint, the pressure from the springs pushes the sprint in place and locks the locking mechanism automatically, see figure 49. Now is the CRS locked and usable in seat mode.

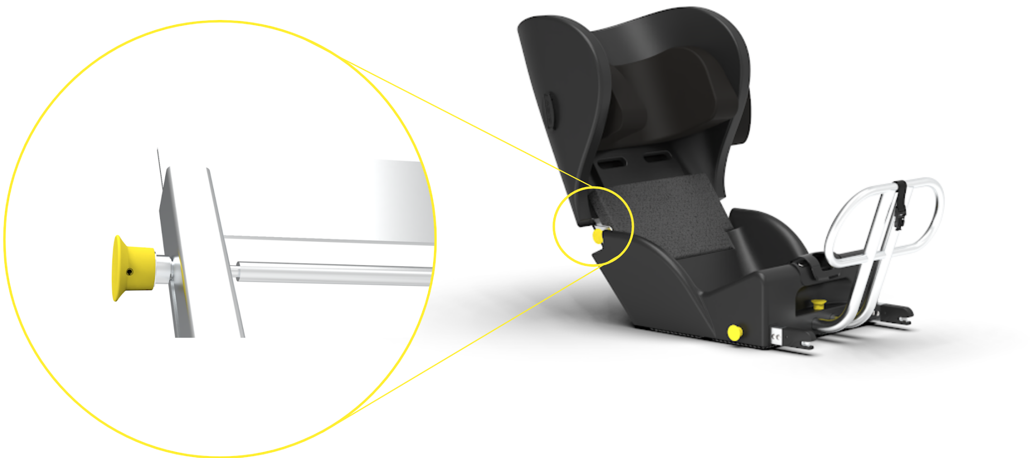


Figure 49: Step 3 of folding mechanism.

Pulling on one of the pull buttons will open the sprints on both sides of the folding mechanism. Therefore only one of the buttons has to be operated. The operations described in step 1-3 are performed in reverse on the lock mechanisms opposite end.

8.4.4 Headrest & Backplate

The headrest is made of Polymeric foam with high density and has a soft fabric cover that can be removed and washed. The foam's density makes it hard enough to stabilize the head of the toddler, but soft enough to be compressed a few centimeters when the CRS is folded. The headrest is always positioned inside the CRSs upper parts side wings. In this way the upper part of the CRS covers the child's head during a side collision and the headrest is there to fill the gap between the head and the CRSs side. The headrest is attached to a plastic backplate, see figure 50, which is connected to the CRSs upper part.

Figure 50: Headrest and backplate of Axkid Free.

The backplate and headrest can move up and down due to an adjustment mechanism that is inspired by Axkid's CRS model Modukid. The harness goes through the backplate and the adjustment mechanism to create the option to adjust the headrest by tightening and loosening the seat belt. To position the headrest in the new position there is a key actuator that locks the headrest in position, visualized in figure 51. To guide the user to understand the key actuator there are two labels on each corner of the front side of the key actuator, symbolizing an opened and a locked padlock symbol. The headrest is locked when the key actuator is tilted against the side with the locked padlock symbol. Another option to adjust the headrest is to manually adjust by unlocking the key actuator (tilt it to the left side) and moving it up or down. The headrest can be adjusted with 120mm, which is the same amount that is commonly used on CRSs for toddlers and allows a good position for children in the stature range of 61-105cm.

Figure 51: Key actuator that operates headrest adjustments.

The headrest and the EPP plate of the backrest are offset with 1cm (see figure 52). This allows the child's head to be laid back which makes sure that it is not tilted forwards if the child falls asleep in the CRS.

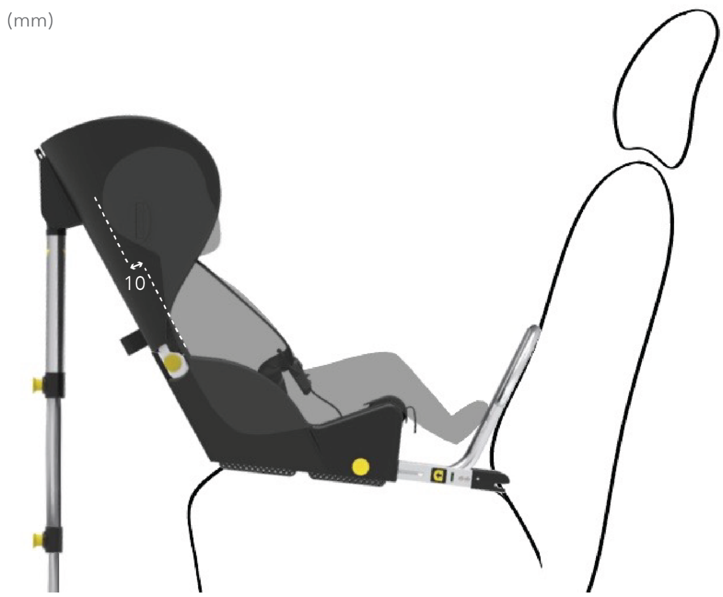


Figure 52: Offset of 10mm between headrest and backrest.

8.4.5 Harness

A five-point harness is used to fasten the child in the CRS. In figure 53, the different names of the parts of the harness are described.

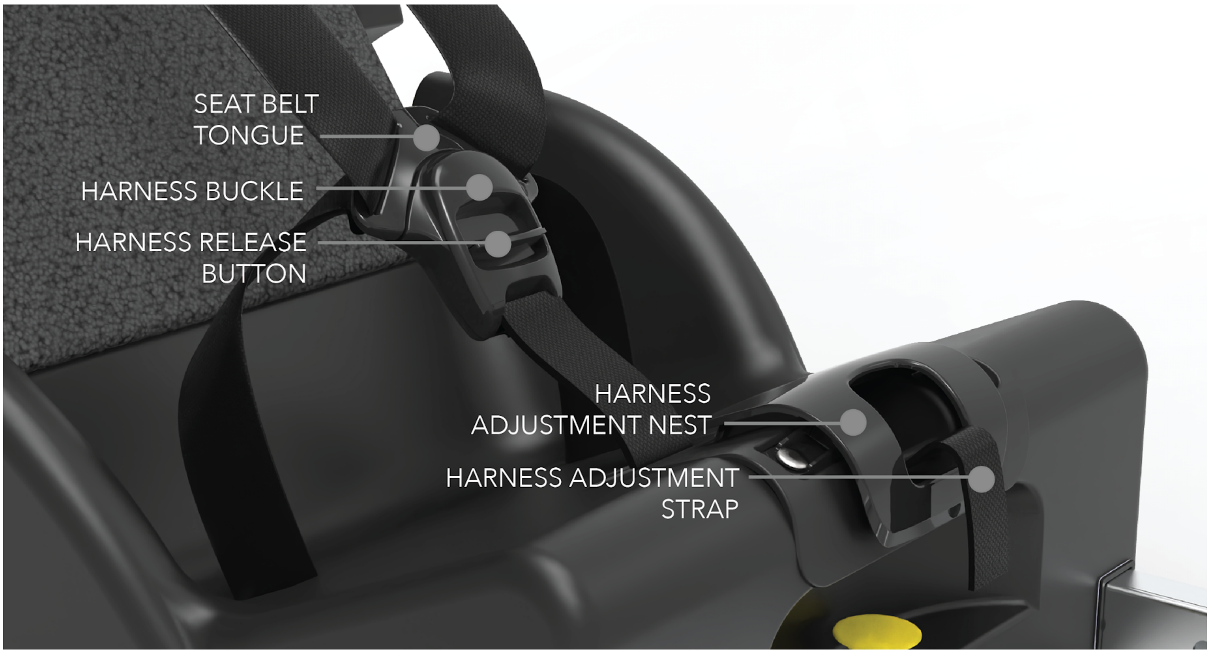


Figure 53: Terminology of different parts of the five-point harness.

Three points of the harness are attached to the lower part. The additional two-points goes through the backplate and down through the upper part to the lower part where it merges down to one strap that goes out through the harness adjustment nest that is located in the middle of the legs of the child, see figure 54, where the harness way through the CRS are illustrated.

Figure 54: Five-point harness of Axkid Free.

A parent or guardian can pull on the harness adjustment strap to tighten the harness. Inside the harness adjustment nest there is a button, out of reach of the toddler. When this button is pushed it is possible to loosen the harness. The seat belt tongue and harness buckle is the same as on the CRS Axkid Modukid. The harness is buckled by connecting the two parts of the seat belt tongue, which connects both side straps of the harness together, and then the seat belt tongue can be attached to the harness buckle. When all the parts are attached together it locks. The buckle can be opened by pressing down the harness release button on the harness buckle.

8.4.6 Support Leg

The support leg is attached to the upper part of the CRS and consists of different parts. See figure 55 for terminology of the support leg.

Figure 55: Terminology of support leg.

The support leg consists of two main parts, the support leg and the support leg attachment, see figure 56. The leg attachment is made of metal, is connected to the CRS's back and hidden by the plastic leg cover of the upper part of the CRS. The attachment also consists of an attachment ring in plastic. The attachment ring is connected to the metal part with two screws, therefore, the ring can be rotated. The support leg has an upper block. This block is bigger than the attachment ring and positioned above it, which connects the support leg to the leg attachment.

Figure 56: Support leg main parts, to the left the support leg
and to the right the leg attachment in metal and the attachment ring.

The metal leg attachment has a cavity, in which the upper block of the support leg can be submerged into, which locks the support leg. This is how to lock and secure the support leg during usage in a car. In a locked position the indicator of the attachment ring turns to green. When unlocking the support leg, the metal profile of the support leg is pulled downwards, in the direction of the arrow, which removes the upper block from the cavity of the leg attachment and turns the indicator from green to red. See figure 57. When unlocked, the support leg is held in place by the attachment ring and can be rotated towards the CRS's back. Here it can be locked into the leg holder.

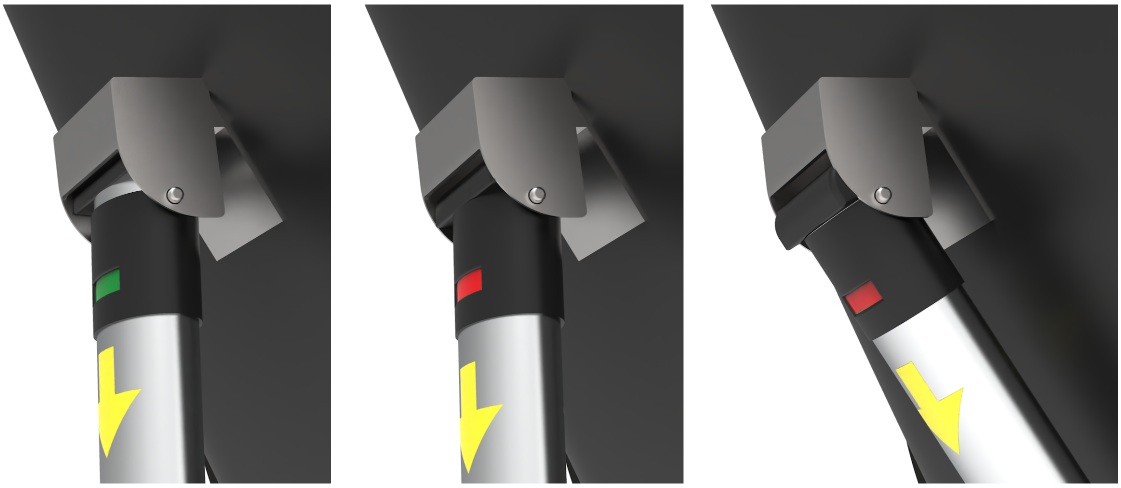


Figure 57: Lock mechanism of support leg. To the left, in the locked position.
In the middle and to the right in unlocked position.

The support leg has a telescoping function and consists of three metal profiles with different diameters. These can be adjusted by pulling the yellow pull buttons that enable the user to extend and submerge the support leg. See figure 58 for the different positions of the support leg. The minimum length of the support leg is 378mm the maximum length of 1000mm. The support leg consists of ellipse-shaped pipes of different sizes that allow the three pipes to be submerged into each other. The ellipse-shape is space efficient, which is important for the CRS to fit inside the R2 Envelope. The largest pipe is 49x30mm. When the support leg is unfolded from the back and at a perpendicular angle, a spring inside the leg attachment drags the support leg and the upper block into the cavity of the leg attachment, which automatically locks the support leg.

Figure 58: The support leg's different positions. To the left folded and connected to the leg holder. In the middle, outfolded and to the right extended.

At the end of the support leg, a rubber block provides a good grip for the support leg towards the car's floor. This end block has a color indicator, which switches from red to green when the support leg is correctly placed on the ground. The pressure from the CRS against the car floor pushes a large push button that is placed underneath the block, which shifts the color on the indicator, see figure 59.

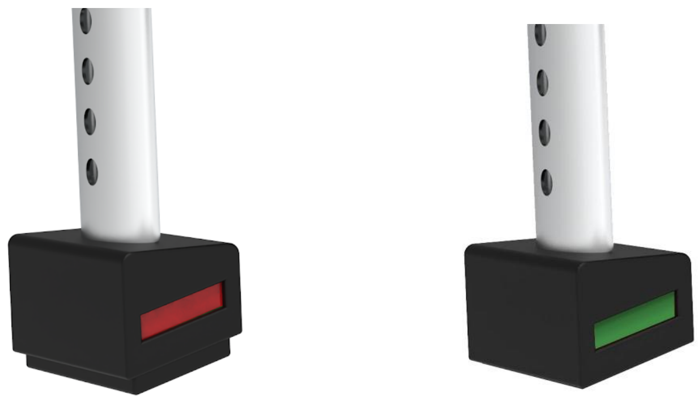


Figure 59: Color indicator at the support legs end block.

8.4.7 ISOFIX Arms

The ISOFIX arms follow the ISO standard ISO 13216-1 and have the same principles and form factors as the CRS Axkid Modukid. They consist of two metal profiles that slide inside two additional metal profiles with a wider diameter inside the metal core of the CRSs lower part, see figure 41. Connected to the ISOFIX arms are the ISOFIX seat bight anchorages that can be connected to the car's anchorage point. When the ISOFIX seat bight anchors connect to the car's anchorage point a color indicator alongside the metal profile turns from red to green to show the user that the ISOFIX arms are correctly connected, see figure 60. To release the ISOFIX arms, the user needs to press the yellow button on the metal profile and in the same action slide the button towards the seat of the CRS, the same direction as the black arrow is pointing. By executing this procedure the seat bight anchor opens and the color indicator turns red again. This procedure is performed on both of the ISOFIX arms to release the CRS. The ISOFIX arms can be adjusted by being extended (maximum 100mm). This action is performed by pulling the yellow pull buttons, one by one, at the side of the CRS, and with the other hand controls the extension of the ISOFIX arms by pulling it.

Figure 60: ISOFIX attachments and related actuators and indication stripe.

8.4.8 Rebound Bar

The rebound bar is inspired by the rebound bar on CRS Modukid by Axkid. It consists of circular metal structures with similar diameter and shape. The rebound bar curves with an angle of 20 degrees, to provide a good angle against the car seat's backrest and to provide a large contact area. The rebound bar is 265mm tall, 315mm wide and can be adjusted 100mm. The rebound bar is attached to the lower part of the CRS by a yellow pull bottom that works like a sprint, just like the similar buttons on the support leg, ISOFIX arms and folding mechanism, and stabilizes the rebound bar. To adjust the rebound bar the yellow pull button needs to be pulled up and it can be adjusted by hand. When released, the pull button automatically locks. The rebound bar is with a covered black fabric, see figure 61, that is removable and washable. A quick-release buckle male is connected to the rebound bar. This is connected to the quick release buckle female of the CRSs upper part when the CRS is folded, which connects the two parts together during mobility mode. The rebound bar of Axkid Free can not be removed from the CRS to prevent misplacing the important rebound device and prevent misuse.

Figure 61: Rebound bar, to the left its configuration and to the right with the fabric cover.

8.4.9 Mobility Mode

The CRS can be folded into a shape that enables it to carry it as a backpack to transport it easily, see figure 62. When the CRS is folded it can be carried in the backpack shoulder straps. A sternum strap is located between the shoulder straps, for ergonomic reasons. To give the user a more pleasant carrying experience there are four lumbar pads in a polymeric foam covered with a mesh fabric on the plane bottom surface of the lower part. It can also be carried by using the backpack handle which is positioned high up between the shoulder straps. To ensure that the CRS does not unfold itself when the user carries it, there is a strap with a quick-release buckle between the top of the rebound bar and the top of the support leg that connects the upper and the lower part of the CRS and holds it securely folded. The length of the shoulder straps can be adjusted to fit the back of as many users as possible.

Figure 62: Axkid Free in mobility mode.

8.5 Usage of Concept

The main users of the CRS concept Axkid Free are parents who travel with a toddler. It is parents that buy, store, transfer, installs and uninstalls the CRS. Therefore the CRS has to be attractive, comfortable and offer good usability mainly for the parents. The toddler is also a user, who will travel in the CRS. Comfort for the toddler is therefore important and a happy and content toddler will lead to pleased parents. The different use situations of the CRS will be described below.

8.5.1 Storage

The Axkid Free CRS concept is smaller and takes up less space when it is stored than the common CRSs on the market, due to its foldability. The measurements of the CRS in folded, mobility mode is approximately 590 x 410 x 290mm, see section 8.2.1 Measurements for more details. This can be compared to an Axkid Modukid which in its smallest state is approximately 550 x 450 x 700mm. The concept does not have any sharp edges that can harm other surfaces or objects that the CRS is stored together with. The CRS is uniform with few extruding parts. The Axkid Free can be stored in mobility mode laying down with the backpack straps facing down. It can also be hung up, for instance on a hock, in the handle on the lower part of the CRS, see figure 63.

Figure 63: Axkid Free concept in mobility mode, stored in a hallway.

8.5.2 Mobility

The concept is mainly intended to be transported by being carried on the back as a backpack, using the shoulder straps which are positioned on the underside of the CRS's seats, see figure 64. Connected to the backpacks shoulder straps there is a backpack handle that offers the CRS to be carried by one hand. Since the concept will weigh around 10 kg, it will be most convenient and ergonomic to transport the CRS on the back, especially for longer distances. By carrying an object on the back, the loads are evenly distributed. To increase the comfort for the user a sternum strap (consisting of a strap with a quick attachment lock) is placed between the backpack shoulder straps to provide extra support. The CRS has lumbar pads to offer support and comfort to the user.

Alternative methods to transport the CRS is to carry it under one arm, the range of the CRS allows this carrying position. However, the weight of the CRS would make it uncomfortable and unergonomic to carry the CRS in this position for a longer time. Depending on the stroller model, it could also be possible to store the folded CRS underneath the child's seat in the storage area. Or to connect the CRS via the quick release buckle that holds the rebound bar and the backrest connected, around the stroller's handle, as long as the stroller composition allows the weight of the CRS at this position without being tail heavy.

Figure 64: Axkid Free concept in mobility mode in a Use Situation.

8.5.3 Installation

Installation of the CRS requires several substeps. To guide the user along with these steps, the interaction elements are highlighted in the concepts accent color - yellow. These substeps of the installation process are described chronologically:

1. **Placement of CRS in Car**
   The folded CRS Is placed in the car, with the backpack straps faced down towards the car's seat. See figure 65 for illustration of step 1.

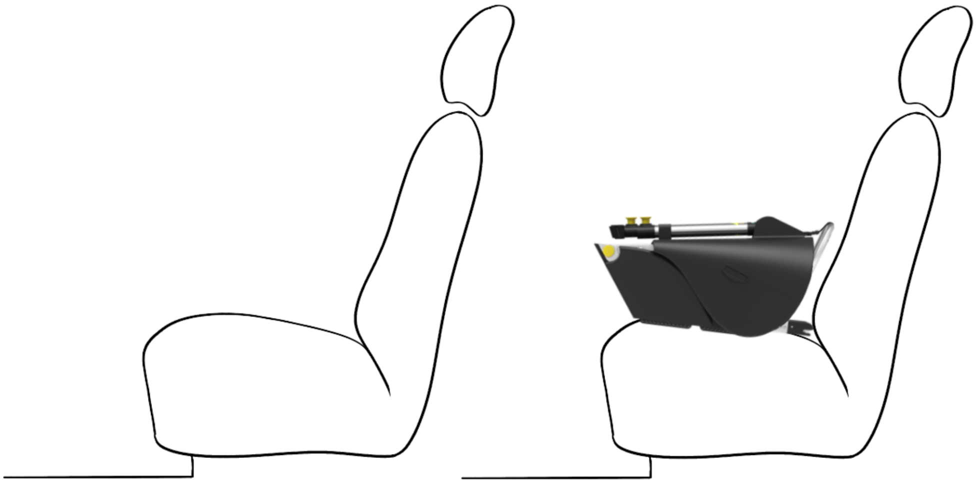


Figure 65: Installation step 1.

2. **Unlocking - Mobility Mode to Seat Mode**
   The quick-release buckle that connects the CRS's back to the rebound bar is opened. This step is illustrated in figure 66.

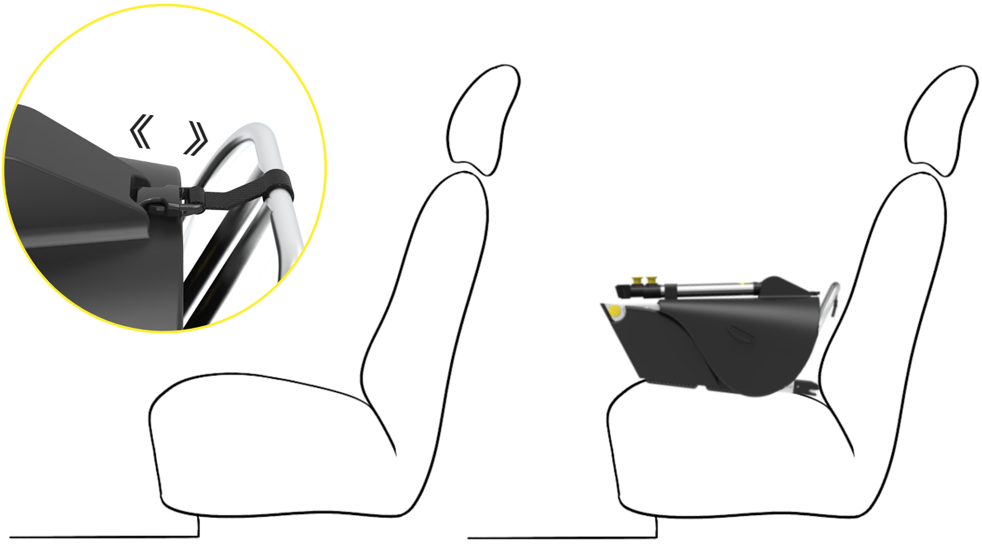


Figure 66: Installation step 2.

3. **Unfolding the Backrest**

   The unfolding of the back is presented step by step, see figure 67 for illustration of the unfolding process.

   1. The CRS's back is folded up with one hand. (When the quick release buckle is opened, nothing else keeps the back and the seat locked together.) The backrest length allows the CRS to be unfolded inside the car without being obstructed by the car's ceiling.
   2. With the other hand one of the yellow pull buttons, at the side of the CRS, is pulled towards the users. This opens the sprints of the folding mechanism.
   3. Which allows the metal bars of the back to slide inside the metal bars of the seat.
   4. When released, the pull button automatically, due to a spring, locks the folding mechanism which is indicated with a click.

   Now the CRS is unfolded and the back is properly locked in a raised position.

   Either one of the two opposite pull buttons at the CRS sides will work to open the sprints of the folding mechanism. Therefore, the button closest to the user can be used, no matter which side of the car that the CRS is installed in. To open the sprint of the folding mechanism, only requires that one of the two buttons are pulled and the other hand can control the positioning of the upper part.

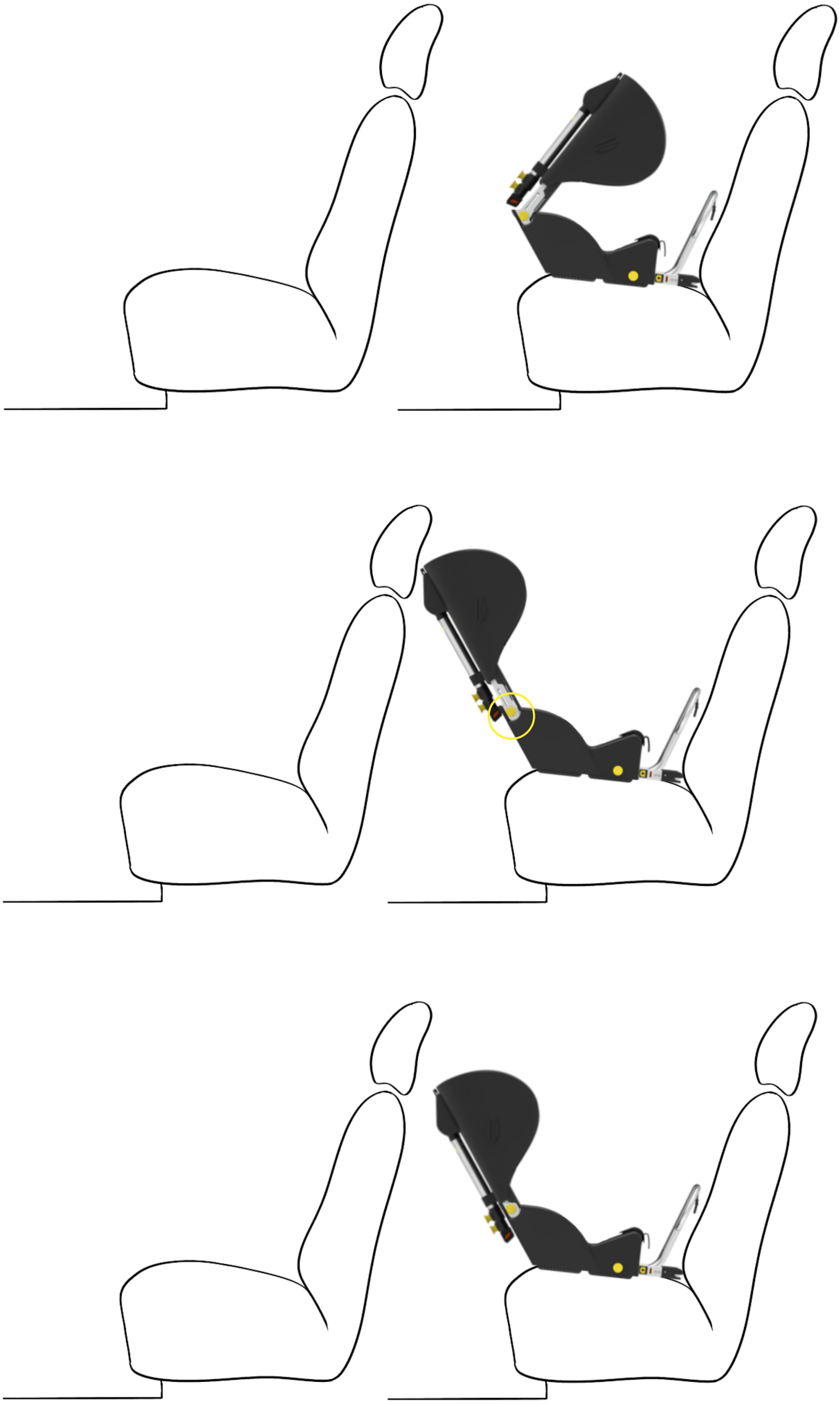


Figure 67: Installation step 3.

4. **Connecting the ISOFIX Attachments**
   When the back is folded up, the ISOFIX attachments are clearly visible (when the back is folded the back covers the ISOFIX seat bight anchorages). The seat bight anchorages are connected to the car's anchorage points. When connected and the ISOFIX is properly locked, feedback is provided to the user through an audible click and the indicator at the ISOFIX arms turns from red to green. See figure 68 for illustration of step 4.

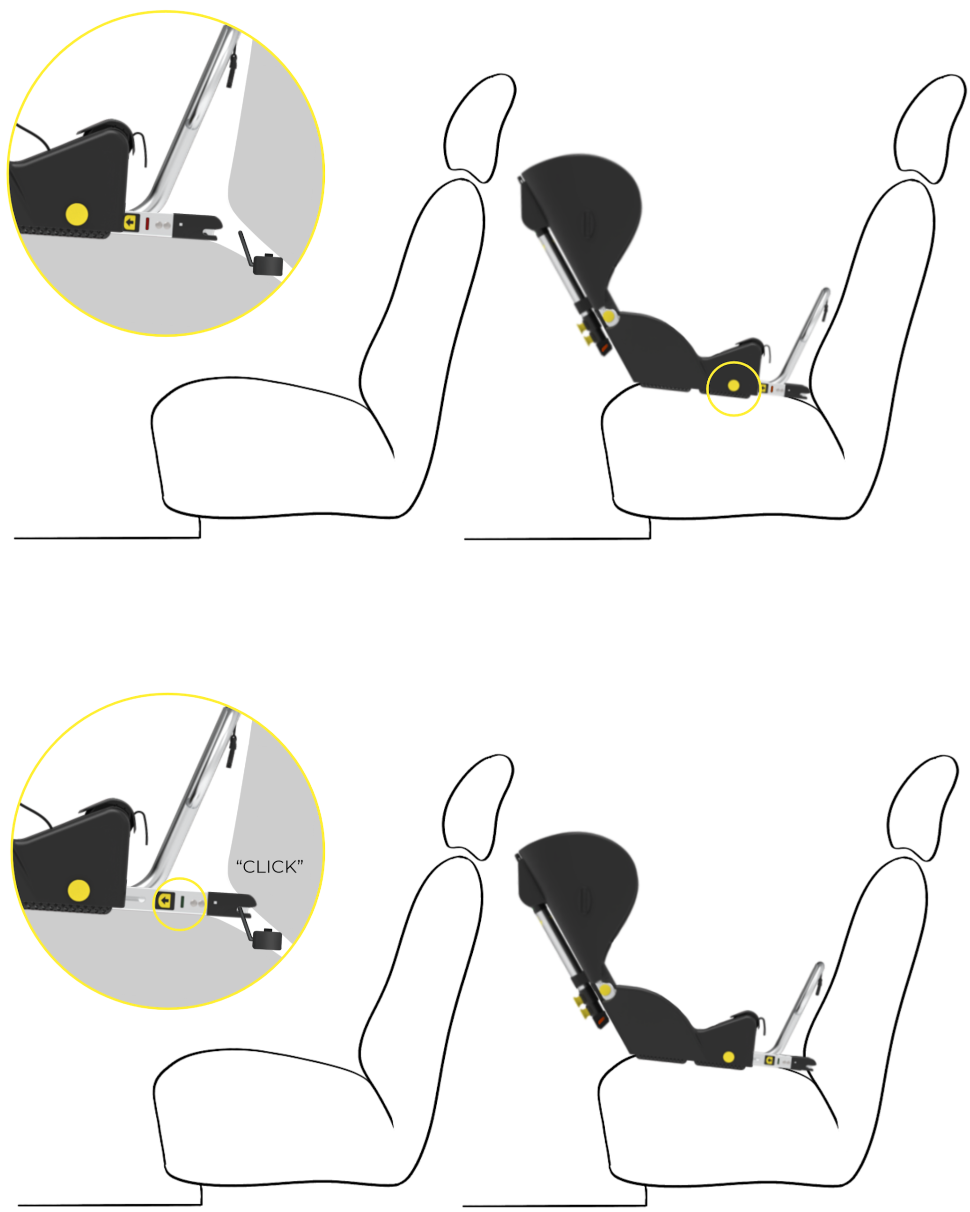


Figure 68: Installation step 4. At the top unconnected and at the bottom connected.

Possible Adjustment of the ISOFIX Attachments

If there is more space left in the car, the pull button in relation to the ISOFIX attachments can be pulled, which allows more of the ISOFIX arms to be extended, which offers more leg room for the child.

If the same car is normally used every time, for example if the same car is borrowed or rented each use situation, the user can keep the setting of the ISOFIX attachment arms and rebound bar set in the optimum position for that car. This would make installation even smoother next time, since these settings do not have to be managed every time. In this case the elongated ISOFIX attachment arms and rebound bar would make the CRS bigger in a folded position, maximum 100mm longer.

5. **Settings of the Rebound Bar**

   When the ISOFIX attachment system is anchored, the rebound bar should be modified, via the pull button above the rebound bar, under the seat. When the rebound bar is pressed against the car seat's backrest it is positioned right, this is illustrated in figure 69.

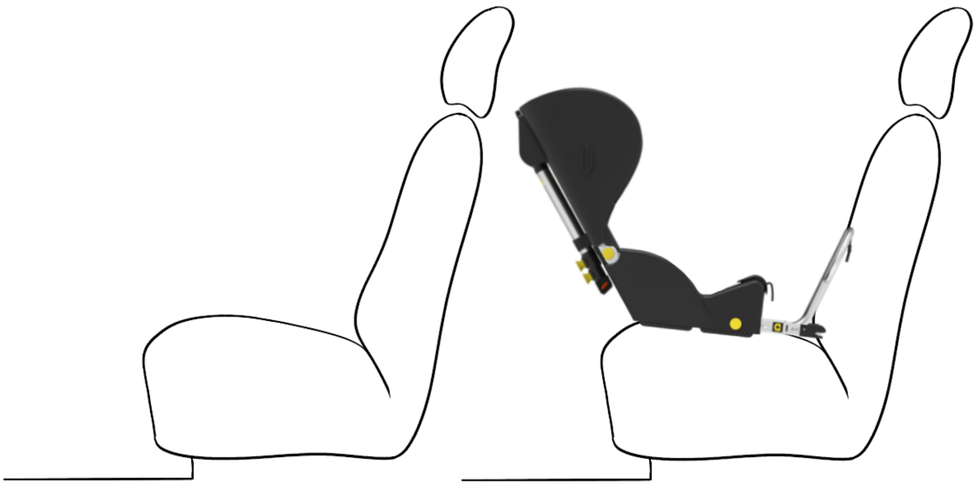


Figure 69: Installation step 5.

6. **Installation of the Support Leg**

   When the CRS is anchored to the car's seat, the support leg will be folded out. This is illustrated in figure 70.

   1. The support leg is removed from its holder on the CRS's back with a light pull.
   2. When the support leg is in the right angle position - perpendicular to the ground, a spring snaps the leg into its place inside the leg house. An indikation stripe on the support leg moves from red to green and displays that the leg is correctly fastened. See section 8.3.6 *Support Leg* for figures and closer descriptions.
   3. To reach the floor of the car, the support leg will be extended. This operation is done by the yellow push buttons on the support leg. When these buttons are pulled, a new level of the support leg is extended. When released, the buttons automatically lock via a spring. When the block at the end of the support leg touches the floor, a part of the block is pressed in which turns an indication stripe on the support legs block from red to green to indicate that the leg is of a proper length. Now the support leg provides anchoring of the CRS and acts as an anti-rotation device.

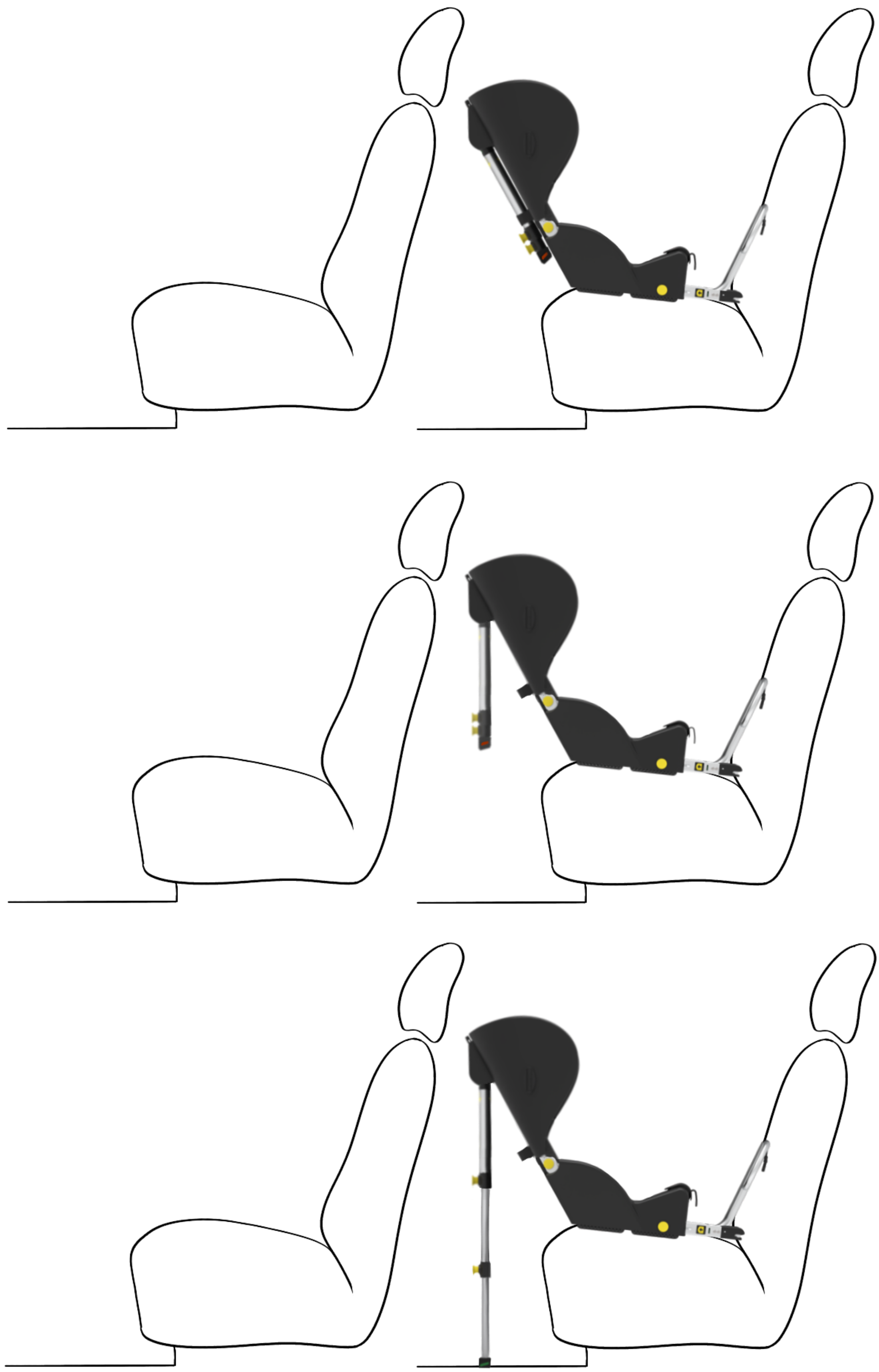


Figure 70: Installation step 6.

The CRS is now properly anchored in the car. This is indicated by green indicators. No red indicators are left when the CRS is anchored correctly.

7. **Preparation of the Seat - Headrest Adjustment**
   When the CRS is folded, the headrest is at its lowest position to take up as little space as possible in between the CRSs upper and lower part, and to make the CRS as small and flat as possible in mobility mode. Therefore the headrest will have to be altered to fit the child and offer the best protection, see figure 71. To prepare, before the child is lifted into the CRS, the headrest is raised out to its maximum length and the strap length of the harness is increased. This is done by unlocking the yellow key actuator of the headrest, see figure 51. The key actuator has explanatory icons to explain the lock mechanism. Followed by pushing a button inside the harness adjustment nest and pulling the harness straps out. This enables the harness to be extended and the headrest is automatically lifted (as long as the yellow key actuator near the headrest is opened).

Figure 71: Installation step 7.
To the left the headrest at its lowest point and to the right adjusted to a use situation.

Now the CRS is anchored and prepared and ready to seat a child.

8. **Seating a Child**
   A toddler is lifted into the CRS and fasted with the five-point harness, see figure 72.
   1. The seat belt tongue is put together, which connects the right side of the harness with the left side. The seat belt tongue is connected to the harness buckle and the harness is fastened.
   2. The strap length of the harness and the headrest position is modified via the strap located in the harness adjustment nest. With a light pull of this strap, the strap length of the harness is decreased and the headrest is lowered until the harness follows the child's body perfectly and the headrest is at the perfect height in relation to the child's stature.

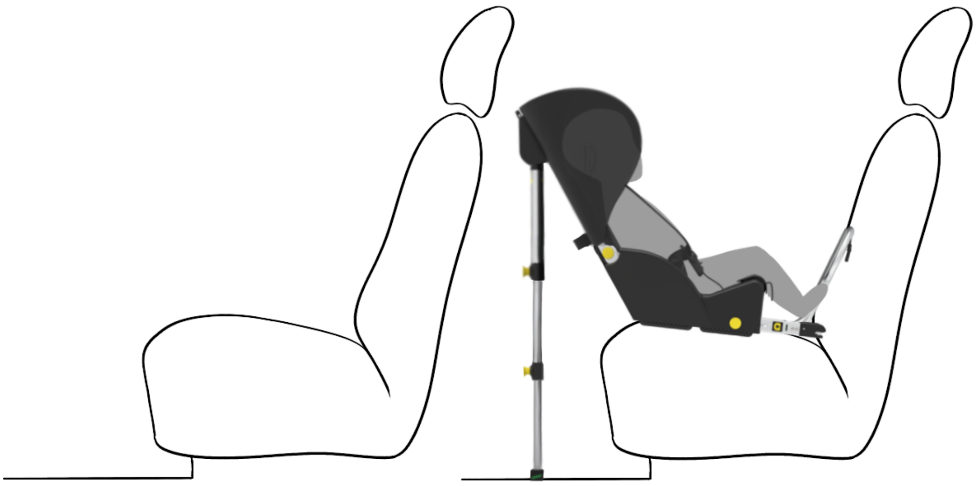


Figure 72: Installation step 8.

8.5.4 On Journey

The concept is designed to offer the best possible protection for a toddler in a car crash. The Axkid Free fits within the R2 envelope in its most constricted mode. This means that the CRS can fit well into many cars and offer the passengers of the car in the front seat (if the CRS is placed in the backseat) legroom. The concept’s slim appearance and small bottom give an airy and spacious feeling inside the car. The width size should allow that several Axkid Frees can be placed in a car’s backseat, as well as offer a good amount of space for other passengers in the backseat.

The range of the side protection of the CRS is optimal to offer the best protection for a child's head in any kind of collision. However, it is not deeper than necessary which allows the child to see and connect with the other passengers in the backseat and to look outside the car’s window.

The concept is designed to offer good comfort for the child while seated in the CRS. The fabric is soft and padded. The angle of the seat and backrest is chosen to offer a comfortable and rested laidback sitting position for the child. Thanks to the short seat and the adjustable ISOFIX attachments and rebound bar, the maximum available amount of legroom for the child can be used in relation to the car. The special design of the headrest, which has a built in difference to the backrest of -1cm, prevents the child's head from falling forward when sleeping. Although this is not a documented danger for the child, parents often get worried when the child's head is bent forward during sleep. This could be distracting for the parent while driving as well as lead to a disliking of the CRS. The soft neck pillow is shaped to support the child's head both when awake and sleeping as well as provide extra protection during a car crash. In figure 73 a toddler is illustrated seated into the Axkid Free concept.

Figure 73: Toddler seated in Axkid Free concept.

8.5.5 Uninstall

1. **Removing Child from CRS**
   The child is unbuckled from the harness by pressing the button on the harness buckle. Then the child can be lifted out of the CRS and the car by a guardian.

2. **Preparation of CRS to be Folded - Headrest Adjustment**
   To prepare the CRS to be folded the headrest should be at its minimum height, to take up as little space as possible when the CRS is in mobility mode. This is done by opening the yellow key actuator of the headrest. Followed by pushing the headrest down to its minimum length and locking the yellow key actuator, which keeps the headrest in place.

3. **Deinstallation of Support Leg**
    1. The support leg is retracted by pulling the yellow buttons on the support leg and pushing in the extended levels of the support leg until the leg is as short as possible.
    2. The leg is removed from its lock by pulling the leg down in the same direction that is indicated by the yellow arrow. When pulled, the leg is loosened from the leg house, the green indicator turns to red and the leg can rotate towards the back.
    3. The support leg is rotated towards the CRS's back and connected to the support leg holder with a light push.

4. **Disconnecting of ISOFIX Attachments.**
   The seat bight anchorages are disconnected from the car's anchorage points by first pressing and then sliding on the yellow buttons that have a black arrow on the ISOFIX arms, see figure 60. This opens the seat bight anchorages' grip and turns the indicator on the ISOFIX arms from green to red. This is easiest done by operating the ISOFIX attachments arms one by one. Now the ISOFIX attachments are disconnected from the car and the CRS can be moved freely.

5. **Optional Adjustment of ISOFIX Attachments and Rebound Bar**
   To make the CRS as small as possible, the ISOFIX attachment arms and the rebound bar can be modified to their shortest positions. If the ISOFIX attachments and the rebound bar already are retracted as far as possible or if the user chooses to leave them in the position that they were used in, these do not have to be modified, it is purely optional.

6. **Folding of Backrest**
   The 3 steps of the process of folding the backrest is illustrated in figure 74.
    1. To unlock the sprints of the folding mechanism the yellow buttons on the side of the CRS's backrest is pulled towards the user, with one hand.
    2. With the other hand, the user lifts the back upwards. This moves the metal bars of the back up within the metal bars of the seat, until the back can not be lifted further, this is 80mm. When the metal bars have been lifted it is possible to release the yellow button on the side. When the back is extended to its maximum, the spring of the button will automatically connect and lock the seat to the back part.
    3. When lifted out to its maximum and the sprint of the lock mechanism is locked, the back can be folded forward, over the seat.

Figure 74: Uninstallation step 6, folding of backrest of Axkid Free.

Either one of the two opposite pull buttons at the CRS sides will work to operate the move that opens the sprints of the folding mechanism. Therefore the button closest to the user can be used, no matter which side of the car that the CRS is installed in. To open the sprint of the folding mechanism, only requires that one of the two buttons are pulled.

7. **Locking Upper Part to Lower Part - from Seat Mode to Mobility Mode**
   The quick-release buckle is closed and the CRS's back is connected to the rebound bar. This is illustrated in figure 75. The CRS is now completely folded and ready to be carried from the car. See the mobility section (8.1.2) for alternatives. By locking the quick-release buckle the soft headrest is pressed together which allows the backrest to come closer to the seat, which makes the CRS as small as possible in folded mode.

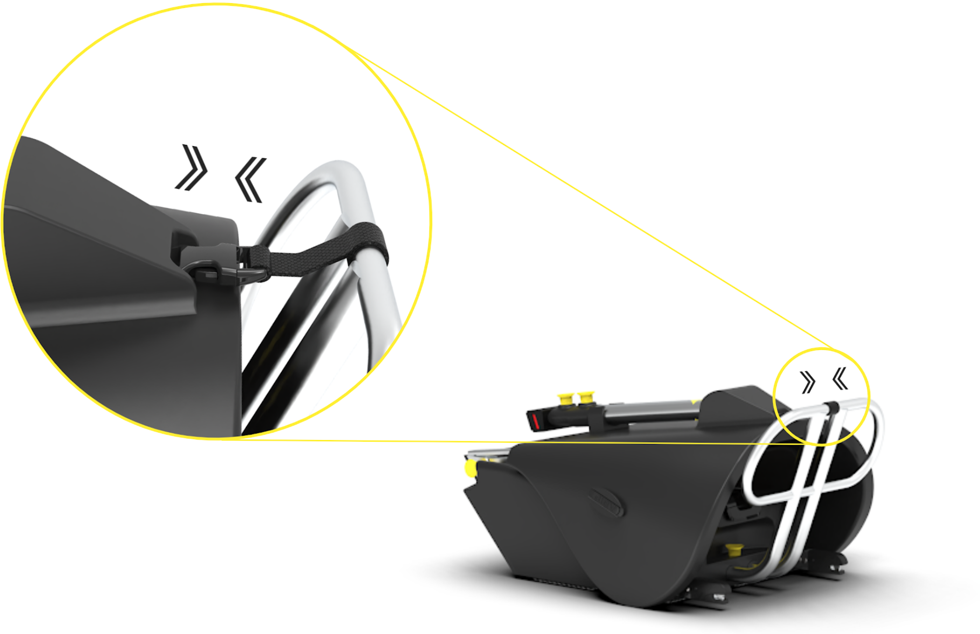


Figure 75: Uninstallation step 7.

8.5.6 In a Collision

The Axkid Free concept is designed to be completely safe in a collision, to the same extent as the CRSs on the market that are non-mobile. To accomplish this, the concept is rear-facing since traveling rear-faced is the absolute safest. Children are vulnerable due to the fact that children have large heads and undeveloped ligaments and muscles of the neck, rear faced travel is safer for children, especially infants and toddlers since the CRS provides support for the head and neck in a collision. The CRS distributes forces from the car's motions evenly which gives a lower strain on the spinal cord, neck and head. A rear-facing CRS is estimated to be more than five times safer compared to a forward-facing CRS. To avoid the temptation of turning children too early the seat is solely rear-facing and not possible to use in forward-facing mode. Thanks to being rear-facing the CRS concept will not impact the child's neck to the same extent as a forward-facing CRS and has thus, a possibility to receive a Swedish Plus approval.

The concept makes use of well-proven anchoring components to reassure safety; ISOFIX-attachments, a rebound bar and a support leg. The CRS's main attachments are ISOFIX attachments. The ISOFIX attachments system increases the chance of the CRS being properly and correctly anchored (in comparison to a seat belt anchored CRS) and will keep the CRS locked in place in the car during a collision. The universal ISOFIX system is well proven to be effective during collisions. The reliable seat bight anchorages are connected to metal arms which are locked in the rigid metal construction within the seat.

During forces in a frontal collision, the child is pressed into the back of the CRS and the CRS wants to rotate. The secondary attachment - the support leg, acts as an anti-rotation device and prevents a forward throw in a frontal collision. The support leg keeps the CRS in place by preventing a rotation, during forces in the car's travel direction, see figure 76. The support leg is placed as high as possible on the CRS back, to prevent rotation and to offer the best support. It is manufactured in rigid metal to be best suited to withstand forces active in a collision.

FRONTAL COLLISION

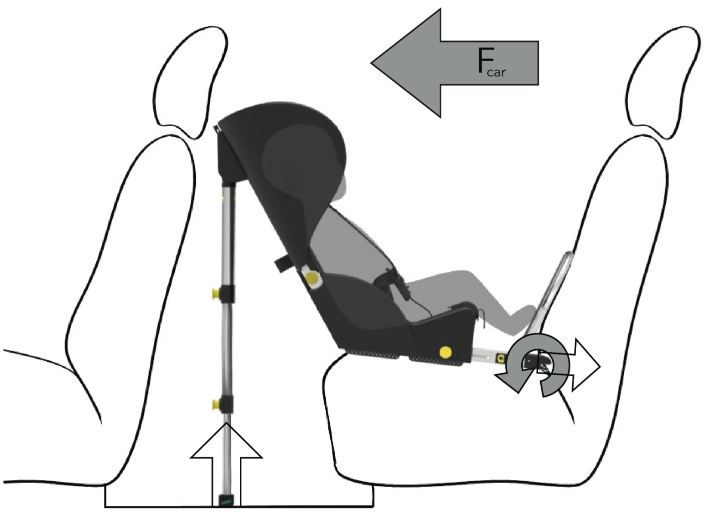


Figure 76: Forces in the car's travel direction, like in a frontal collision, affects the CRS concept.

During a rear-end collision a child that travels rear-faced wants to, together with the CRS, rise against the car seat's backrest. To prevent rotational movements like this, in the opposite direction of the car's travel direction, the CRS has a third attachment system in the form of a rebound bar, see figure 77. This acts as a rebound device during rear-end collisions and in the back throw, that appears in the later part of a frontal collision, as well as preventing the CRS from moving and hitting the car's ceiling during a rollover accident. The larger the contact surface towards the car seat's backrest and the higher up the rebound bar reaches, the better the prevention of a rebound motion. The rebound bar is designed to have an optimal level between its size in relation to space and weight efficiency. The rebound bar is in rigid metal and the shape creates a wide contact surface. A wide contact surface makes a rebound bar more durable and effective compared to a small contact surface.

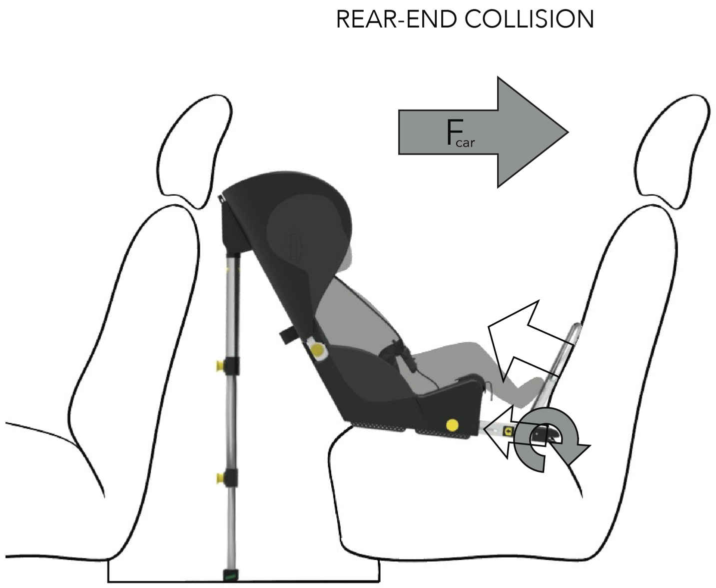


Figure 77: Forces opposite of the car’s travel direction, like in a rear-end collision, affects the CRS concept.

In a side collision, all car passengers' heads are thrown towards the object that creates the impact. The child's head will be pressed to the sides of the CRS. To protect the child during side collisions the Axkid Free concepts’ back is shaped to create a protective arc of side protection. The arc is deep with a small width which will lower the risk of the child’s head can rotate out of the CRS. The side protections shape is designed to provide good protection for toddlers in the range of 61-105cm stature height. The headrest cushion is shaped to fit the head which will keep the head in place and soften the force and motion of the head when it is thrown against the CRS’s side protections. By being movable, the headrest provides the best protection for all toddlers. The backrest is long to provide perfect protection also for the taller toddlers since the headrest is soft. To further prevent the impact in a side collision, an ASIP is added to the CRS’s side that is closest to the car door, see section 8.2.2 Upper Part, to read more about ASIP. The ASIP, which is made of styrofoam, takes the first hit in a side collision and when the styrofoam is pressed together, loads from the impact are absorbed which lowers the impact on the CRS.

The five-point harness will effectively keep the child within the CRS during a collision and creates a good connection to the child’s hips. The wings on the CRS’s lower part creates side protection for the child. They will connect the child's hips, which is a strong part of the body, to the CRS which prevents the child from being tossed within the CRS and allow the CRS to give the best possible protection. A child’s legs are not in any particular danger during a car crash, to be space-efficient the CRS lower side protections the largest focus was on the hips.

The folding mechanism of the Axkid Free concept is designed to withstand a car crash. It is of great importance that the CRS can not fold or that the back and seat part can be separated during an impact. To prevent this, the back part and the seat part is connected with durable metal with large contact surfaces thanks to the 120mm length of the metal bars.

The sprint mechanism that connects the metal part of the back with the seat is of the same model (however, this new sprint is more elongated) as on the pull buttons currently used on Axkids Modukids ISOFIX arms, which can withstand forces of a car crash. Due to the length of the metal bars, it means that the back and seat have to be separated by 120mm before they can be separated or folded. In addition to the sprint of the lock mechanism, the CRS harness also pulls the two parts together which prevents the back and seat from being separated. The composition of the folding mechanism, where metal bars are connected and overlapped, prevents the CRS from folding in a collision.

These results regarding the CRS concept’s abilities in a collision are speculated events and based on assumptions. To make sure that the concept reacts as anticipated - crash tests have to be performed, both simulated and in real car crash simulators.

8.6 Usability

Good usability of the concept - that is, how well the CRS concept succeeds in helping a user to achieve his/her goals with effectiveness, efficiency and satisfaction in a use situation, is important. This has been of great importance and high priority during the development process. How easy a CRS is to use and understand is crucial for both customer satisfaction and safety reasons.

8.6.1 Re-usability & Learnability

The Axkid Free concept is developed for parents who do not own a car, therefore the CRS will be used more rarely than non-mobile CRSs, in the most common use situation. On the other hand, since the CRS should be installed and removed during every use cycle, which is not common for non-mobile CRSs, which are often stored in installed positions in a users car, the usability of the installation and uninstallation is of even greater importance for this concept, due to that these operations will be performed more times.

Since the concept is estimated to be used rarely in the most common use situation, the Re-usability of the CRS is important. Re-usability implies the level of usability a product has after a comparatively long period of time away from the use situation. This demand provides in this case with clues to the user about how to operate the product, similar to Learnability - which is the level of usability a product has when the user has already achieved that goal of the task once before. Clues on how the concept should be managed are that all the CRS different actuators are highlighted in an accent color - yellow, which is in clear contrast to the black CRS and is an immediate eye-catcher that improves visibility. A yellow arrow on the support leg also displays that the leg should be pulled. Many of the actuators are the same model, appearance and function in the same way, which gives clues to how the different functions work and should be operated. The inner consistency between the actuators also provides confidence to the user who more quickly gets to know how the button works and can provide reliability and trustworthiness to the different operations.

The anchoring methods, ISOFIX, rebound bar and support leg have been chosen due to their superiority in usability compared to seat belt attachments and tethers. The ISOFIX attachment system increases the chances of a correctly anchored CRS, in comparison to a seat belt attachment system and is therefore safer. The ISOFIX system is well established and well known in the industry and is consistent within the CRS. A support leg and rebound bar is anchored in the same way each time, independent of the car model. While tethers are anchored in different ways in different cars. Since the user group will not own a car themselves and probably use a wider range of car models it is therefore important that the CRS is always easy to understand, used correctly and in a safe way.

8.6.2 Indicators & Feedback

To enhance usability and prevent misuse, feedback about the different states that the CRS is in is of great importance. The usage of feedback will provide the necessary understanding for user interaction and increase the success rate of the task.

The CRS consistently provides feedback in relation to its lockable objects in the form of green indicators, representing the correct and safe usage - correctly anchored CRS, or red indicators, which represent that the CRS is not correctly anchored. These indicators are present on both of the ISOFIX arms and on the support leg. On the support leg there is an indicator at the top connected to the leg holder which displays when the support leg is correctly anchored to the leg holder. See section 8.3.6 *Support leg,* for figures. There are also indicators at the block, at the end of the support leg that turns from red to green when the support leg is long enough to reach the floor of the car. These indicators are located on the sides of the support leg block to enhance visibility and makes it possible to see the indicators state from the side, independent of which side of the car the CRS is montated in.

In accordance with the ISO standard (ISO 13216-1), ISOFIX seat bight anchorages provide a reassuring *click* feedback and the color indicator on the arms turns from red to green when it is properly locked. This feedback makes it clear when the mechanism is properly looked and the combination of visible and audible feedback enhances and clarifies the experience that the task is completed.

The buttons that open the ISOFIX bight anchorages are the same in function and construction as the Axkid Modukid, however, the look of the actuator is different. From a completely grey button surrounded by a grey plastic, which provides fewer clues on how to use it and lacks visibility, on the Axkid Modukid. To, a yellow button, which is in clear contrast to the black surroundings, to enhance visibility, that has an arrow. The arrow is supposed to help the user to understand that after being pushed down, the button should be pulled in the arrows direction. This actuator is visualised in figure 60. On the support leg a yellow sticker in the shape of an arrow indicated that the leg should be pulled down. The usage of arrows incorporates Norman's design principle mapping, this is visualized in figure 57.

The pull buttons that operate ISOFIX arms, rebound bar, the extension of the support leg sections and the back's folding mechanism have all the same appearance and function. This creates a consistency within the system and increases affordance that helps the user to understand the CRS. The buttons are all yellow to be clearly visible and have a shape that gives clues that it should be pulled, see figure 60. They all lock automatically when released.

8.6.3 Easy to Make the Safe Operation

It is of importance to avoid misuse of a CRS for safety reasons. The most critical parts are the different locking mechanisms which, when left open, pose a danger since if the CRS is not properly anchored to the car it will not work as intended. To prevent the locking mechanisms from being forgotten and left opened the actuators of the Axkid Free concept have been designed with automatic lock mechanisms. When released the pull buttons automatically recoils thanks to a spring that locks the mechanism. This means that the folding mechanism of the back, the ISOFIX arms, the rebound bar and the support leg will always be locked and safe.

The leg house that locks the support leg to the CRS's back work by a similar operation. Thanks to a spring the support leg will automatically be snapped into its socket and locken when the leg is held perpendicular to the floor. This move is visualized by a red/green indicator.

To avoid hazards, constraints have been added. One of these constraints is that the CRS can never be used when the back is extended. The folding mechanism makes the CRS's back to fall forward over the seat in its upper, extrened position. Another constraint is that all of the CRS's parts can not be removed due to various blocking mechanisms that prevent objects like the rebound bar and the ISOFIX arms to be dragged out of the CRS. This is to prevent possible mistakes of leaving part behind or forgetting to bring certain parts. Something that is of greater importance for this concept that should be used *on the go,* in cars that the users do not own themselves and because of that the CRS will be used rarely, which could make it easier to forget the function of certain parts.

8.7 Fulfillment of Regulations & Standards

Figure 78 visualizes that the body of the Axkid Free concept fits inside the transparent colored R2 envelope dimensions. The support leg is the only part that stands out, which is allowed and necessary. The support leg dimensions are regulated by another envelope regulation. This means that the Axkid Free fulfills the dimension requirements of the International ISO Standard 13216-3.

Figure 78: The Axkid Free in the R2 Envelope, from side and front view.

The Axkid Free concept also fulfills the ISO Standard 13216-1, which corresponds to the design of the ISOFIX attachments. The ISOFIX system is rigid and has the right geometry to fit the ISOFIX anchor points in the car. The ISOFIX attachments are clearly visible and give clear feedback with both color-coding and audible click to ensure when the mechanism is properly locked. The Axkid Free concept also has all the necessary components needed to anchor the CRS in a secure way (rebound bar, support leg and ISOFIX arms) according to the design guidelines in relation to CRSs. Therefore, the Axkid Free concept should be able to fulfill the requirements of the UN R129 regulation.

9. DISCUSSION

More and more parents are estimated to live in cities without owning a car. The CRSs have to keep up with this trend to guarantee children's safety in the future. Therefore, this project was initiated. In this Chapter, it will be discussed if the project could fulfill its purpose and choices concerning the Axkid Free will be motivated.

9.1 A Need For a New CRS

The rear-facing CRSs of today are developed with the main goal of being safe, stable and for parents who own a car. These users do not need to remove their CRS from the car after every usage. Therefore the products can be big, heavy, bulky and a smooth and quick installation or uninstallation are not in focus. For users who do not own a car the use situation of these CRS products is bad. As urbanisation and sustainability awareness increases more and more parents choose to live without owning a car. A trend that is estimated to grow in strength. However, car travels are needed in some situations and during these circumstances the parents who do not own a car need safe CRSs adapted for their needs and use situations. With the bulky CRSs of today increase the chances that parents do not use rear-facing CRS to the extent that is necessary and instead puts the toddler forward-facing CRS too early. To reassure child traffic safety in the future, a new, mobile, and safe CRS was found to be needed during this project. Both User Studies and Benchmarking confirm that there was a lack of a rear-facing solution that is both mobile and safe in a car crash on the CRS market.

9.2 Project Purpose

The purpose of this master thesis was to develop a CRS that enables and simplifies for parents who do not own a car. The result is the Axkid Free concept, a rear-facing, foldable and carryable CRS concept that is more mobile and offers better storing opportunities than the common CRS on the market today. By offering a safe CRS that is developed to fit parents who do not own a car, the needs and prerequisites to own a car as a guardian or parent, can be lowered. In this way the concept could allow a car free lifestyle by simplifying the usage of shared mobility services for parents and allow children to travel safely to a bigger extent.

9.3 The Most Favorable Customer Group

The customer group that was found to be the most appropriate customer group for a product concept of a rear-facing CRS adapted for shared mobility was parents who do not own cars. This group displayed purchasing power and a need for a new CRS product during User Studies. Therefore, parents who do not own a car, in addition to being the main user, were also found to be the main customer group of the concept. Due to an unwillingness of using CRS designed for shared usage both from parents, due to safety, convenience and hygiene issues, and from possible distributors or renters. Since parents generally were found to be an undesired customer group, it was decided that a consumer product should be developed rather than a product designed for shared usage.

9.4 How the Concept is Adapted For the Target User

A CRS is according to findings of user studies, often stored in cars. CRSs for toddlers are often bulky, heavy and difficult to install and are therefore not moved around more than necessary. For users that do not own a car, it is not a possibility to store the CRS installed in a car and therefore the new concept is adapted to offer better storage opportunities. This is done by a foldable concept that takes up less space and that can be hung on a hook in the backpack handle.

The need of a mobile CRS that could be transported with ease on trains, busses, by foot or in any other way, was described during the User Studies. The small, light and manageable Axkid Free enables smooth transportation to and from the car. The back-pack function enables that the user's hands are free and can carry and oversee other possessions that are brought along like a stroller and bags.

Easy and intuitive installation reduces the installation and uninstallation times of the CRS, a need that was described by all CRS users during User Studies. The Axkid Free is smooth to install since the whole installation and unfolding of the CRS can be managed inside of the car and uses the ISOFIX attachment system.

What all parents rated as the most important factor of a CRS was that it was safe in a car crash (with overwhelming results, see figure 16 and 17). The Axkid Free concept is rear-facing, the safest travel option for toddlers and is developed with components like support leg, rebound bar and ISOFIX-attachments that are proven crash-safe and with a high degree of usability to reduce misuse. These attachment systems are also time-saving components and are installed in the same way, non-dependent on car models.

9.5 Additionally Positive Results

In addition to fulfilling the purpose of the thesis, the design of the Axkid Free concept also has managed to fulfill some user needs that were desired from other user groups - grandparents and parents with cars (see table 3 - Appropriate customer groups for a CRS adapted for shared mobility). However, the CRS concept is not created with a focus towards these groups - the concept is useable for them too. The lightweight and that the CRS is more manageable from an ergonomic perspective, by being able to carry it on the back, make it more suitable for the older generation as well as better to use on travels for parents who own a car. A need for a safe CRS that could be used on travels for parents who owned cars was found during User Studies, especially in the Survey. In the future, the older generation will also be living in cities to a larger extent and have less storing opportunities than today. Then the smaller size will make this concept well adapted for the urban grandparent as well as the urban parent.

That the CRS concept takes up a smaller volume and is lighter than an ordinary CRS has positive effects. The small transport volume means that less air is transported, which makes the transport of the product more environmentally friendly and cheaper for the client, Axkid.

9.6 User Studies

The method that was used to gain access to and create a dialogue with parents with a car-free lifestyle, which was developed during this project, called User Studies via Social Media (described in section 4.1.5) was found effective and provided a lot of valuable insights for the project. To search for users that were inaccessible to the project in social media channels worked well and provided many interviewees. It was clear that the topic of rear-faced CRSs engaged many users and that the issues and problems concerning the CRS and a car-free lifestyle had provoked users.

The fact that the rear-faced CRS was viewed as a problematic product whose design had affected the users made people eager to share their experiences. Many expressed the hope that their information could help the development of a new product that could possibly improve their future use situation. If the method would be as effective during other user studies in other projects might depend on the theme of the project and the level of engagement that the subject could awake from users. Since users themselves choose to leave a comment on a post, the subject must be of interest to them. It is also possible that only those with something clear to say about the topic will answer and that those who are pleased or believe that their experience is ordinary will not take time to write a comment. Therefore this method likely attracted the users that had a special interest in the topic and these answers could have differed from the average user.

By creating a dialogue in the commentator field an interview-like situation appeared. This was a very time-efficient method to gain qualitative answers from many users, since many interviews took place at ones, no traveling or meeting times were involved. During a live interview, subtle information can be picked up by eye contact, pauses and so on. This was not possible in this format and hidden information could have been lost by interviewing in this format. The chat format, however, created another level of information since the comments are public and users could agree, disagree and share similar experiences with each other in addition to the classical interviewer-interviewee conversation. This triggered new answers and made some Interviews similar to an online focus group.

During the User Studies Part 1 and 2 the main part of the interviewed parents were women. Despite an extra focus towards finding male respondents only 18% of the answers came from men. Since half the users of CRS are men this is a possible source of error of the User Studies. It is also of interest that women appeared to have a greater interest in the CRS as a product.

9.7 The Design of the Axkid Free

In this section, the Axkid Free CRS concept’s configuration and design will be discussed. How the estimations regarding this concept safety have been made since it has not been crash tested and why different components look and function in certain ways.

9.7.1 Safety & Configuration

That the Axkid Free concept is safe and could provide the necessary protection for a toddler during a car crash has been the highest priority during the development process. Since a valid prototype of the concept has not been made that can be tested in a crash test, due to the timeframe of the project, estimations have been made and proved CRS components used. The most important factor to secure safety is to make a CRS rear-facing. According to Jakobsson et al. (2013) the rear-facing CRS has become heavier, bulkier and more complex over the years and means that this development might not be an improvement from a safety perspective. This speaks for the fact that the bulkiness and heaviness of the CRS models on today's market does not improve safety and that this sleeker and lighter concept could have the same chance in a crash test as long as it makes use of safe components.

When comparing the Axkid Free with the Axkid Modukid, many similarities are found. These are conscious design decisions and have been made in agreement with the client, Axkid. By taking inspiration from the Axkid Modukid and applying well-proven and safe components to the new concept have enabled that the concept has come further in the development process. To make use of components that are already crash-tested and safe has been a way to ensure that the concept is safe without the possibility to crash testing it. Another advantage of making use of existing components is that style and function keep brand consistency between the different CRS models from Axkid. The user can recognize operations and feel reassured by the fact that this new model is as safe as the other models. Reusing components could also have manufacturing advantages for the client's perspective. Alterations of the inspired parts have been made to enhance usability and improve the concept further.

The Axkid Free concept makes use of well-proven components to reassure safety like ISOFIX-attachments, a rebound bar and a support leg. These three attachment systems work exactly the same in all car models which makes it easy for the user who switches cars often and is fast and intuitive to install in a car. The support leg has indicators that guide the user and prevents misuse. ISOFIX attachments are chosen because of the fast and easy installation, something that is very valuable from a user perspective. That the attachments make use of indicators that provide feedback when the installation is correct or not make them safer and reduce the risk of misuse, an advantage compared to seat belt attachments.

The ISOFIX attachments of the Axkid Free have settings options that allow the ISOFIX arms to be extended to offer more legroom for the child when the size and model of the car allow it. That parents believe that the child has too little legroom in the rear-facing CRS is a common reason for turning the child to forward-facing CRS. Therefore the largest possible legroom was prioritized for safety reasons, even though the extra setting options enhance the complexity of the CRS.

No parts can be completely removed from the product, this is to ensure that no part can come loose or go missing since an incomplete CRS is not safe. This is extra important for this mobile CRS concept since it will be traveled with and used in many different cars.

9.7.2 Usage & Usability

To use components that have a high level of usability, are as intuitive as possible and that can provide evident feedback is a safety factor that prevents damages in a car crash. As a first time user of a CRS, it properly does not appear as a very intuitive product. The guessability is low for CRS in general. For a CRS developed for shared usage the guessability might have to be enhanced. This is, however, not a problem since the product should be owned by the user. The main user of the Axkid Free does not have access to a car every day, perhaps not even every week. Therefore, re-usability and learnability is more important for the Axkid Free concept. By having the different actuators in an accent color give the user clues on which setting to perform.

9.7.3 Design Language

The semiotics and design language of a CRS is very important and affects both how users perceive the product and if they choose to buy it or not. According to findings during User Studies, the parents with a car-free lifestyle were more open to new and innovative solutions of CRSs. Since the concept already is quite controversial by being foldable, a classic CRS design language was chosen for the concept to provide reliability to the new concept. Since the users are also the owner and buyer of the CRS there was a point to make use of attributes that sell and are attractive to parents today, even though the concept will be used in new ways.

Rounded and enclosed shapes were used throughout the design language. The Axkids Frees wide side protections creates an enclosed appearance that aims to be perceived as caring and protectable. The side protection allows a rounded appearance, even though the back is L-shaped rather than C-shaped. The rounded headrest looks comfortable and soft for a child’s head. The CRS is sleek and airy without appearing as fragile. The small manageable size and the backpack straps enhance the concept mobility.

Everything close to the child, while seated, should radiate comfort and coziness. Therefore, black, padded and soft fabric will be used inside of the CRS and a fabric case covers the rebound bar. Since a mobile concept will be handled in a public environment the soft fabric is protected from dirt inside of the CRS and the outside consists mostly of black hard plastic that can be cleaned easily. The fabric is also removable and washable.

Since the Axkid Free is foldable the folding mechanism must be perceived as safe and stable when unfolded. To enhance the feeling of robustness the metall of the folding mechanism is unpainted and visible when the seat is unfolded to display the durability of the CRS composition. How the folding mechanism works - slidable metal bars that provide stability, are not hidden but easy to see and understand when the CRS is operated. This to inform the user about the folding mechanisms stable design which will make the concept trustworthy.

The actuators have a yellow accent color to create a new and innovative appearance as well as display on their funktion. The yellow color is one of the colors in Axkids brand guidelines. Many of the actuators are the same, the pull buttons, and their appearance and function is the same, which gives clues to how the different functions work and should be operated. This can also provide confidence to the user who gets to know how the button works and can provide reliability and trustworthiness to the different functions.

9.8 Sustainable Development Aspects

The shared mobility movement is both a result of urbanization as well as a conscious choice by customers towards a more sustainable lifestyle. Therefore, the project can be seen as a contribution to sustainable development since it aims to offer a more sustainable lifestyle by offering safe alternatives to parents that want to use shared mobility. If Axkid can offer a more flexible car seat, it will probably enable parents to use shared mobility services to a larger extent than they do today. Participants in User study Part 1 said that the family needed to buy a car, when the child became large enough for the large rear-facing CRS model. Hopefully Axkid Free enables parents to live a car-free life if they want to.

Axkid Free is foldable and takes smaller space in a folded position compared to many other CRS models on the market that do not have that feature. A compact and small CRS in folded mode is easy to store, but also does not require large space during shipping. A large and bulky CRS may lead to more transportation pollution and higher transportations costs, due to fewer CRS models in each shipping (a lot of “shipped air”).

9.9 Societal & Ethical Aspects

It is five times safer for children to travel in a rear-facing than a forward-facing CRS, but still, many children travel in a forward-facing position far too early. Offering a safer travel option with a rear-facing CRS for shared mobility is therefore of great importance on a societal, ethical level and from a child's health perspective. Not all parents have the economical option to own a car and safe travel options for their children should be available even for them. A CRS that is easier to bring along could enable rear-faced travels in situations where it is common to compromise with safety like taxi journeys, abroad or during shorter temporary journeys.

A goal with the product concept is to simplify the situation for parents to travel with their children in a secure way. The concept will hopefully result in a larger degree of freedom and independence for parents that do not own a car.

Things that were considered related to the outcome of the project was that the final concept offers a high level of usability and correct semiotics to ensure that users will not believe that children are correctly restrained if the product is used incorrectly. If this project results in a future purchasable CRS, it is important that the CRS will be well tested to ensure it is 100% safe before being released.

10. FURTHER DEVELOPMENT

The Axkid Free concept needs to be developed and investigated further to reach the level of a finished product. The next step during future work should be to create a physical prototype and evaluate this towards users. During the upcoming process construction of parts and manufacturing methods have to be investigated more closely. The concept has to be evaluated against different regulations, especially the position of the support leg has to be confirmed. Before being released, the concept has to be crash tested optimized after different loads in a car accident. The construction of the folding mechanism has to be carefully tested since this principle is new.

10.1 Prototype & User Evaluation

The next step to develop the concept further during future work is to develop a physical prototype. This prototype could be evaluated against users (parents who do not own a car). The prototype should investigate:

- Usability
- User experience
- If parents feel comfortable with the folding mechanism
- If the new CRS can be operated as intended
- The weight distribution when the CRS is folded and how it feels on the back, both when using the backstraps and while carrying the CRS by hand in the handle
- Placing different sizes of toddlers in it, analyzing the comfort and fit for different childs

When evaluating the concept it is recommended that a more equal gender distribution between users are used, since the User Studies during this project did not gain access to so many male users (18% of the respondents in the survey were men). If the concept should be further developed and sold in countries outside the nordic, users from other countries should also be investigated and the concept evaluated against them.

10.2 Regulations & Safety Tests

- It has to be confirmed that the support leg of Axkid Free is positioned correctly according to regulations (If not, the support legs position should be altered.)
- The concept needs to be crash tested
- The construction of the folding mechanism has to be evaluated to reassure that it can withstand the forces during a collision
- Optimizing construction for crash safety and manufacturing.
- Minimizing weight by using generative design of different parts and material selection

10.3 Insights for Development of a CRS for Shared Usage

The User Studies during this project have provided many findings of parents' feeling of using a rented, borrowed or second hand CRS. Today, parents were very reluctant to do this, with the main reason that they were scared about how safe a rented, borrowed or second hand CRS would be. Since they did not know the CRS's state or if it had been harmed before. If a future goal would be to develop a CRS adapted specially for shared usage, findings indicate that special features would need to be added that could guarantee that the product is safe in order to gain parents' trust. There would likely be a need for some evident tool or sensor that displays for the user if the CRS has or has not been involved in a car accident during the previous usage. This type of solution, a sensor or other solution that could guarantee that the CRS was safe, could possibly mean that more parents felt safe enough to borrow or rent CRSs. How this solution should work or if it would be effective needs to be investigated further. However, findings from this project's User Studies indicated that there is a need to ensure parents about the state of the CRS that can guarantee the traffic safety of their toddler.

11. CONCLUSIONS

Many insights were gained during this project. In this chapter, the conclusions of the project will be presented. The conclusions will be presented by answering the Research Questions from section 1.4.

11.1 Which is the Most Favorable Customer Group for a CRS Adapted for Shared Mobility?

In User studies Part 1 it was found that parents who do not own a car, in addition to being the main user, is the most favorable customer group for a CRS adapted for shared mobility since they displayed a need for a new product and purchasing power. Parents who do not own a car, expressed a strong willingness to own their own CRS rather than to share, borrow or rent. To make sure that the CRS has not been involved in an accident .Findings showed that it was very important for parents to guarantee the traffic safety of the toddler by knowing that the CRS was 100% safe. If a CRS is harmed in a traffic accident, it could be invisibly damaged and not safe. Other investigated target groups such as taxi companies, carpool services etc. were disregarded as target groups for this concept, due to findings that indicated a lack of need for such a system. The cause was partly a concern about being responsible for safety and management regarding CRSs as well as parents were not a preferred customer group for them.

11.2 What Needs & Priorities of a CRS Does the Main Customer Group Have?

The main customer group - parents who do not own a car, had needs of a CRS that were lightweight, easy to bring along, fast to install, and easy to store after usage. This is how the main customer group prioritized among these provided factors regarding a CRS, according to the answers during User Studies in the Survey:

1. Crash safety
2. The child's comfort
3. Can be installed quickly
4. Easy to bring along/mobile
5. Intuitive to install correctly
6. It takes up a small space to store
7. Environmental friendliness
8. Smart extra features

11.3 How Will the New CRS Be Designed and Constructed to Fulfill the Needs of the Main Customer Group?

The new CRS concept, Axkid Free, is rear-facing, foldable and mobile. It is developed according to the UN R129 regulation and has a rebound bar, support leg and uses ISOFIX attachments to secure optimal safety and quick installation. When folded, the CRS can be carried as a backpack or as a suitcase through backpack straps positioned under the CRS seat. It has an approximate weight of 10kg. In this way the CRS is designed to be transported and easy to bring along as well as takes up smaller space, both at home and on travels. Since the CRS can be carried on the back, the user's hands are free for more important tasks such as; to carry bags, drag a stroller or hold a child's hand. The Axkid Free is fast and easy to install thanks to the thoughtful design of the attachment systems which offers consistency through color-coding of different interaction components.

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APPENDIX

In this Appendix, additional information regarding the project will be presented. The topics are:

- A1: Geometrical Dimensions of i-Size Child Restraint Systems According to UN Regulation R12.
- A2: Survey Questions
- A3: Findings from Survey
- A4: Expressed Requirements from Users
- A5: Morphological Matrix
- A6: Three Fundamental Concepts of Phase 3 Described
- A7: Kesselring Matrix Weighted Selections Criteria with Motivation
- A8: Kesselring Matrix 1, Evaluating 3 concepts
- A9: Kesselring Matrix 2
- A10: Measurements

A1: Geometrical Dimensions of i-Size Child Restraint Systems According to UN Regulation R12

Table A1: Geometrical dimensions of i-Size Child Restraint Systems according to UN regulation R129 in centimeters (United Nations, 2013).

Stature height [A]	Sitting height 95‰ [B]	Shoulder breadth 95‰ [C]	Hip breadth 95‰ [D]	Shoulder height 5‰ [E1]	Shoulder height 95‰ [E2]
45	39,0	12,1	14,2	27,4	29,0
50	40,5	14,1	14,8	27,6	29,2
55	42,0	16,1	15,4	27,8	29,4
60	43,5	18,1	16,0	28,0	29,6
65	45,0	20,1	17,2	28,2	29,8
70	47,1	22,1	18,4	28,3	30,0
75	49,2	24,1	19,6	28,4	31,3
80	51,3	26,1	20,8	29,2	32,6
85	53,4	26,9	22,0	30,0	33,9
90	55,5	27,7	22,5	30,8	35,2
95	57,6	28,5	23,0	31,6	36,5
100	59,7	29,3	23,5	32,4	37,8
105	61,8	30,1	24,9	33,2	39,1
110	63,9	30,9	26,3	34,0	40,4
115	66,0	32,1	27,7	35,5	41,7
120	68,1	33,3	29,1	37,0	43,0
125	70,2	33,3	29,1	38,5	44,3
130	72,3	33,3	29,1	40,0	46,1
135	74,4	33,3	29,1	41,5	47,9
140	76,5	34,2	29,6	43,0	49,7
145	78,6	35,3	30,8	44,5	51,5
150	81,1	36,4	32,0	46,3	53,3

A2: Survey Questions

Enkät om bakåtvända bilbarnstolar för föräldrar utan bil

Uppgifterna som du lämnar i denna enkät kommer att vara tillgängliga för Eric Elinder och Jaquline Hultman, som genomför examensarbetet "Child Restraint System for Shared Mobility" på Chalmers, och är i enlighet med EU:s Dataskyddsförordning (2018), GDPR. Syftet med enkäten är att förstå behov och krav hos användare av bilbarnstolar, för att få insikter i detta ämne och därmed möjliggöra bästa möjliga resultat vid utvecklandet av ett produktkoncept av en bilbarnstol. Uppgifterna sparas inte efter projektets slut (augusti 2020). Vi är mycket tacksamma för att du vill delta. Enkäten kommer att ta ca 8 min att genomföra.

*Obligatorisk

1. GDPR *

- Jag samtycker enligt ovan
- Nej, tack

Om dig

2. Ditt kön? *

- Man
- Kvinna
- Icke-binär
- Annat

3. Var bor du? *

- Storstad - kommun med minst 200 000 invånare.
- Större stad - kommun med minst 50 000 invånare.
- Mindre stad/tätort - kommun med minst 15 000 invånare.
- Landsbygdskommun - kommun med mindre än 15 000 invånare.
- Övrigt: ____________________

4. Hur bor du? *

- Hus
- Lägenhet
- Annat

5. Äger du bil? *

- Ja
- Nej
- Övrigt: ____________________

6. Har du barn i åldern (0 - 18 år)? *

- Ja
- Nej
- Övrigt: ____________________

Barn och bilbarnstolar

7. Vilken ålder har dina barn?

	0-1	1-5	5-12	12-18
Barn 1	☐	☐	☐	☐
Barn 2	☐	☐	☐	☐
Barn 3	☐	☐	☐	☐
Barn 4	☐	☐	☐	☐
Barn 5	☐	☐	☐	☐
Barn 6	☐	☐	☐	☐

8. Har du tillgång till en bakåtvänd bilbarnstol? *

- [ ] Ja, jag äger en bakåtvänd bilbarnstol
- [ ] Ja, jag lånar regelbundet en bakåtvänd bilbarnstol
- [ ] Ja, jag brukar hyra en bakåtvänd bilbarnstol.
- [ ] Nej, men jag ägde en bakåtvänd bilbarnstol tidigare
- [ ] Nej, jag använder inte en bakåtvänd bilbarnstol
- [ ] Nej, jag använder en annan typ av bilbarnstol (t.ex. babyskydd eller framåtvända bilbarnstol)

Övrigt: [ ] ____________

Framtidens bakåtvända bilbarnstolar

9. På en ny bakåtvänd bilbarnstol vilka faktorer skulle du prioritera? Välj dom 5 faktorer som d tycker är viktigast.

	Prio 1	Prio 2	Prio 3	Prio 4	Prio 5
Snyggt utseende	[ ]	[ ]	[ ]	[ ]	[ ]
Krocksäkerhet	[ ]	[ ]	[ ]	[ ]	[ ]
Intuitiv att installera rätt	[ ]	[ ]	[ ]	[ ]	[ ]
Barnets komfort	[ ]	[ ]	[ ]	[ ]	[ ]
Lätt att bära med sig/mobil	[ ]	[ ]	[ ]	[ ]	[ ]
Den tar liten plats att förvara	[ ]	[ ]	[ ]	[ ]	[ ]
Smarta extra funktioner	[ ]	[ ]	[ ]	[ ]	[ ]
Går snabbt att installera	[ ]	[ ]	[ ]	[ ]	[ ]
Miljövänlighet	[ ]	[ ]	[ ]	[ ]	[ ]

10. Vad tycker du är det största problemet med en bakåtvänd bilbarnstol idag?

Förvaring och transportering

11. Hur förvarar du den bakåtvända bilbarnstolen idag? (Om den inte står i en bil.) *

- Förråd eller garage utanför min bostads yta
- Inne i min bostad
- Övrigt: ______

12. Vad tycker du angående förvaring av en bakåtvänd bilbarnstol? *

	1	2	3	4	5	6	
Det funkar bra							Det är ett mycket stort problem

13. Vad tycker du angående att transportera en bakåtvänd bilbarnstol till en bil? *

	1	2	3	4	5	6	
Det funkar bra							Det är ett stort mycket problem

Tillgång till bil

14. I vilka av dessa sammanhang och hur ofta, har du behov av en bil (då barn ska åka med i bilen)?

	Varje vecka	Varje månad	Några gånger per år	Mer sällan	Aldrig	Vet ej
Hälsa på släkt och vänner	☐	☐	☐	☐	☐	☐
På semesterresa i Sverige	☐	☐	☐	☐	☐	☐
På väg till flyg eller liknande	☐	☐	☐	☐	☐	☐
På bilresa i Europa	☐	☐	☐	☐	☐	☐
Storhandla (mat, IKEA, liknande)	☐	☐	☐	☐	☐	☐
Då jag ska transportera många eller stora föremål	☐	☐	☐	☐	☐	☐
Annat	☐	☐	☐	☐	☐	☐

15. Om du svarat "annat" i tidigare fråga, definiera vad det är för sammanhang.

Färdmedel

16. Vilka färdmedel använder du tillsammans med barn?

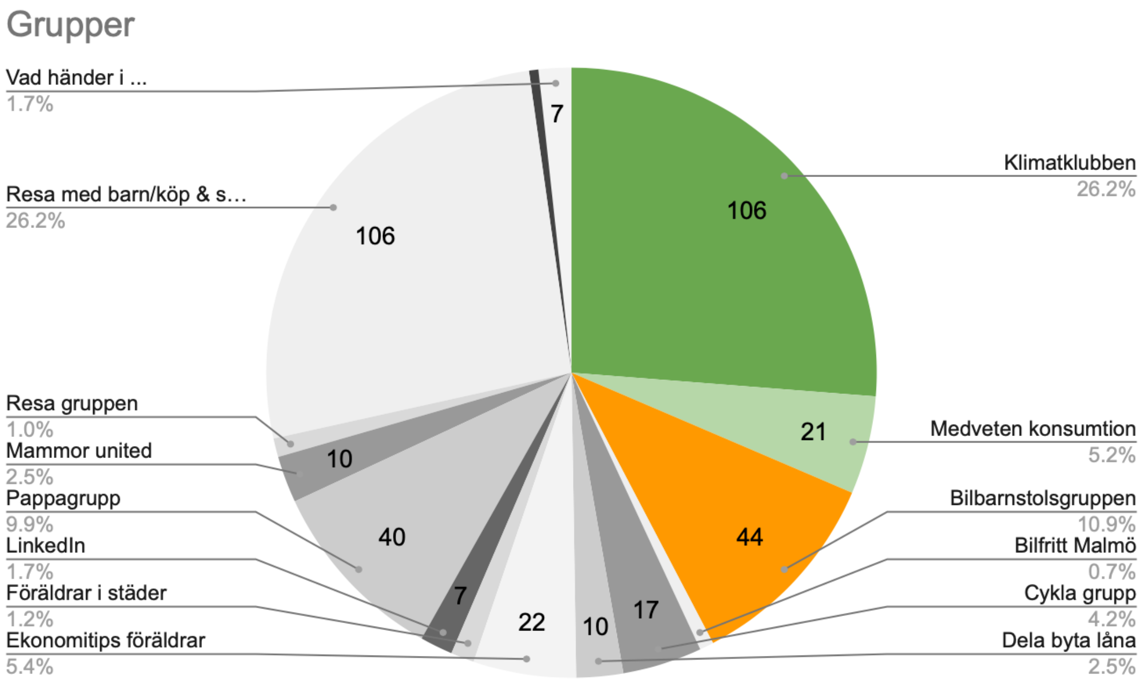
	Varje vecka	Varje månad	Några gånger per år	Mer sällan	Aldrig	Vet ej
Långfärdsbuss	☐	☐	☐	☐	☐	☐
Flyg	☐	☐	☐	☐	☐	☐
Tåg	☐	☐	☐	☐	☐	☐
Kollektivt (kommunalt)	☐	☐	☐	☐	☐	☐
Hyrbil via biluthyrningsfirma	☐	☐	☐	☐	☐	☐
Hyrbil via bilpool	☐	☐	☐	☐	☐	☐
Bil lånad av vänner eller familj	☐	☐	☐	☐	☐	☐
Taxi	☐	☐	☐	☐	☐	☐
Bil som jag äger själv	☐	☐	☐	☐	☐	☐

Snart slut...

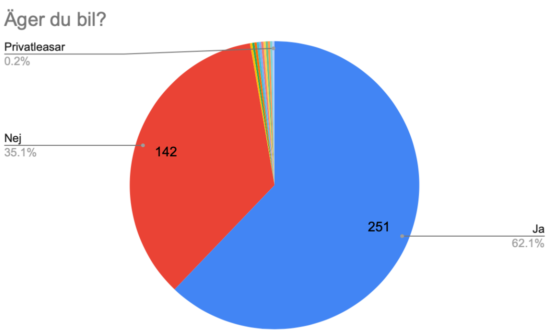
17. Om du hade fått önsketänka - Hur skulle en bakåtvänd bilbarnstol vara eller fungera för at passa dig bättre? *

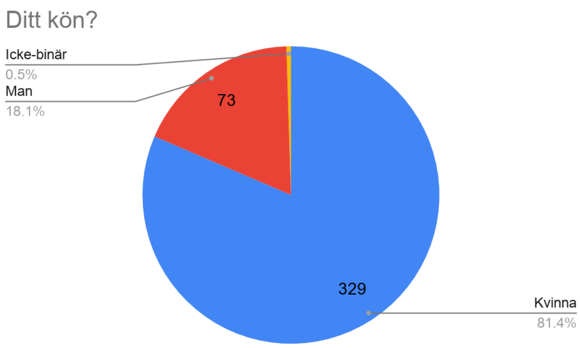
A3: Findings from Survey

Different Groups, n=404

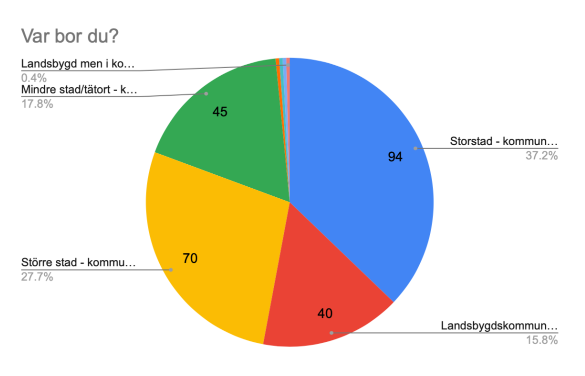


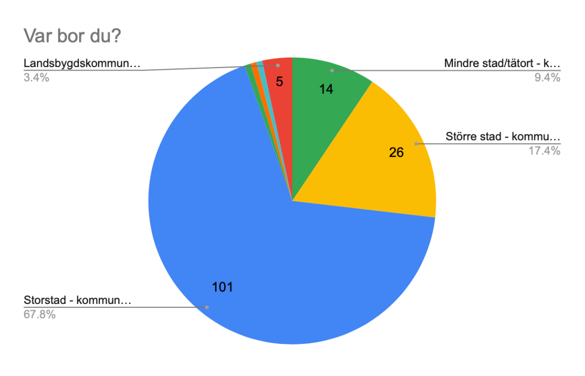
Alla Svar (All answers), n=404:

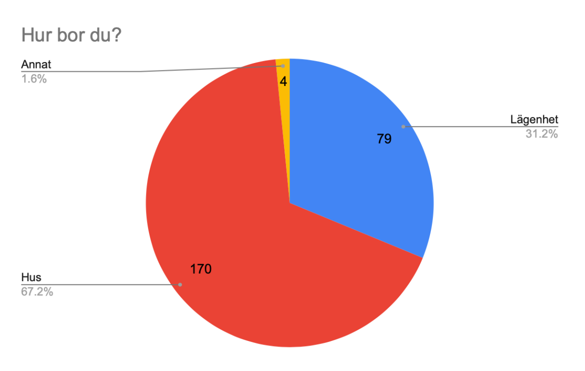


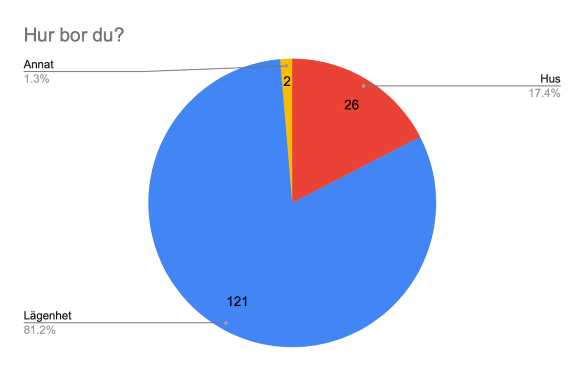


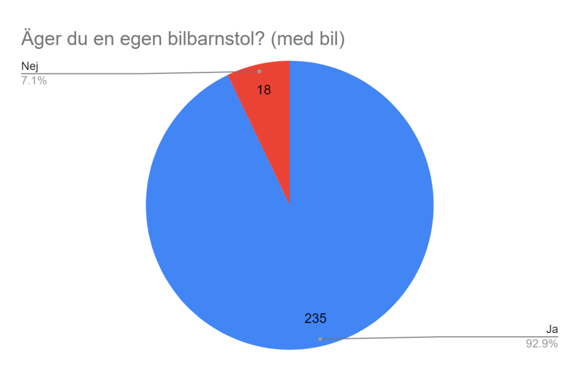
Med bil (Who owns a car), n=251	Utan bil (Who do not own a car), n=149

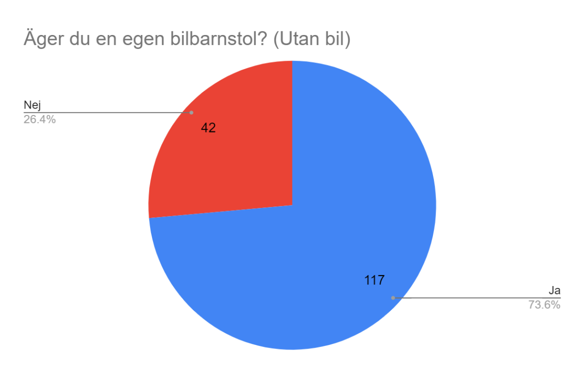


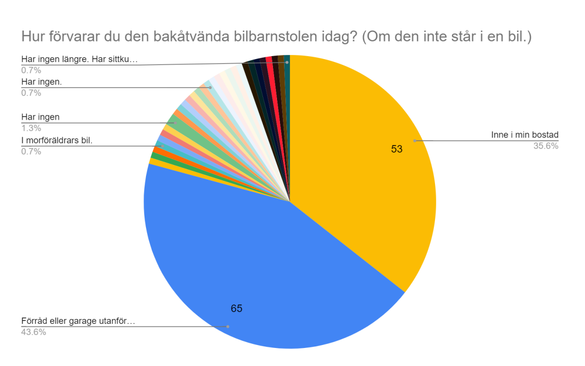


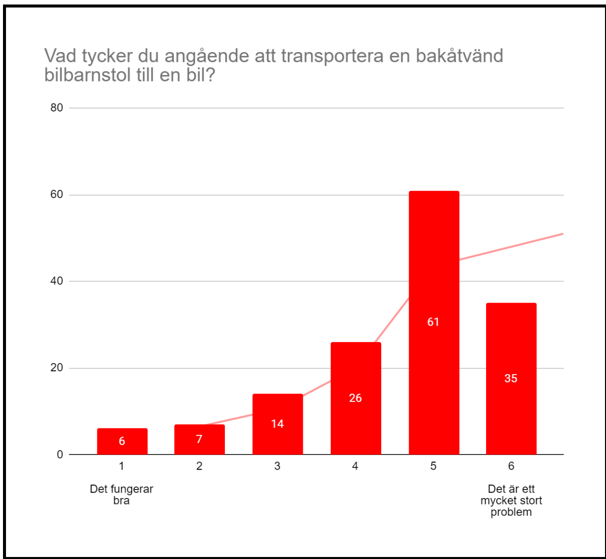


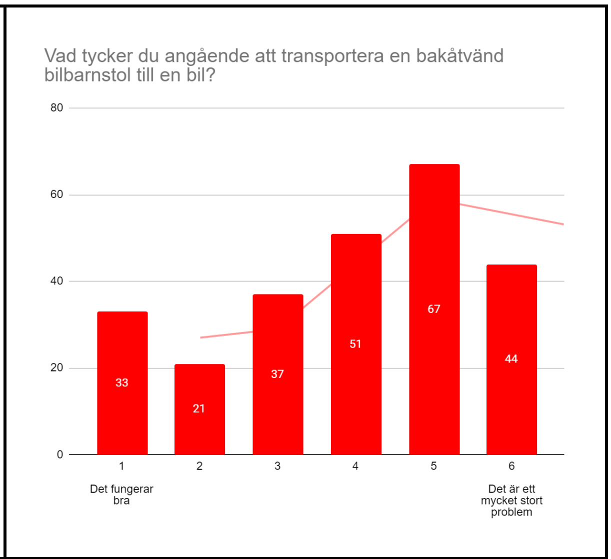


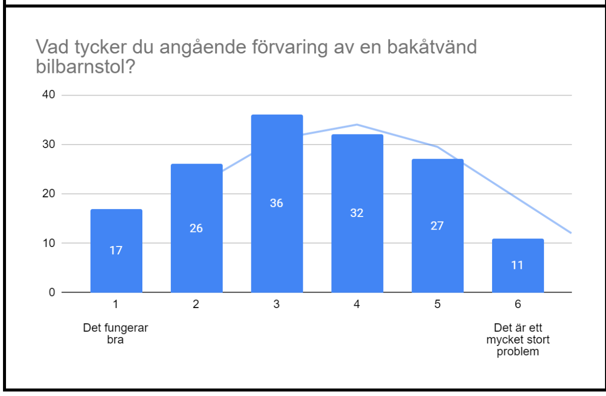


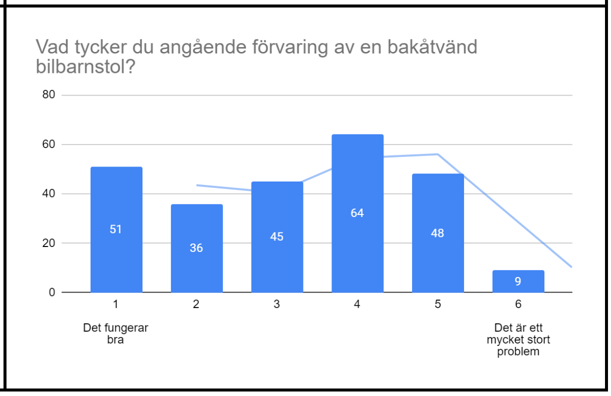





Vad tycker du angående att transportera en bakåtvänd bilbarnstol till en bil?
80
60
40
20
0
6
7
14
26
61
35
1
2
3
4
5
6
Det fungerar bra
Det är ett mycket stort problem


Vad tycker du angående att transportera en bakåtvänd bilbarnstol till en bil?
80
60
40
20
0
33
21
37
51
67
44
1
2
3
4
5
6
Det fungerar bra
Det är ett mycket stort problem


Vad tycker du angående förvaring av en bakåtvänd bilbarnstol?
40
30
20
10
0
17
26
36
32
27
11
1
2
3
4
5
6
Det fungerar bra
Det är ett mycket stort problem


Vad tycker du angående förvaring av en bakåtvänd bilbarnstol?
80
60
40
20
0
51
36
45
64
48
9
1
2
3
4
5
6
Det fungerar bra
Det är ett mycket stort problem

A4: Expressed Requirements from Users

In this list, summarized requirements, needs, and wishes that were discovered in user study part 1 and 2 in relation to different categories are presented. This is not a requirement list but findings from User Studies summarised without mutual order, therefore not all of these expressed requirements will be fulfilled.

According to users, the CRS concept needs to:

Storage

- Be accessible
- Be able to store in the apartment, wardrobe, basement storage or garage
- Be protected during storage
- Be stackable or the ability to store stack things on top of the CRS
- Handle external pressure and impacts.
- Look good during storage

Mobility

- Be moved from home to the vehicle where it will be used
- Be easy to carry
- Enables control over the toddler
- Enables the possibility of transporting other goods as well
- Be some water and dirt resistant
- Be manageable on other types of transports (buses, trams, trains).
- Be moveable in different urban terrain

Comfort

- Be comfortable to carry/move for the parent/guardian
- Give the possibility to relieve the body of the parent/guardian
- Have great travel comfort for the toddler
- Be comfortable during installation and uninstallation of the CRS
- Have leg space for the toddler
- Enables good sleeping position (neck not falling forward)
- Enables the toddler to see parents from CRS without not climbing out from the CRS

Safety

- Be safe in a car crash - be estimated safe during a crash tests
- Be safe to carry/move around
- Be visible in darker environments
- Put toddler in a correct position in the CRS during travel and in a car crash
- Give the driver great visibility and not cover the necessary field of view during driving.
- Be pinching safe

Installation

- Be intuitive to install
- Be fast to install
- Have okay guessability
- Have great learnability
- Have great Re-usability
- Give clear semantic instructions on how the CRS is attended to work
- Give feedback if CRS is restrained correctly or not
- Be adapted to cars with ISOFIX
- Have leg space for the e.g. front-row passengers
- Enables three CRS in the backseat row
- Have an easy and adaptable seatbelt
- If the CRS is foldable, a great thing would be to put it in the car folded and be able to unfold the CRS in the car.

Extra

- Have a cup holder
- Have a rotation ability to simplify the restraining of the toddler
- Have a tilting ability to the CRS to offer a more comfortable sleeping position for the toddler
- Be made of non-toxic materials
- Be made of environmentally friendly materials

After Usage

- Be easy to clean
- Be easy to store

A5: Morphological Matrix

A6: Three Fundamental Concepts of Phase 3 Described

Concept 1: Lego

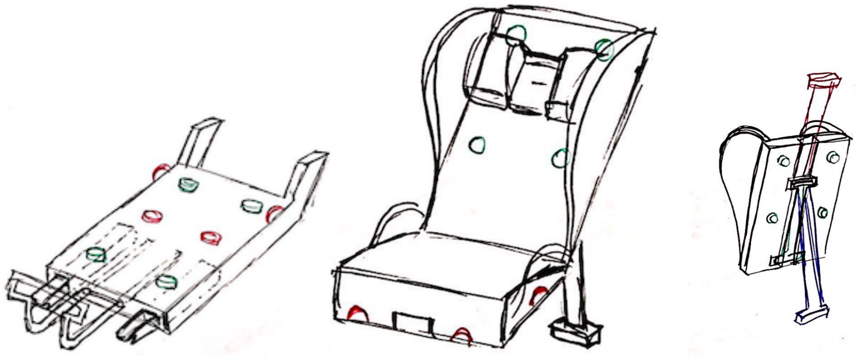


Figure 1A: Concept 1 Lego.

Parts
Main parts:

- Bottom plate with connected ISOFIX attachments and Rebound bar
- Back Part consisting of backrest with connected seat and support leg

Extra parts:

- Wheels connected to bottom plate with strings
- Backpack handles connected to the bottom plates backside

Mounting of CRS
To install CRS in a car the bottom plate is put in the car’s seat and ISOFIX are retracted from the bottom plate and attached to the car‘s ISOFIX attachments.
The Support leg is folded out from the back rest.
The back part is then placed onto the projecting pillars of the backplate. The CRS seat is locked onto the bottom plate with clips (illustrated in red in figure 1A).
The support leg is telescoped out to have the right length to reach the floor.

Demountering of CRS
The ISOFIX attachments are unlocked and the CRS can be removed from the car.
The clips that connect the back part to the bottom plate are unlocked and the two parts are separated.
The supportlegs teleskope function is folded in and the leg is folded into the backrest.
The rebound bar is folded out further to make room for the back support which is placed onto the bottom plate and locked with the clips (illustrated in green in figure 1A).

Mobility
When the back part is connected to the bottom plate:

- The CRS can be carried on the back by the backpack handles.
- wheels can be connected to the ISOFIX attachments and dragged like a suitcase by dragging the CRS with the support leg. (In this case the support leg should not be folded into the back rest before the bottom plate and the backrest is connected.) See figure 2A.

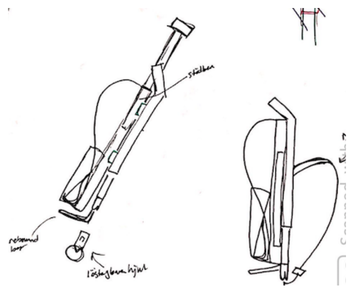


Figure 2A: Concept Lego mobility mode.

Storage
In a folded position the CRS is approximately 70cm long because of 60cm, se Figure 3A, from the backrest and the additional length of the rebound bar and back support pillars.
The CRS has protruding objects (open into the chair part in storage and mobility mode).

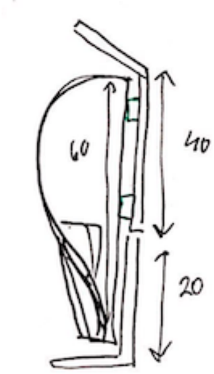


Figure 3A: Concept Lego storage measurements.

Adjustment option
- Movable ISOFIX arms.
- Movable rebound bar.

Loose objects
- Wheels
- Rebound bar
- Support leg

Concept 2: Box

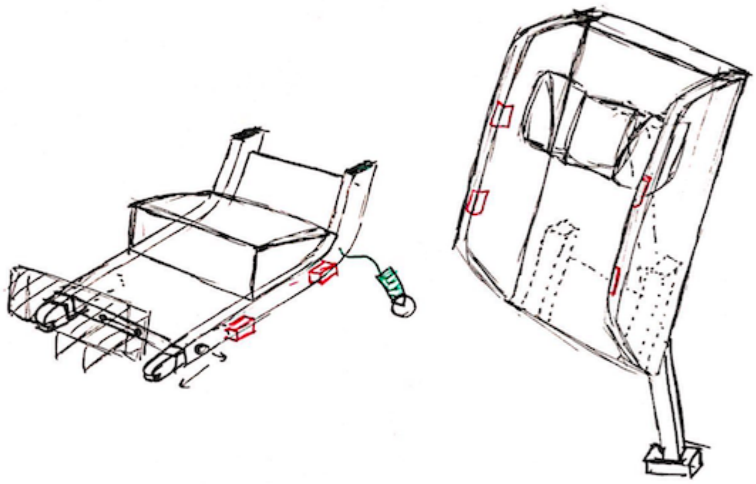


Figure 4A: Concept Box.

Parts, see figure 4A.

Main parts:

- Bottom plate with connected ISOFIX attachments and rebound bar with connected seat
- Back part consisting of backrest and support leg

Extra parts:

- Wheels connected to bottom plate with strings
- Backpack handles connected to the backrests backside

Mounting of CRS

To install the CRS in a car the bottom plate is put in the car's seat and ISOFIX are retracted from the bottom plate and attached to the car's ISOFIX attachments.
The support leg is folded out from the back parts backrest.
The back part is then placed onto the projecting pillars of the backplate. The CRS seat is locked onto the bottom plate with clips illustrated in red**.**
The support leg is telescoped out to have the right length to reach the floor.

Demountering of CRS

The ISOFIX attachments are unlocked and the CRS can be removed from the car.
The clips that connect the back part to the bottom plate are unlocked and the two parts are separated.
The supportlegs teleskope function is folded in and the leg is folded into the backrest.
The bottom plate and the back part is concepted together via clips on the side protection illustrated red

Mobility

When the back part is connected to the bottom plate, see figure 5A.

- The CRS can be carried on the back by the backpack handles.
- wheels can be connected to the ISOFIX attachments and dragged like a suitcase by dragging the CRS with the support leg. (In this case the support leg should not be folded into the back rest before the bottom plate and the backrest is connected.)

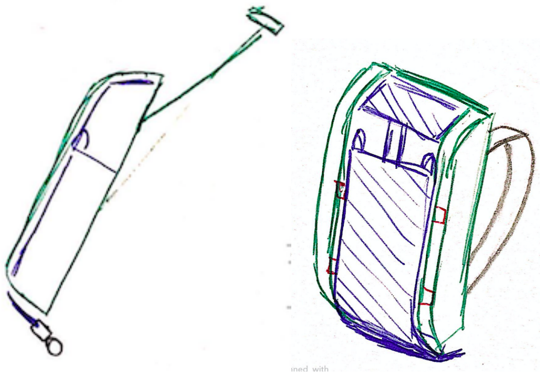


Figure 5A: Concept Box, mobility mode.

Storage
The backrest and the bottom plate's flat surfaces are at opposite sides in folded position, these surfaces together with the side protection creates a uniform shape. This uniform shape creates a box hence the concept's name. However, this box is not perpendicular due to the need of an angled shape of the backpilers, that provides a good laid back back position for a child during use.

In a folded position the CRS is approximately 70cm long because of 60cm fråm the backrest and the additional length of the rebound bar and back support pillars.
The CRS has protruding objects (open into the chair part in storage and mobility mode).

Adjustment option

- Movable ISOFIX arms.
- Movable rebound bar.
- Support leg

Loose objects

- Wheels
- Rebound bar

Concept 3: Small Fold

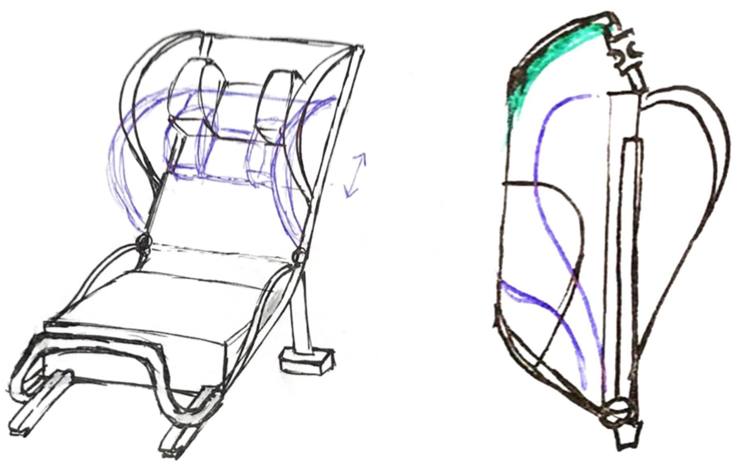


Figure 6A: Small fold.

Parts
Exists of one main part, with a joint between the cushion and the back. The rebound bar and

the ISOFIX are attached to the cushion and the support leg is attached in the back. Small fold has also backpack straps located at the back. See figure 6A.

Mounting of CRS

To install the CRS in a car the ISOFIX are retracted from the bottom of the CRS and attached to the car‘s ISOFIX attachments and the rebound bar positions in place and locks.
The CRS unfolds from backpack mode to car mode.
The Support leg is folded out from the back rest.
The support leg is telescoped out to have the right length to reach the floor.

Demountering of CRS

The ISOFIX attachments are unlocked and the CRS can be removed from the car.
The rebound bar pulls out to the furthest position.
The neckrest pulls out the further position.
The support legs teleskope function is folded in and the leg is folded into the backrest.
The CRS folds into backpack mode and carries away in backpack straps

Mobility

Is transported like a backpack.

Storage

The backrest and the bottom of the cushion makes two flat surfaces that are at opposite sides in folded position, these surfaces together with the side protection creates a uniform shape. This uniform shape. However there is an open pass, between rebound bar and cushion at the top.

Adjustment option

- Movable ISOFIX arms.
- Movable rebound bar.
- Support leg

Loose objects

- No loose objects.

A7: Kesselring Matrix Weighted Selections Criteria with Motivation

Selection Criteria	Weight 1-5	Weight score motivation
Mobility *- Mobile in many use situations*	5	Developing a mobile CRS is an essential aim of this project. It was also rated highly among parents without cars in the survey. Which motivates the top score five points.
Storage *- Small and easy to store (boxy)*	3	Being able to store the CRS in a good way is something useful, especially for the urban user. Mobility was more important than storage in the survey, which motivates a lower score.
Mechanics (Crash safety)	2	The goal with the project is to come up with a final concept that is feasible. The mechanic selection criteria rates concepts that are more feasible higher because it will require more effort to reach a feasible final concept. However most problems are possible to solve, it only requires more time and resources.
Fast and smooth to install	3	Fast installation was given a high priority in the survey, but not the highest.
Comfort for the child - *Legroom, headrest, smoothness*	2	A child's comfort is important to enable a secure seating position, which is important for safety reasons. That the parent thinks that the child is comfortable is important to ensure that the parents use the chair and does not change to a forward facing CRS too early.
Features: Protected during storage and transportation (isn't harmed by other things) and seat protection	1	One useful feature is that the CRS is protected during storage and transportation. However there are a lot of other criterias that are more important for a CRS.
Prevent misplacing of components	2	It is important that a CRS will not be useless if objects or parts are missing or misplaced. The fact that users will own the CRS themselves will make them more observant of missing parts and they will know if the CRS is complete or not. If the CRS would be intended for shared usage this score would be higher.
Intuitive to install (Good re-usability)	4	Intuitive to install is important because a wrong installed CRS might not protect the child in a car accident. Re-usability might be important to think about in developing this CRS because a CRS developed for shared usage might not be used as frequently as one designed for staying in a non shared private vehicle.
Applicable to other stakeholders (Car pools, grand parents, shared usage)	1	The CRS developed in this project is designed for the chosen target group; parents. However, if the CRS could be useful for other stakeholders like car pools, taxis or shared usage etc. would make the CRS concept more successful. This is not, however, a big focus area.

Easy to clean	1	It is a plus that a CRS is easy to clean since it is around children, motion sickness and should be transported to a big extent. It will increase convenience and satisfaction for users. This is not a commonly prioritated area in current CRS, therefore, it is a plus but not a high priority.
Styling (Both on the go and in car)	1	That the styling of the final CRS is pleasant, both when the user transports the CRS around and home during storage.
Crash Safety	5	That the CRS is safe and protects the child in a car accident is the core purpose of using a CRS.
Semiotics - Robust	4	It is important that the CRS gives a robust expression, not fragile and unsafe.

A8: Kesselring Matrix 1, Evaluating 3 concepts

Chalmers				**Kesselring matrix**					
Creators	Eric Elinder & Jaquline Hultman			**Created**		2020-03-16			
		Concepts							
Selection Criteria		**Ideal**		Concept 1: Lego		Concept 2: Box		Concept 3: Small fold	
	Weigth 1-5	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Mobility *- Mobile in many use situations*	5	5	25	4	20	4	20	4	20
Storage *- Small and easy to store (boxy)*	3	5	15	3	9	4	12	4	12
Mechanics (Crash safety)	2	5	10	3	6	3	6	2	4
Fast and smooth to install	3	5	15	3	9	3	9	4	12
Comfort for the child *- Legroom, headrest, smoothness*	2	5	10	3	6	3	6	3	6
Features: Protected during storage and transportation (isn't harmed by other things) and seat protection	1	5	5	1	1	3	3	2	2
Prevent misplacing of components	2	5	10	3	6	3	6	5	10
Intuitive to install (Good re-usability)	4	5	20	-		-		-	
Applicable to other sakeholders (Car pools, grand parents, shared usage)	1	5	5	-		-		-	
Easy to clean	1	5	5	-		-		-	
Good looking (styling) Both on the go and in car	1	5	5	-		-		-	
Crash Safety	5	5	25	-		-		-	
Semiotics - Robust	4	5	20	-		-		-	
Total		35,00	170,00	20,00	57,00	23,00	62,00	24,00	66,00
Decision		**Choosen concept: Concept 3: Small fold**							

A9: Kesselring Matrix 2

Chalmers — **Kesselring matrix**

Creators: Eric Elinder & Jaquline Hultman

Created: 2020-05-18

		CRSs							
		Ideal		Axkid Free		Nachfolger HY5		Axkid Modukid	
Selection Criteria	Weigth 1-5	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Mobility ***- Mobile in many use situations***	5	5	25	4	20	5	25	1	5
Storage ***- Small and easy to store (boxy)***	3	5	15	4	12	5	15	1	3
Fast and smooth to install	3	5	15	5	15	1	3	3	9
Comfort for the child ***- Legroom, headrest, smoothness***	2	5	10	4	8	2	4	5	10
Features: Protected during storage and transportation (isn't harmed by other things) and seat protection	1	5	5	4	4	5	5	1	1
Prevent misplacing of components	2	5	10	5	10	2	4	4	8
Intuitive to install (Good re-usability)	4	5	20	5	20	1	4	4	16
Applicable to other sakeholders (Car pools, grand parents, shared usage)	1	5	5	3	3	2	2	2	2
Easy to clean	1	5	5	3	3	1	1	3	3
Styling (Both on the go and in car)	1	5	5	4	4	4	4	3	3
Crash Safety	5	5	25	5	25	2	10	5	25
Semiotics - Robust	4	5	20	3	12	1	4	5	20
Total		60,00	160,00	26,00	69,00	31,00	56,00	37,00	36,00
Decision		**Winning CRS: Axkid Free**							

A10: Measurements

ISOFIX Adjustments:
- At its least extended = 80mm
- Most extended = 180mm

Lower Part
- Length of the bottom plate (against the back of the user in backpack mode) = 300mm
- Width of the bottom plate (against the back of the user in backpack mode) = 320mm
- Distance of the bottom to the highest top of cushion = 14mm
- Angle of the cushion relatively the ground = 25°
- Length of the back of the of lower part = 200mm
- Angle of the back relatively the ground = 125°
- Angle of the cushion relatively the back = 100°
- The distance between the widest part of the lower side impact protection = 373mm
- The thickness of the side impact protection = 30mm
- The sitting depth of the cushion = 280mm

Upper Part
- The maximum length of the upper part = 380mm
- The maximum outside distance between the side upper impact protection = 410mm
- The maximum inside distance between the side upper impact protection = 350mm
- The thickness of the upper impact protection = 30mm
- The maximum width of the side impact protection relatively the backside of the back = 235mm
- The maximum width of the side impact protection relatively the inside of the back = 210mm
- Thickness of backside = 25mm

Rebound Bar
- Maximum height 265mm
- Minimum extension = 150mm
- Maximum extension = 250mm
- Diameter thickest pipe = 25mm
- Diameter thinnest pipe = 15mm

Support Leg
- Maximum diameter largest support leg profile longest side 49mm
- Maximum diameter largest support leg profile shortest side 30mm
- Length of the support leg folded = 378mm
- Length of the support leg maximum extended = 1000mm

Headrest (In natural position)
- The maximum width of the headrest support material is = 70mm
- The Minimum width of the headrest support material is = 30mm

- It sloping with 13°
- Length of the headrest = 170mm
- Thickness back 8mm
- Maximum depth of headrest = 150mm

Mobility Mode
- Length outside = 591mm
- The maximum outside distance between the side upper impact protection = 410mm
- Length of the bottom plate (against the back of the user in backpack mode) = 300mm
- Width of the bottom plate (against the back of the user in backpack mode) = 320mm
- Total bottom length (inc shortest ISOFIX) = 380mm
- Hight lowest place = 190mm
- Hight highest place = 265mm
- 9° angle of back relatively the ground

Seat Mode
- Max base length = 300 (base) + 250 (Max, top of the rebound bar) = 550mm
- Min bas length = 300 (base) + 150 (Min, top of the rebound bar) = 450mm
- Length of back = 584mm
- Max height in folded mode = 290mm (from bottom to support leg house)

- Width of the bottom plate (against the back of the user in backpack mode) = 320mm
- The maximum outside distance between the side upper impact protection = 410mm

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