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Innovative Child Restraint Harness

Master’s thesis in Automotive Engineering

SOFIE HELMERSSON & MARIA REHNBERG

Department of Applied Mechanics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2015

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Prototypes developed within the project.

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Abstract

Children's car seats can be bulky, hard to move and tedious to mount. Volvo Cars has designed a lightweight and inflatable rearward-faced child seat concept. One important part of the child seat is the harness. Innovations within harness are limited and designed to fulfil the legal requirements rather than being user friendly.

The aim of the project is to define the requirements of how an optimal child restraint harness should be designed to increase the customer value of the child seat without affecting the safety level of the child seat. The harness should be mountable in the new concept child seat developed by Volvo Cars.

Customer experiences and values were investigated using questionnaires and a focus group meeting. Important aspects/issues were identified. Various concepts addressing these were evaluated and two promising concepts were produced. The first concept is a three-point belt similar to those found in cars and the second concept is a three-point belt shaped like a Y and buckled between the child's legs. The traditional three-point belt concept addresses the issue experienced by some users when placing the child in the seat, the child is often placed on top of the buckle. In the concept, it is avoided because the buckle has been moved to the side of the seat where it is more easily accessed. The Y-belt facilitates the fastening of the child by reducing the number of actions compared to a five-point harness. Both concepts are equipped with a mechanism to ensure that the shoulder belt is positioned close to the child's neck and belt retractors to facilitate fastening of the child.

Key words:

Child safety, child restraint system, harness, user friendliness

Innovativ bilbarnstolssele
Examensarbete inom Fordonsteknik
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Institutionen för tillämpad mekanik
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Sammanfattning

Bilbarnstolar kan vara klumpiga, svåra att förflytta och ta lång tid att montera. Volvo Cars har utvecklat ett lätt och uppblåsbart bakåtvänt bilbarnstolskoncept. En viktig del av bilbarnstolen är selen. Inom selen är innovationer begränsade och utvecklade för att möta lagkrav snarare än att vara användarvänliga.

Målet för detta projekt är att definiera kraven för hur en optimal bilbarnstolssele ska vara designad för att öka kundvärdet hos bilbarnstolen utan att påverka stolens säkerhetsnivå. Selen ska vara monterbar i den nya konceptstolen utvecklad av Volvo Cars.

Kundupplevelser och värderingar undersöktes genom en enkät och möte med en fokusgrupp. Viktiga aspekter identifierades. Olika koncept som adresserade dessa utvärderades och två lovande koncept byggdes. Det första konceptet är ett trepunktsbälte liknande de bälten som finns i personbilar och det andra konceptet är ett Y-format trepunktsbälte som knäpps mellan barnets ben. Konceptet med traditionellt trepunktsbälte adresserade problemet som en del användare upplever när de placerar barnet i stolen, barnet placeras ofta ovanpå knäppet. I konceptet undviks detta eftersom knäppet har flyttats till sidan på sitsen där det är mer lättåtkomligt. Det Y-formade bältet underlättar fastsättningen av barnet genom att reducera antalet moment jämfört med en fempunktssele. Båda koncepten är utrustade med en mekanism som försäkrar att axelbandet är positionerat nära barnets hals samt rullbälten för att underlätta fastsättningen av barnet.

Nyckelord:

Barnsäkerhet, bilbarnstol, sele (i bilbarnstol), användarvänlighet

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Preface

This master's thesis has been performed by Sofie Helmersson and Maria Rehnberg at Volvo Cars Safety Centre, Torslanda, Sweden, during the spring 2015. The research was carried out in collaboration with the department of Vehicle Safety, Applied Mechanics at Chalmers University of Technology, Gothenburg, Sweden.

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SOFIE HELMERSSON & MARIA REHNBERG

Notation

1 Introduction

Children's car seats can be bulky, hard to move and tedious to mount. Volvo Cars has designed a lightweight and inflatable rearward-faced child seat concept. One important part of the child seat is the harness. Innovations within harness are limited and designed to fulfil the legal requirements rather than being user friendly.

Injury is the leading cause of child death among the OECD countries, and road traffic accidents are the dominating reason for child injury deaths (UNICEF Innocenti Research Centre, 2001). In the United States, unintentional injury is the leading cause of death, serious injury and acquired disability in children from 1 to 14 years old (Arbogast & Durbin, 2013). There has been a decline in motor vehicle fatalities and serious injuries in the recent years (Arbogast & Durbin, 2013).

1.1 Child anatomy

The anatomy of infants and children differs greatly from that of adults in several ways which shows that it is not correct to identify these as miniature adults (Burdi, Huelke, Snyder, & Lowrey, 1969).

The human body grows and develops continuously from birth to senescence. Even though the development is sporadic and non-uniform it does not occur haphazardly (Burdi, Huelke, Snyder, & Lowrey, 1969). Most of the body dimensions follow the same trend, which involves rapid growth separated by a period of relatively slower or uniform growth. There are notable differences in the timing of these incremental growth spurts. The brain is one example since the growth is rapid during the period before birth and then slows considerably during the pre-school years. At birth the brain is typically around 25% of its adult size compared to the total body weight which is only about 5% of the adult weight (Burdi, Huelke, Snyder, & Lowrey, 1969). During the first year of life, half of the postnatal growth of the brain volume occurs and achieves about 75% of its adult size by the end of the second year. As a contrast to this growth, the genital organs develop very slowly during the same period and instead reach their adult size during the second decade of life. The subcutaneous tissue can also be an important factor in the design of protective devices for the infant body. The thickness of this tissue tends to increase rapidly during the first nine months, while the total growth of the body tends to be much slower. This period is followed by a period of less rapid growth meaning that the thickness of the subcutaneous layer, at an age of 5 years, is about half compared to the nine month old infant.

It is of high importance to make sure that the loading of the body occurs on the solid skeletal elements, where the body is strongest (Burdi, Huelke, Snyder, & Lowrey, 1969). The sitting height of an infant just after birth represents about 70% of the total height at birth, which rapidly decreases to about 57% for a child at the age of three (Burdi, Huelke, Snyder, & Lowrey, 1969). During the following years this decrease slows down and for a 13 year old girl and a 15 year old boy the sitting height is about 50% of the total height of the child. Generally said, children have the same height, weight and general body proportions independent of sex up to 10-11 years of age, even though it is not uncommon that girls are slightly taller than boys at the ages 6-10 (Burdi, Huelke, Snyder, & Lowrey, 1969).

The centre of gravity of children is located vertically higher than on an adult, which means that the tendency of a child to tip forward is higher compared to an adult, which has a lower centre of gravity (Burdi, Huelke, Snyder, & Lowrey, 1969).The centre of gravity can also be expected to have higher variability at the younger ages (Burdi, Huelke, Snyder, & Lowrey, 1969).

The heavier head mass and the resulting higher seated centre of gravity in young children in combination with the weaker neck supporting structures may be the basis for the high frequency of head injury in automotive collisions (Burdi, Huelke, Snyder, & Lowrey, 1969). Another contributing factor is the relatively soft, pliable and elastic bones of the cranial vault and the fontanels; which makes the head of a child less resistant to impact trauma, compared to the head of an adult (Burdi, Huelke, Snyder, & Lowrey, 1969). In a collision with an unrestrained child this leads to that the head of the child will be the leading point of motion. A head injury of an infant can cause considerable neurological problems since a blunt impact to the head can produce a depression of an entire bone or bones, impinging upon the brain and its nutrient blood vessels (Burdi, Huelke, Snyder, & Lowrey, 1969).

The neck muscles are generally not developed sufficiently to dampen violent head movement, especially in children since the strength of the neck muscles increases with age (Burdi, Huelke, Snyder, & Lowrey, 1969). The neck vertebrae of children are immature models of the adult. In young children only the body of the first and second vertebrae are ossified and do not fuse with the other vertebral parts until age 7 and 3 to 6 respectively (Tarrière, 1995). A child’s neck also has higher cervical mobility. Children bending forward display a displacement of the first two cervical vertebrae relative to the underlying vertebrae with up to 4 to 5 mm (Tarrière, 1995). If the tolerable limits of neck motion are exceeded, a dislocation of vertebrae and possibly injury to the spinal cord can occur. In a rapid deceleration, and if the head is rotated or snapped to the rear or side, these anatomical features may cause serious damage to the delicate system of critical arteries supplying the head, to nerves, to the vertebrae, or to the spinal cord itself.

In infants and young children the thoracic walls are thinner and the ribs are more elastic compared to an adult. Consequently the chest wall deflection onto the vital thoracic organs, due to the highly elastic nature of the ribs, will be greater in an impact to the thorax of an infant or small child compared with the same impact of an adult.

The combination of the changes in shape of the chest of a child, from circular to elliptical one, and the relatively unprotected thoracic organs leads to challenges while designing some restraint system that fits tightly to the chest wall without increasing the level of injuries of the child.

Children have higher injury rates for abdomen and lower extremities than adults while the injury rates are lower for children as compared to adults in the general case (Jakobsson, Isaksson-Hellman, & Lundell, 2005). The pelvis is not fully ossified at birth and the ossification continues postnatal and the pelvis increases in length, width and depth (Chumlea, 1983). The different component parts grow at different rates, in different locations and in different directions and are not easily characterized. The highest growth rate is shortly after birth. The development from the early crawling to erect posture is normally a gradual transition, which involves the interrelationships of the extremities, spine and pelvis to become the more well-balanced weight-bearing relationships typical of the adult (Burdi, Huelke, Snyder, & Lowrey, 1969). In the first standing phase of the infant the pelvis is tilted far forward on the thighs and an upright stance is first obtained in infancy concurrent with the development of the lumbar curve. The curvature of the vertebral column and the tilt of the pelvis are not conducive for an upright seated position of the child. During pubescence the body enters into another phase of rapid growth. Changes in shape of the pelvis during pubescence may be accounted for the secondary centres of ossification, which do not appear until age 10-15. Below the age of 8 or 10 the iliac wings are round and smooth in shape (Tarrière, 1995).

For an infant or a child blunt abdominal injuries are much more critical than in adults due to their developing and immature structure, large organ relationships and the complete lack of overlying muscle or skeletal protection. These organs have minimal protection from the highly elastic ribs of the child in an impact. The positions of the organs inside the body differs compared to the adult body which results in that children are more available to traumatic insult, an example is the bladder located higher outside the pelvic area and both the liver and the kidneys are more exposed. By this, an impact to the right side of the lower chest or upper abdomen may cause serious traumatic liver injuries.

1.2 How to protect children in cars

The first restraining device for infants was introduced in 1898 and consisted of a bag with a drawstring that the child was placed in and attached to the seat to prevent that the child moved around and fell off the seat (Czubernat, 2015). The first rear-facing child seat prototype designed for safety, inspired by the way astronauts are retrained during launch into space, was presented in 1964 by Professor Bertil Aldman (Aldman, 1964).

60% of collisions are frontal impacts. Overall, the frontal impacts are more severe and frequent than rear impacts and it is therefore important that CRSs should be designed with maximum protection sought for this type of impact (Tarrière, 1995). The weak neck of a young child makes it at risk of neck injuries when restrained forward-facing (Tarrière, 1995) (Jakobsson, Isaksson-Hellman, & Lundell, 2005). By restraining the child rearward-facing the movement of the head relative to the thorax can be significantly reduced and the forces are distributed over the entire trunk of the body instead of the small surfaces provided by the harness in forward-facing CRSs (Tarrière, 1995).

It is important to note that the distance between the front ends of the iliac crests (the anterior superior iliac spines) and the fleshy front of the thighs is minimal when a child is seated, which results in that the lap belt does not have a good anatomical anchor point (Burdi, Huelke, Snyder, & Lowrey, 1969). This creates a risk of submarining, that the belt passes above the pelvis (Tarrière, 1995), causing the body to flex around the restraint in a crash. This can lead to severe internal injuries and could impact the lumbar spinal column (Eradi & Fisher, 2010). It is therefore important to make sure that the forces in an impact situation are distributed in such a way that hip interaction is achieved and loading on softer areas is avoided.

Even though the legislation is similar in most countries the recommendations differs around the world. In all regions, there is an agreement that babies should travel rearward-facing and that older children need a booster to obtain good belt fit (Arbogast & Durbin, 2013). Differences in when to translate to forward facing varies between countries (Arbogast & Durbin, 2013).In Sweden there has been a firm recommendation that children should be seated in a rear facing CRS up to the age of four or as long as possible. After this period children should use a booster seat or booster cushion up to 10-12 years of age (Gustafsson & Cosini, 2011).

1.3 Misuse of child restraint systems

Some studies have been conducted to evaluate the use and misuse of CRSs to point out the differences in behaviour and to evaluate if people act according to the recommendations. These studies can be used while developing a new system since they identify the areas of misuse. Misuse of CRSs includes incorrect restraint of the child in the seat, such as loose harness straps and incorrect height adjustment.

In a comparison between different studies of usage of child restraints the Swedish National Road and Transport Research Institute, VTI, found that the misuse level was alarmingly high (Anund, et al., 2003). One of the most common types of misuse regarding the harness in the CRS is loose harness straps. Other reported types of misuse are shoulder belts behind the back or under the arm, incorrect height adjusted harness straps and misuse of harness positioning clip. Some of these misuses resulted in that the children were able to climb out of the restraints.

An important and interesting finding is that in many of the cases, where misuse was noted, the parents thought that the child was correctly restrained, even though the observer was able to point out that they were not (Anund, et al., 2003). Another finding is that the parents who are seeking or receiving information had a lower level of misuse. One of the reasons for misuse is stated to be misunderstanding of instructions, which highlights the importance of the readability of the instructions.

To follow up child restraint usage in Sweden an observational study of 5000 children aged 0-10 years was conducted by the National Society for Road Safety, NTF (Gustafsson & Cosini, 2011). The study observed children outside 347 pre-schools in 70 of Sweden's 290 municipalities. The aim of the study was to investigate how children are restrained while travelling by car to pre-school. Observed parameters were mainly: if the belt was used, misuse of the belt, use of restraint system, misuse of restraint system and placement in front of active airbag. Important to note is that trips to pre-school may not be representative since these trips are usually shorter and performed under higher pressure of time compared to many other trips.

About 87 % of the 1 050 rearward facing child restraint systems (RFCRSs) had a correctly mounted harness (Gustafsson & Cosini, 2011). Misuse was identified at the height adjustment of the harness. 42 % of children aged 1-4 years were using the harness of the CRS, the other 58 % were identified as misuse since they were using a forward facing CRS or were placed directly on the car seat using the car seat belt, which are both against the recommendations and laws. Only 1 % of the children travelling in RFCRSs were unbelted.

The observer also checked the position of the belt on the children. Four incorrect positions were stated as: too far out on the shoulder, not adjusted against the hip, under the arm or too loose. If more than one source of misuse was identified the main reason was reported. 87 % of the children travelling in RFCRSs had the belt correctly positioned on the body. The main reason for incorrect position was that the belt straps were too loose on the body (11.5 % for children in RFCRS), which was found as the main reason for all children 0-6 years old. About 0.9 % of the children travelling in RFCRSs had the belt too far out on the shoulder, 0.2 % had the belt not correctly adjusted against the hip and 0.4 % had the belt strap under the arm. Of the children sitting directly on the car seat only 49.1 % of the belt positions were correct.

Skjerven-Martinsen (2014) investigated real motor vehicle crashes in southeast Norway where child passengers were involved. The injury mechanism was investigated by medical examination of the children and investigating the vehicles. It was found that the risk of severe or fatal injury of child passengers in motor vehicle crashes are significantly higher when they are incorrectly restrained. In a study in conjunction with regular traffic controls, restraint use was observed in children up until the age of 16 (Skjerven-Martinsen, 2014). The age group 0-3 years had the highest frequency of severe and critical errors; the most common errors were loose or improperly routed harness straps and incorrect CRS installation. Skjerven-Martinsen concludes that ensuring correct routing and tightness of harness straps is a main challenge for future awareness campaigns. She also concludes that information campaigns should advocate the use of chest clips.

Decina and Lococo (2005) investigated child restraint use in October and November 2002 in six US states. For all the CRSs, the most common misuses were loose vehicle safety belt attachment to the CRS and loose harness straps. For rear-facing convertible CRSs these misuses were 50.7% and 54.3% respectively. The third most common critical misuse was improper position of harness strap. In 28.6% of the rear-facing convertible CRSs the harness retainer clip was improperly positioned and in 5% there was improper threading of the harness retainer clip. The reasons for error are not straight forward since three-fourths of parents read manufacturer instructions and claim that they follow the directions correctly (Block, 2002). Decina and Lococo therefore conclude that reading instructions is not enough.

1.4 Legal requirements

The legal requirements for the certification of the CRSs differ around the world. The major regions will be covered in this chapter, specifically addressing harness related issues. The legal requirements of Sweden are controlled by the World Forum for Harmonization of Vehicle Regulations, which is a working partly of the Inland Transport Division of the United Nations Economic Commission for Europe (UNECE).

1.4.1 ECE R44/04

A CRS sold in Europe, the Middle East and most Asian countries must be approved according to the standards of ECE R44/04, which is a European approval standard. This standard was introduced in 1982 and will be replaced by the next generation, ECE R129, which the first part was introduced June 2013 (United Nations, 2014). It is not stated for how long the R44 will be phased out by the R129.

In this regulation it is stated that the child should be easily and quickly installed and removed from the CRS. By this it is also defined that each shoulder restraint and lap strap shall be capable of movement relative to each other during the release of the child, in case the child is restrained by means of a harness belt or a Y-shaped belt without a retractor. It should be possible to handle the release with a single operation on one single buckle.

A crotch strap is required on all forward facing child restraint systems (FFCRSs), to prevent submarining. Using this crotch strap it should not be possible to adjust the lap strap to lie above the pelvis of both the smallest and largest dummy within the range of the child seat. It is required to ensure, in a dynamic test, that the lap belt does not pass fully beyond the pelvic structure of the dummy, during the period prior to maximum horizontal head excursion. It is also defined that the restraint must be placed to not cause discomfort to the wearer in normal use or assume a dangerous configuration. The distance between the shoulder-straps in the neck area should at least correspond to the width of the neck of the appropriate manikin.

If retractors are used, it is only allowed to install automatic locking retractors (ALR) or emergency locking retractors (ELR) in the CRS. Devices used for Group I (CRS for children of mass from 9 kg to 18 kg) should not allow the child to easily slacken the part of the system that restrains the pelvis after the child has been installed.

The buckle shall be designed to preclude any possibility of incorrect manipulation; it should not be possible to leave the buckle in a partially closed position or to inadvertently exchange the buckle parts when the buckle is being locked; the buckle shall only lock when all parts are engaged. The contact surface of the buckle should not be narrower than the defined minimum width of the strap. Independent of loaded or not the buckle shall remain closed whatever its position. The buckle shall be easy to operate and to grasp. The buckle shall be possible to open by pressure on a button or on a similar device. The size of the surface which the pressure must be applied to in the position of actual unlocking and when projected into a plane perpendicular to the button's initial direction of motion depend on if the device is enclosed or not. For enclosed devices the area shall be minimum 4.5 cm^2 with a minimum width of 15 mm and for non-enclosed devices the area shall be 2.5 cm^2 and a minimum width of 10 mm. It is also defined that the width shall be the smaller of the two dimensions which is forming the prescribed area and shall be measured rectangular to the direction of movement of the release button. The colour of the buckle release area shall be red and no other parts of the buckle shall have this colour. The placement of the buckle shall be, for Group II (for children of mass from 15 kg to 25 kg) and Group III (for children of mass from 22 kg to 36 kg), so that the child occupant can reach it. As an addition to this, the buckle shall always be placed so its purpose and mode of operation are immediately obvious to a rescuer in an emergency situation. The opening manoeuver of the buckle shall enable the child to move independently of the CRS (chair, chair support or impact shield) and if a crotch strap is included in the device, this must also be released in the opening manoeuvre. It is also defined that a clip connection between the shoulder straps of a harness belt is in conflict with the statement that a single operation is required for the release of the child.

The range of adjustment shall enable correct adjustment of the child restraint for all manikins for which the device is intended according to specifications and allow a satisfactory installation in all specified vehicle models. All adjustment devices shall be of a "quick adjusting" type, except the device used only in the initial installation of the vehicle which is not required to be of this type. It is also specified that the adjustment of a "quick adjusting" device shall be easy to reach when the child restrain is correctly installed inside the vehicle and the child or manikin is in position. It shall also be easily adjustable to the child's physique and the force needed to operate a manual adjusting device shall not exceed 50 N. For one adjusting device the amount of strap slip shall not exceed 25 mm or 40 mm for all adjusting devices.

If an automatically-locking retractor is used, the strap of the safety belt shall not unwind by more than 80 mm between locking positions of the retractor. It is defined that the belt shall remain in its initial position or return to that position automatically after a rearward movement followed by a forward movement of the occupant.

If an emergency-locking retractor is used it shall be locked when the vehicle reaches a deceleration of 0.45 g. It is also stated that it shall not lock if the strap acceleration is less than 0.8 g or when the sensing device is tilted by not more than 12° or more than 27° in any direction from the specified installation position. In case the operation of the retractor is depending on an external signal or power source, failure or interruption of this signal must be taken into consideration to ensure that the retractor will be locked automatically in these situations. If one of the sensitivity factors relates to strap extraction, in case of a multiple sensitivity emergency-locking retractor, locking shall occur at a strap acceleration of 1.5 g as measured in the axis of strap extraction.

Common for both the automatically locked retractor and the emergency-locking retractor is that if the retractor is a part of the lap belt, the retracting force of the strap shall not be less than 7 N and when it is a part of a chest restraint, the force of retracting shall be between 2 N and 7 N. If a guide or pulley is present and the strap passes this one, the force shall be measured in the free length between the manikin and the guide or pulley. In case the assembly includes a device, which operates manually or automatically, that prevents the strap from being completely retracted it is stated that that device shall not be in action when these measurements are effected.

The straps must fulfil the requirements of minimum width of the straps which are in contact with the dummy shall be 25 mm for groups 0, 0+ and I, and 38 mm for group II and III. This shall be measured during the test procedure under a load equal to 75 percent of the breaking load of the strap. It is also stated that it shall not be possible to pull the complete strap through any adjusters, buckles or anchoring points.

1.4.2 ECE R129 / i-Size

The new regulation ECE R129 has some improvements valid for this kind of CRS (United Nations, 2013). The implementation of these regulations is divided into three phases. Phase one is dedicated to ISOfix Universal Integral CRS (called i-Size), phase two is dedicated to Booster seat and cushion and phase three is dedicated to belt Integral CRSs (Groupe Utac Ceram, 2013). Phase one was introduced on 9 July 2013.

Some of the most significant changes within the new regulations is that it is mandatory to travel rear faced until the child is 15 months old and that children here are grouped depending on their height instead of their weight (as in R44). The most important differences regarding the design and function of the harness in the CRS are discussed below.

It is stated that all devices which utilize a lap strap must guide this to ensure that the loads transmitted by the lap strap are transmitted through the pelvis. In the event of a collision the assembly shall not be imposed on the crown of the child’s head. It is also defined that it shall not be possible to remove or detach any components not designed to be removed or detached, without the use of specific tools. To avoid any risk of incorrect assembly and use, any components designed to be removable for maintenance or adjustment purpose shall, with the assembly and disassembly processes, be explained in detail in the restraint user guide. It must also be possible to utilize the full range of adjustment of the harness belt, without disassembly.

In case a shoulder strap positioner (between the two shoulder straps) is present, it shall be designed to prevent incorrect manipulation. It shall not be possible to make the shoulder straps twist while using the device. It shall also be easy to operate and to grasp the shoulder strap positioner. The opening shall be possible in one simple action, but still difficult for the child occupant to manipulate the release mechanism. The device shall be possible to fasten in no more than one action and the force for fastening and release shall not exceed 15 N. It is also defined that the height of the shoulder strap positioner shall not exceed 60 mm. The requirement of the width of the straps in contact with the dummy is the same for all groups of occupants according to this regulation and shall be 25 mm.

To permit satisfactory installation in all vehicles which are i-Size compatible and a correct adjustment of the CRS with all size for which the device is intended, the range of adjustment shall be sufficient. It is also defined that all adjusting devices shall be of the “quick adjuster” type. Within the previous regulation this was partly valid except the adjustment used for the initial installation of the restraint in the vehicle.

1.4.3 United States of America

The legal requirements differ a lot between the ECE and the regulations valid in the US, FMVSS 213. Below follows the most notable parts.

In this regulation it is defined that the upper torso shall be restrained by belts passing over each shoulder of the child or a fixed movable surface (NHTSA, 2012). The lower torso shall be restraint by a lap belt assembly creating an angle between 45 and 90 degree with the seating surface (at the lap belt attachment points) of the child restraint or a fixed movable surface. It is also specified specific for each seating system recommended for children whose masses are more than 10 kg that a crotch restraint shall be connectable to the lap belt or other device used to restrain the lower torso or a fixed or movable surface.

The regulation states that the harness shall provide both upper and lower torso restraint, by terms of belt passing over each shoulder of the child and also by terms of a lap and crotch belt. When the child is placed in the device the harness shall prevent the child from standing upright on the vehicle seat.

The buckle shall not release during a test when a force less than 40 N is applied and shall release when a force of no more than 62 N is applied. The push button application shall be 0.6 square inch (3.87 cm2).

1.4.4 Canada

The regulations in Canada, CMVSS213 (Transport Canada, 2013), are based on the ones valid in the US. Here it is also clearly mentioned that the harness must have a belt passing over each shoulder, which differs from the legislation ECE where this part is not regulated. Another important thing that is different for the US and Canada regulations compared to ECE is the fact that is it stated in ECE that the buckle shall only lock when all parts are engaged.

1.4.5 China

The national standard of the people’s republic of China defines the regulations in a script named Restraining Devices for Child Occupants of Power-Driven Vehicles (State General Administration for Quality Supervision, Inspection and Quarantine of the P.R.C. And Standardization Administration of China, 2012). This regulation is based on the ECE R44/04 regulation.

1.4.6 Australia

The regulations in Australia are based on their own Australian Standards, which differ a lot compared to the rest of the regulations in the world.

The different types of restraint system are divided into eight categories, where Type D is rearward-facing chair with harness for children aged 6 months to 4 years (Standards Australien/Standards New Zealand, 2011). One recommendation which is not mentioned in the other legislations is that the restraint should not weigh more than nine kg.

It is also stated that the crotch strap shall be designed and located so that it does not load the genital region of the child in a frontal impact, which is unique as a regulation in Australia. This may be a result of the fact that children in Australia switch to forward-facing rather early but still uses the CRS with a harness and that this leads to higher forces in this region.

Regarding the usability, it is stated that it shall be possible to do normal wearing adjustments without loosening or removal of the restraint system from the vehicle, with the occupant placed in the chair. By the term normal wearing adjustment it is not included that it should be possible to do adjustment for different age groups and heights. The normal wearing adjustment for the harness shall be accessible to an adult operator when the CRS is installed in a vehicle. The adjustment shall either be visible or positioned legibly and permanently marked adjacent to the adjuster. The adjusting device shall be designed in such way that the mechanism returns to the locked position automatically after a release by the operator.

If a releasable chest cross-strap is included, the strap shall be adjustable to a suitable position and remain releasable in that position. In an emergency situation, a tear-away action with a force of not more than 80 N shall release the cross strap. As an addition to this it is mentioned that it should be close to this limit to reduce the possibility that the child will release the cross-strap.

Similar to the ECE regulations the minimum webbing width shall be 24 mm, for leg or crotch strap. But a difference is that it is stated that the contact area between a TNO P3 dummy and the harness shall be minimum 14 000 mm2. A manual adjusted harness shall not have less than 100 mm of material extending from the adjuster when a TNO P6 dummy placed in the CRS, to provide a grip for adjustment purpose. It is also defined that the harness shall have minimum five points attached to the chair. To adjust the shoulder straps height there shall be minimum of two slots provided, positioned at specific places. The restraining harness shall only have one adjuster.

As within the other regulations, it is stated that the release mechanism shall allow a quick release of the child from the restraint system and the vehicle, without removing the CRS from the vehicle or having to unthread the harness straps.

When a buckle is used as a quick-release device some requirements needs to be fulfilled. The actuation surface shall be not less than 350 mm2 and every width shall not be less than 15 mm. As within the ECE regulations, a single pressing operation shall force the device to disengage. Another difference is that the actuation surface shall be red or orange, compared to ECE where only red is accepted. The accepted colours are defined in AS 2700. It is also defined that the buckle tongues shall not extend above the pelvic area and shall be located on the vertical centreline over the pelvic area of the occupant.

If the quick-release device is not a buckle, the release area shall be of a different colour to the external surfaces and shall have a high level of visual contrast with adjacent surfaces. The word “Press” or “Pull” as appropriate, or arrows (or both) indicating the actuating action shall be legible and durable on the actuation surface.

1.5 Current harness systems RFCRS

The following CRSs are described in this comparison: Britax Multi-Tech II, Maxi-Cosi 2wayPearl/Pearl XP, Axkid Minikid, Klippan Triofix and BeSafe iZi Kid, which can be seen in Figure 1.1.

Figure 1.1 Pictures of CRSs analyzed in the text. (Britax, 2015) (Axonkids, 2015) (HTS BeSafe AS, 2015) (Oy Klippan Ab, 2015) (Dorel Juvenile, 2015)

All the CRSs have a 5-point safety harness and are sold on the European market (Axonkids, 2015) (Britax, 2015) (Dorel Juvenile, 2015) (HTS BeSafe AS, 2015) (Oy Klippan Ab, 2015). Britax Multi-Tech II and Maxi-Cosi 2wayPearl can be installed both forward facing and rearward facing. Maxi-Cosi Pearl Xo is sold on the Scandinavian market and can only be installed rearward facing. Axkid Minikid and BeSafe iZi Kid are only installed rearward facing.

All these CRSs are rather similar and just details separate them from each other. Folksam had a special CRS, called Folksam Macro, which instead were produced with a traditional three-point belt with a lockable retractor, see Figure 1.2. This CRS was available for leasing for Folksam customers during 1992-1997 (Kullgren, 2015). Changes in legal requirements forced Folksam to stop the production of this CRS since the adjustment for fulfilling these requirements were found to be too expensive and not economically justifiable. According to

Kullgren (2015), safety was the main reason for choosing a traditional three-point belt system, just as it is for grown-ups, since the load on the occupant will be higher with a more rigid harness. The feedback Folksam received was that this CRS was easy to handle and no known bigger complaints were known. During development a locking device was implemented to the belt retractor since some parents had an issue with the regular belt retractor though the child was able to pull out more belt strap itself and thereby cause slack in the system.

Figure 1.2 Folksam Macro with a traditional three-point belt system.

1.5.1 Tightening the harness

All harnesses on the market are tightened with a harness adjustment strap positioned between the child's legs. All the harnesses lock automatically into the positioned where the strap is released. All systems tighten the harness at the shoulders.

1.5.2 Loosening the harness

In Britax Multi-Tech II, Axkid Minikid and BeSafe iZi Kid the harness is loosened by pressing a button below the harness adjustment strap at the same time as both shoulder harnesses are pulled forwards, requiring a two-hand move. Klippan loosens the harness by lifting a harness adjuster lever just above the harness adjustment strap while pulling both shoulder harnesses. In Maxi-Cosi 2wayPearl the harness can be loosened by pulling out the harness at the shoulders when the crotch strap and buckle are folded forwards, held in position with a magnet. The Maxi-Cosi can be adjusted with one hand and the child cannot loosen the harness while fastened.

1.5.3 Placing child in seat

The CRSs have different functionalities for keeping the shoulder straps away from the back of the seat when the child is placed in or removed from the seat. BeSafe has magnets in the side support marked in orange and in the shoulder pads. These lock into place holding the shoulder straps to the sides. Maxi-Cosi has springs inside the shoulder pads that hold the shoulder straps out from the back of the seat. It also has a magnet keeping the buckle folded forward. Britax has rubber holders with holes where the belt tongues are placed in order to keep the harness to the sides.

1.5.4 Adjusting head support and shoulder belt height

The adjustment of the head support and shoulder belt height is the area where the CRSs differ the most. Britax is adjusted by pulling the top end of the support leg out from the back of the CRS and lifting a belt adjuster into different slots. Maxi-Cosi is adjusted by pinching the head support, where there is a button on the back of the headrest unlocking the positioning. The head support height is adjusted together with the tightening of the harness in Axkid. It can also be locked in 7 positions for increased comfort for the younger children. In BeSafe the height of the head support and shoulder belts are adjusted by pulling a release handle upwards at the back of the head support while pulling the head support up or down. In Klippan the shoulder belt height is adjusted by pulling out the shoulder harnesses as much as possible. A shoulder belt pipe at the back of the seat is then moved from one mount into another. The head support height is adjusted by pulling a handle at the back of the head support and adjusting the height.

1.5.5 Buckle

According to regulations, see section 1.4, the buckle release area should be red. There are sliding buttons (top-down) and push buttons (in). Buckles with simultaneous latching tongues meet the requirements of ECE R44, ECE R129 and FMVSS213. Buckles with independent latching tongues meet the requirements of FMVSS213.

1.6 Studies in the area of child restraint harnesses

Pettersson and Osvalder (2005) examined the usability of child car seats by observing six parents handling two different child car seats and a 40-minute drive with their children in the car seats. It was found that the misuse increased with the complexity of the child car seat. The parents seldom consulted manuals and did not necessarily follow them when consulted. Pictures on the seats proved more efficient than manuals. Pettersson and Osvalder conclude that the design of the seat adjustments should be instructive and allow adjustments when the child is seated.

The harness design in four convertible CRSs was studied by Rudin-Brown, Kumagai, Angel, Iwasa-Madge & Noy (2003). These were of different restraint configurations: one swing-shield, two 5-point harnesses and one T-shield. Three differently dressed child test dummies were installed by 42 participants, both inside and outside of a vehicle. The installation errors in FFCRSs was significantly greater than rear-facing and they were also perceived to be easier to use by the participants. One reason for this was identified as the seat positioned in the vehicle pushed up against the vehicle seat back, making it difficult to access the harness tightener. Rudin-Brown, Kumagai, Angel, Iwasa-Madge & Noy (2003) also concluded that most of the use error could have been avoided if feedback had been provided to the users about the proper use of the system through indicators or instructions directly on the CRS. They also suggest using the method provided in the report for assessment of CRSs.

1.7 Volvo Compact Child Seat

Volvo Cars has designed an inflatable concept seat, called Compact Child Seat (CCS), see Figure 1.3 (Jakobsson, Broberg, & André, 2013) or Inflatable Child Seat (Volvo Car Group, 2015). RFCRSs are perceived as being bulky, difficult to install and leaving the child with little leg room (Görlitz, 2007). The aim of the concept seat is to address these issues (Jakobsson, Broberg, & André, 2013) as well as providing a CRS that is easy to bring along. The seat is made of a drop-stitch material which retains its shape even when it is inflated. The design is made up of multiple adjoined air chambers and the total weight of the system can be limited to about 5 kg. The system is attached to the vehicles by straps connected to ISOfix anchorages and a strap around the front seat backrest or a support leg (Jakobsson, Broberg, & André, 2013). The harness system for the concept seat has not yet been developed.

Figure 1.3 Compact Child Seat, developed by Volvo Cars. (Volvo Cars)

1.8 Product development

Customer value is defined as the relation between the perceived satisfaction of needs that a product offers and the resources it requires to be used, see Equation 1 (Lindstedt & Burenius, 2006). The resources can be in the form of money, time or effort.

$$Customer\ value = \frac{Satisfaction\ of\ needs}{Use\ of\ resources}$$

Equation 1 Definition of customer value

An increase of the customer value of a product can thus be achieved by increasing the product's satisfaction of needs or reduce its use of resources.

A systematic approach to product development creates more successful innovations (Coffey, Siegel, & Smith, 2009). Coffey, Siegel & Smith (2009) propose the use of a method that encourages creativity while at the same time prevents waste of time and money. Using an iterative process in product development is often required since the interrelationships between the steps are complex and information is often required from a subsequent step (Pahl & Beitz, 1996). They constructed a general process for finding solutions, see Figure 1.4. This process forms the basis for the methods used in this project.

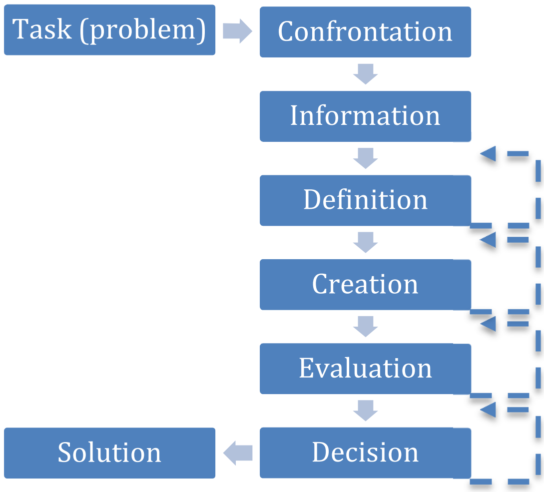

Figure 1.4 General process for finding solutions.

Pugh's concept matrix is an evaluation method to select the best concept by comparing each concept with a selected reference for different criteria (Lindstedt & Burenius, 2006). For each criteria the concept is compared to the reference and the result is indicated in a table. If the concept is better than the reference it is indicated with a plus, if it is poorer than the reference it is indicated with a minus and if it is the same as the reference it is indicated with a zero. To compare the concepts all pluses for a concept are added and the minuses are subtracted. The score gives an indication of which concept is the best (Lindstedt & Burenius, 2006).

Kesselring's method is a relative evaluation matrix where the different criteria are weighted (Johannesson, Persson, & Pettersson, 2013). The concepts are compared according to the different criteria to a combination of the best the market has to offer today. The scores are multiplied with the weight and the total score of the concept is then given by the sum of the products. The highest scores indicate the highest potential.

2 Project definition

Volvo Cars has initiated this master thesis project in order to increase the customer value of the harness in the Volvo Compact Child Seat.

2.1 Objective

The purpose of the project is to investigate and develop a new child restraint harness to increase the customer value of the child seat. The harness should be mountable in the new compact child seat developed by Volvo Cars.

The objective of the project is to identify the customer values of an optimal child restraint harness without affecting the safety level of the child seat as well as propose and evaluate some design concepts.

2.2 Boundaries

The focus of the project will be the harness of the child seat. Other parts of the child seat will not be developed. The harness will not be made for serial production. A crash test is not within the scope of this project. In this study the parents are identified as buyers and users, the voice of the children is not taken into consideration as the parents are supposed to be well aware of the children's level of satisfaction and can speak for them.

3 Methods

Users of CRSs were recruited and questioned about their experiences of the systems. A brainstorming session was held with two groups to generate concepts based on the user experiences. These were evaluated using Pugh and Kesselring matrices and the highest scoring concepts were further developed. Physical prototypes were constructed and evaluated.

3.1 Problem confrontation

The first step in the development process was confronting the problem by investigating what was known and unknown about child restraint harness usability already. Design standards and legislation were studied as well as previous user studies. Existing child seats were studied at NTF - The National Society for Road Safety. NTF provides information to the public about CRS (NTF Väst, 2015) and were seen as a good source of information of issues experienced by users and the CRSs. CRSs belonging to Volvo Cars were investigated by placing, fastening and removing a 1.5 year old child dummy in a Britax Multi-Tech, a Maxi-Cosi Pearl and an Axkid Kidzone.

3.2 Problem definition

The problem was defined in order to understand the problem. The definition includes the range of children that the system should accommodate and the definition set up for the project, see section 2. An investigation of the anthropometry of children that the child seat should accommodate was conducted to find system defining measurements. Boundary conditions for the design of the system set by the Volvo Compact Child Seat (CCS) were defined through contact with the material supplier and the CCS work group and an inspection of the CCS.

3.3 User study

A user study was conducted to examine the user needs and experiences. User experiences and perceived issues were discussed with a focus group consisting of CRS users. The discussion with the focus group formed the basis for a questionnaire that was sent out to a larger number of CRS users to get quantitative results.

3.3.1 Recruiting participants

An email was sent out to employees at Volvo Cars who had signed up for participation in developing new products for the ergonomics department. The recipients were asked if they belonged to any of the following categories:

- Currently have children travelling in a RFCRS
- Have had children travelling in a RFCRS during the last 2 years
- Have great experience from children in RFCRS, e.g. grandchildren

The recipients were also asked about the year of birth of their child/children.

3.3.2 Focus group study

A focus group was created from the responding recipients of the email. Parents who currently had children in RFCRSs were given priority, but the invited group also included grandparents.

A meeting was held where the participants were asked to give their spontaneous reactions to the harness in RFCRSs. A Britax Multi-Tech was presented as well as a Maxi-Cosi Pearl XS and an Axkid Minikid. These were chosen because of their different harness solutions. Britax-Multi-Tech is the system currently used by Volvo Cars. Maxi-Cosi Pearl XS allows loosening of the harness when the buckle is folded forwards and does not have an extra button for this functionality like the others. Axkid Minikid automatically adjusts the height of the head support and harness when the harness is tightened. Information about which CRSs the attendees were familiar with was collected.

To facilitate the discussion different scenarios and possible issues were presented to the group, see Appendix A.

3.3.3 Questionnaire study on behaviour and attitudes

To obtain a more quantitative result, a questionnaire was sent out by e-mail to the recipients of the first email who belonged to any of the stated categories as well as to personal contacts of the authors. MS Word was used to create the questionnaire and it was given to the respondents as a restricted-for-editing file. The questionnaire was based on the findings from the focus group study. In the questionnaire the participants were asked questions about their use of CRSs. Information about which system they had the most experience with was collected as well as the CRS position in the car and the car model.

The respondents were asked to rate their satisfaction with different aspects of the CRS on a scale from 0 to 10. Questions were also asked about how often the respondents were using the CRS and how often the child or respondent did a number of listed actions. To identify what aspect the respondents found the most important when buying a CRS the respondents were asked to rank different aspects. Finally some general “yes or no” questions were asked. After each question the respondents were able to leave additional comments in free text. The whole questionnaire in Swedish can be found in Appendix B.

3.4 Idea generation

Two separate brainstorming sessions for idea generation were held. Within the first group the participants were other master thesis students at Volvo Cars, called novice group. The second group was the supervising team of the master thesis, this group is called experienced group. This was done in order to get ideas from both people who were unexperienced when it comes to CRSs and an experienced group.

Papers, pens and post-its were provided throughout the brainstorming session, which was moderated by the authors. The participants were then asked to brainstorm ideas and the ideas were written down on a board. After 30 minutes a summary of the questionnaire results were shown to the participants and some written comments and further discussion were allowed.

3.4.1 Novice group

Since some of the participants did not previously know each other, they were introduced to each other. The project was briefly presented to the participants and it was highlighted that the objective of the study is to develop a user-friendly child fastening mechanism. The background of using RFCRS's was presented to the group by giving a short talk about the anatomical differences between toddlers and adults. A short video showing a crash test including both a FFCRS and a RFCRS was demonstrated as well as frontal and rear impacts with the CCS.

Three child seats were presented to the participants; a Britax Multi-Tech, a Maxi-Cosi Pearl and an Axkid Minikid. A child dummy was also presented to the participants to facilitate testing of the systems.

3.4.2 Experienced group

Four child seats were demonstrated to the group; a Britax Multi-Tech without support leg and upholstery, a Maxi-Cosi Pearl, an Axkid Minikid without support leg and upholstery and an untampered Axkid Minikid. A child dummy was placed in the upholstered CRS's and was available throughout the session.

3.5 Concept generation

Ideas generated outside of the brainstorming sessions were added to the ideas from the brainstorming sessions. The generated ideas were then grouped by the authors according to the following categories:

- Shoulder positioning mechanism
- Hip positioning mechanism
- System tightening
- Lock mechanism
- Height adjustment mechanism
- Facilitating placement of child
- Hip support
- Others

The first two groups as well as "Others" were defined as being system defining. All possible combinations of the ideas in these categories were generated.

3.6 Concept selection

Different attributes of RFCRS were listed and the ideas were ranked using the listed attributes in a Pugh matrix (Lindstedt & Burenius, 2006), see section 1.8. The concepts with a negative score were eliminated, i.e. the concepts that were found to not increase the customer value compared to the best on the market today. The attributes were further detailed and weighted. A Kesselring matrix was used with the weighted attributes to rank the remaining concepts (Kesselring, 1951). The attributes about the level of safety and user friendliness were weighted as the most important attributes since these are the attributes identified as the most important ones for the concept. The concepts with a total sum of less than 80.0 % of the ideal were eliminated.

The remaining concepts were analysed according to the following categories:

- System tightening
- Lock mechanism
- Height adjustment mechanism
- Facilitating placement of child
- Hip support

The ideas belonging to these categories that were found to be possible solutions to the remaining generated concepts were added to these in a mind map. The attributes were then grouped based on the perceived value they would bring to the CRS in the categories budget, mid-range and luxury.

3.7 Concept description

The remaining concepts were illustrated with sketches and described in detail where each concept were divided into three categories budget, mid-range and luxury. This was done to deepen the understanding of the differences between the concepts and their renditions.

3.8 Final concept evaluation

The remaining concepts were evaluated using Pugh matrices in their budget, mid-range and luxury renditions. A second Pugh matrix was used for each category to ascertain that the result was independent of the chosen reference. The two highest scoring concepts in each category were kept while the rest were eliminated.

3.9 Function analysis of the attributes

To clarify the attributes of the remaining concepts a functionality analysis was done where each previous category of function and the categories budget, mid-range and luxury were reviewed. The different solutions were studied as well as the possibilities of implementation in different CRS's. The attributes were also defined according to the boundary conditions of the CCS.

3.10 Prototype construction

By use of the function analysis and the definition of the concepts two final complete concepts were chosen for further definition, construction and production to visualize the functionality. The prototypes were then demonstrated in two disassembled Britax Max-Way.

3.10.1 Prototype definition

To keep the prototype construction realistic and viable it was decided to continue with the concepts to the next level, but only one version of each concept which was found to be a compromise between the budget, mid-range and luxury versions.

Based on this, the final concepts were defined for further development to make these possible to produce within the time schedule of the project.

3.10.2 Prototype production

To create an illusion of how the prototype will look and function, two simple prototypes were created by use of two Britax Max-Way and some separate belt systems, scissors and a stapler. Sewing was done by hand and using a sewing machine. The separate belt systems and materials for these was donated to the project by Holmbergs Safety System Holding AB. Holmbergs is a world leading complete supplier of restraint systems for child seats and is located in Halmstad, Sweden (Holmbergs Safety System Holding AB, 2015). By use of these simplified models more detailed systems were defined and sketches of the complete system was sent to Holmbergs for production in their factory. The sketches can be seen in Appendix H.

These systems make the holistic view of the harness more equivalent to reality and allows a more detailed analysis and evaluation of the prototypes.

3.11 Prototype evaluation

To investigate whether the prototypes fulfil the stated requirements and if the usability of the harness in the CRSs has been improved an evaluation was made. The participants from Volvo Cars of the first questionnaire were invited to a new focus group session to evaluate the prototypes. The invitation was sent out by email. At the evaluation session the prototypes were displayed as well as an unaltered Britax Multi-Tech II. A crash test dummy the size of a 1.5 year old was available for testing in the different CRSs. A short questionnaire was prepared were the participants were asked questions about how they experienced the prototypes as well as the unaltered Britax Multi-Tech II to enable a comparison between the new prototypes and an unaltered CRS. The questionnaire consisted of nine statements where the participants were asked to rate if they agreed with the statement or not on a scale from 1-10, where 10 represented “totally agree” and 1 represented “do not agree”. All the statements were phrased in such a way that agreeing with them would indicate a positive opinion about the CRS. The participants were also able to add comments about the different prototypes at a dedicated space at the end of each page. The questionnaire in Swedish can be found in Appendix I. The participants were able to physically touch and try the prototypes by using the crash test dummy to investigate the CRSs deeper.

The result from the collected questionnaires was analysed and a comparison between the unaltered CRS and the prototypes was made to investigate if the prototypes increased the customer value of the CRSs or not.

4 Results

The problem was identified by talking to experts and users of CRSs. Based on a questionnaire that was sent out to users of CRSs ideas were generated. Two concepts were defined as solutions to the defined problem. Both concepts had a three-point harness which reduced the number of actions and the complexity of the system compared to the systems on the market today.

4.1 Problem confrontation

Stefan Kaleby at NTF Väst described problems expressed to him by parents (Kaleby, 2015). The problem most frequently asked about by parents is children unbuckling their harness. There are, as defined in section 1.5.5, two different ways of unbuckle the buckle, sliding buttons (top-down) and push buttons (in). Kaleby argues that it is harder for children to press inwards than downwards. Further Kaleby expressed that the high force required to unbuckle the harness could be a problem to people with disabilities, e.g. rheumatics.

Another problem encountered by NTF is that parents do not tighten the hip belts tight enough, especially during the winter when the clothes worn by the children are larger and prone to folds where the hip belts get stuck. The visibility of the harness is also bad since both the harness and the seat are the same colour, often black. This is a problem in bad lighting conditions. Kaleby's impression was that magnets for holding the belt tongues to the sides are used but holes are not.

One other frequently asked question is how to act when the child is about to getting out of the harness by itself. Kaleby speculates that it may be a result of parents who tilt the seats to a greater angle than what is comfortable to the child. Children prefer to sit more upright than adults and Kaleby see this as a reason for children to want to escape.

During testing of the CRSs at Volvo Cars it was found that buckling and unbuckling the harness required pressing hard on the belt tongues and the release button respectively. All the examined seats had buckles where the force on the release button should be directed downwards. The height adjustment mechanism on the Maxi-Cosi 2wayPearl was perceived as practical, requiring just one hand to grab the head support and pull, while Britax Multi-Tech required that the support leg be removed to access the height adjustment mechanism. In Axkid Kidzone the connection between the harness tightening and the height adjustment mechanism was also perceived as practical.

4.2 Problem definition

A problem definition was set up based on the project definition, child anthropometry and the restraints provided by the CCS.

The harness should:

- Be user friendly
- Increase the customer value of the harness compared to today
- Fit a child from the time they are newborn until they reach the age of 4
- Be implementable in the CCS
- Provide a secure fastening of the child in a RFCRS

4.2.1 Child anthropometry

A CRS should fit children for the size they are made for. Pheasant (1996) includes data on British and American children gathered from Tanner, Whitehouse and Takaishi (1966), Martin (1960) and Snyder, et al. (1977). According to Pheasant (1996) the 50th percentile child reaches 105 cm at the age of four while this happens between the intervals 3.0-3.9 years to 4.0-4.9 years according to Steenbekkers (1993), which consists of anthropometric data collected from Dutch children in 1990-1991. The assumption was therefore made that this stature corresponds with the fourth birthday and data up until this age was used. For the lower limit the smallest measurement of the 3rd percentile in the age interval 0-2.9 months (Steenbekkers, 1993) and for the 5th percentile newborn (Pheasant, 1996) was used. For the upper limit the largest measurement of the 97th percentile girl or boy in the interval 4.0-4.9 years (Steenbekkers, 1993) and the 95th percentile boy or girl age 4 (Pheasant, 1996) was used.

The sitting shoulder height was deemed a limiting factor in the design of the CRS. This gives the required distance from the seating surface to the shoulder in the CRS, see Appendix D.

4.2.2 Volvo Compact Child Seat

The material presents new challenges when designing a harness that are not present when using hard plastic. The shape of the fabric is created by gluing a strap around the edges. This process limits the ability to create small holes or sharp edges, the minimum diameter of a hole in the material is 80 mm. The surface of the material cannot be used to take large loads.

4.3 User study

73 Volvo Cars employees with experience of CRSs were recruited by email. Of the recruited employees seven attended a focus group meeting where their experiences of using CRSs were discussed. The main problem identified by the group was that the belt buckle fell into the seat when they placed the child in the seat and thus forced them to find it underneath the child. Features of the seats that are designed to keep the belt straps away from the seat when the child is placed in the seat were not used by the focus group. Based on the information gathered during the focus group meeting a questionnaire was sent out to all the recruited participants. The impressions from the focus group meeting were further highlighted in the responses.

4.3.1 Recruiting participants

The email was sent out to about 500 Volvo Cars employees and 73 of these answered with some kind of experience of CRSs. 34 participants answered that they have children travelling in a RFCRS and 21 participants answered that they have had children travelling in a RFCRS during the last two years, although 16 of these were also included in the first category with current use as well. 45 participants answered that they had great experience from children in RFCRS, 18 of these also belonged to other categories.

4.3.2 Focus group study

An invitation was sent out to 36 of the recruited participants to attend a focus group meeting. Seven of these attended the meeting, of whom three were grandparents and four were parents using CRSs. The attendees at the meeting with the focus group thought that it is more important to be able to easily adjust the harness than the height of the head support and harness. Contrasting colours was not stated as an important factor for finding the harness by the participants since buckling up the child is a ritual they could "do in their sleep". The crotch strap and the buckle are the main areas of concern since the child is seated on it when it is first placed in the chair. The parents then have to find the buckle under the child. The belt tongues falling down into the seating area was not identified as a problem, some of the parents just placed the belt over the side of the CRS to keep the belts out of the seating area. Magnets and hook and loop fasteners are used for keeping the harness away while the child is seated in the chair. The hole for placing the belt tongues that can be found in Britax CRSs did the attendees not use at all. The situation when the child gets out of the harness by itself can be avoided by tightening the harness harder, this is a behaviour seen in the children mainly during longer trips and solved by some of the attendees by changing the position or inclination of the CRS.

Regarding the attachment of the belt tongues before buckling, the attendees were of different opinions. Some of the attendees argued that the puzzle technique can help to keep the belt tongues together while buckling while others argued that the puzzle could be tricky when the CRS is not used on a regular basis. Two more identified problem areas were the release button of the buckle and the button for releasing the length of the belt. The way of tightening the system over the child's hip differs between the attendees, only one of the attendees tightened this part of the belt every time the child was fastened. The tightening of the system was identified as a bigger problem during the winter since the child wears bigger clothes which makes it more difficult to ensure that the system is as tightened as needed. It also differed between the attendees how often the length of the belt was adjusted. Some only adjusted twice a year between a winter and summer setting while others had as a procedure to always completely loosen the belt length while unbuckling and thereby had to tighten the system when fastening the child the next time. Even though the methods differed the group all agreed that it is of higher importance that the tightening of the system is more easily adjusted than the height adjustment of the system since this adjustment is not as frequent as the tightening adjustment. A sensor inside of the buckle which indicates an unbuckled buckle can be useful even in situations when the child is unintentionally left unbuckled.

4.3.3 Questionnaire study on behaviour and attitudes

The questionnaire was sent out to 71 employees at Volvo Cars and 24 persons outside Volvo Cars, and was forwarded by some of them even further. In total, 53 answered questionnaires were received of which 38 were Volvo Cars employees and 15 were from outside Volvo Cars. A summary of the responses can be found in Appendix C.

When analysing the level of general satisfaction of the harness it was found that the majority of the respondents were satisfied or very satisfied, which is in line with the comments from the focus group. The most annoying part was the height adjustment of the harness, which differs from the focus group results but can be explained by how the questions were asked in the focus group discussion.

The majority of the children do not complain about sitting in the RFCRS, but most of the children are giving trouble during fastening, though not on a daily basis but more or less often. Not that many children get out of the harness by themselves but they are significantly more in number than the ones who unbuckle themselves. These results are in line with the findings from the focus group study.

While comparing the different brands of CRS a high number of Britax users use the built-in belt holders and only one out of three BeSafe users uses the magnetic belt holders. This finding differs completely from the focus group results. It is important to mention that the number of both Britax users and BeSafe users is too low to make a true statistical comparison.

The identified issue to unintentionally leave the child unbuckled was not a problem, only three people responded that it happens some time per year. How often the different adjustments were made on the CRS was also in line with the focus group discussion. The length of the belt is adjusted relatively often, even the inclination of the seat is adjusted occasionally. The rest (position of the head support and the height of the shoulder belt) are adjusted less frequently.

When buying a new CRS the highest ranked aspects were identified as test results and recommendations from experts, followed by the size of the chair and how well it fits into the car. The recommendations from retailers and the price were lowest ranked in this comparison. Some respondents also highlighted the possibility to adjust the inclination as well as how it affects the other passengers.

The general questions show that more than half of the respondents thought that the buckle is in the way when placing the child in the seat and that the shoulder belt is not as annoying. This result is completely in line with the findings from the focus group study.

There were also some questions about belt retractors. The majority were positive during fastening but negative to having a belt retractor during the trip. The perceived safety was considered lower with belt retractors with comments about the risk of the child being out of position in a collision. Even though it was shown earlier in the questionnaire that the children who unbuckle themselves are very few the majority of the respondents were positive to a warning of unbuckled buckle.

4.4 Idea generation

The following concepts were generated during the brainstorming sessions with the two different groups.

4.4.1 Novice group

Six participants formed the novice group. In total, 19 ideas were generated during this brainstorming session, see Table 4.1.

Table 4.1 Concepts generated during a brainstorming session in novice group at VCC.

Concepts	***Description***
The door	The harness can be opened like a door that can be closed easily to fasten the child. The door snaps into place.
Liseberg	As at the amusement park Liseberg a slightly more rigid harness can be folded down and attached to a T-construction between the child's legs. In practice this would be a three point solution.
Parachute	A harness is worn by the child prior to entering the child seat, where there is more space to do so. The harness is attached to the seat.

Automatic height adjustment	The height can be automatically adjusted, so there is no need to tighten by hand.
Side button	The button to unlock the buckle is moved to the side of the seat. This way it is not directly in front of the child. This does not exclude that the buckle itself is by the child's stomach.
Magnetic lock	A magnet is used to hold the belt tongues together.
Hip springs	The springs in the Maxi-Cosi Pearl springs mostly upwards. If there were springs that spring outwards it would reduce the risk of placing the child on the belt straps.
Shoulder springs	The springs in the Maxi-Cosi Pearl do not reach down far enough. Padding and springs are extended so the belt straps are better kept from the seat.
Magnetic clothes	The child wears clothes with magnets that attach to the seat.
After inflation	The side structure is blocking when placing the child in the seat from the side. By not inflating the side structure in the inflatable concept seat until the child is in place it would not block as much.
Arm holder	To facilitate when the child is giving trouble the child's arms are attached.
Tree-point belt	Tree-point belt in Y-formation is used. The padding can follow the belt straps into the seat so that the belt tongues are at shoulder height, it is thereby not possible to place the child on them. The buckle itself can also be rolled further in. Padding around the hips can be used to avoid unwanted side adjustments.
Belt retractor	A belt retractor is used during fastening but can be locked when the buckle is buckled or is only allowed to roll the belt in.
Automatic tightening	A motor is used to tighten the harness. Ideally the user can just lock the buckle and the seat tightens the harness automatically.
Hold-out retractors	The spring that retracts the belt is used to hold out the belt from the seat back.
Y-belt	A V-shaped belt is threaded over the child's head and attached to the buckle.
Belt button	A belt button is used to stop the belt tongues from sliding all the way to the seat corner.
Turn the seat	It is difficult to see the opposite side when fastening the child from the side. It would therefore be beneficial to be able to turn the seat to face the user.
Car jacket	The child is wearing a jacket that is attached to the car, where the jacket acts as a car seat, or to the car seat.

4.4.2 Experienced group

Seven participants formed the experienced group. 29 ideas were generated during this brainstorming session, see Table 4.2.

Table 4.2 Concepts generated during a brainstorming session with the experienced group.

Concepts	***Description***
Hip claws	Claws can be folded over the child's hips in order to keep the hip in place, always or during an impact.
Hip air bags	During impact, there are carbonic acid cartridges or similar that inflate bags, a hem in the seat rips open so that there is space for the inflated bag. In this way, the hip is kept in place.
Net	A net is used to catch the child during impact.
Y-belt	A three-point belt where a V-shaped belt is lowered over the head of the child and attached to the belt buckle, which is attached between the child's legs.
No thigh buckle	The buckle is moved away from between the child's thighs. It is a problem that it is buckled against the thighs of the child. For some children the crotch strap can seem short and the buckle is placed very low.
The Dalmatian	Gather the shoulder belt in a load bearing structure, such as a comfort cushion. This allows the belts to come out vertically through the back of the seat and be redirected in the load bearing structure. It can have a built-in head support. The straps are coming out centrally, i.e. will help the harness straps to be close to the neck during an impact. The comfort cushion can help guide during entry and exit. The Dalmatian can be combined with a three-point belt if the loose end is sufficiently stiff.
Vertical hold-out	Use a vertical passing through the back of the seat for holding out the shoulder belts to the sides.
Lap bar	Use a T-shaped lap bar over the hip to keep it in place.
Adjustable hip width	Make it possible to adjust the hip width to keep the child's hips in place.
Magnetic lock	Use magnets to facilitate joining of the buckle tongues. (Takata uses a similar solution)
Fastening jacket	The child gets dressed with a jacket or a vest with a built-in harness outside of the vehicle. It is later attached to the seat.
Impact material	Use a material that changes properties during an impact. During an impact the child is held in place.
Weight lock	Use the weight of the child to attach the child to the seat.
Temperature material	Use a material that reacts to the child's temperature and behaves accordingly. E.g. being pliable when the child is first sensed and attaching the child after a certain time interval.
Positioning half shoulder	A normal three-point belt is used in combination with a shoulder belt that does not go all the way down, this is only used to position the child and avoid that the child moves freely during the ride.
Comfort bump	Use a comfort bump instead of the crotch buckle. This allows for the use of a four-point belt. The comfort bump

	can be slided back and forth and adjusted with the head support.
Comfort retractor	Use a retractor belt that is allowed to spring slightly in each direction during use for higher comfort.
Separate button	Separate the buckle from the release button. The button can be placed on the side, on top or somewhere else.
Lock roof	Have a roof over the release button to prevent the child from seeing the button and crumbs and dirt getting into the lock.
Crotch pull	Pull on the crotch strap with the belt buckle instead of the shoulder straps. By doing this, pulling through the entire seat is avoided.
After adjustment	Adjust the belt after the user has attached the child. Since this adjustment is so small rolling retractors are not needed, it can be adjusted linearly.
ARH	Roll up the straps on a vertical roll that is self-adjusting in height. There used to be a similar system in Volvo's cars.
Hip car belt	Use the car's belt, e.g. from the front passenger seat, to attach the child's hips. The shoulders are attached with a shoulder harness.
Hip retraction	The harness is tightened by pulling on the hip straps, e.g. by using belt retractors.
Universal retraction	Tighten the harness in all attachment points.
Sliding lock	The lock is situated in the seating surface and can be slided back and forth according to the size of the child. In this way, there is no blocking buckle.
Overlapping belts	The belts are placed on top of each other rather than in parallel at the attachment to the belt buckle. By doing this, a narrower buckle is possible.
Fold-out pins	Use pins that are folded out over the child's hips when it is in place. Before that, they are in parallel, take less space and fit between the child's hips.
Spring	Use a spring instead of belt retractors. The length of the belt needed for adjustment is short and a full belt retractor is not necessary. A spring can be used instead.

4.5 Concept generation

The generated ideas from the brainstorming sessions were compared and superfluous ideas, due to overlapping, were removed. Additional ideas generated by the authors were added to the list of generated concepts, see Table 4.3. Since the ideas from the brainstorming sessions did not cover existing solutions these were added to the list.

Table 4.3 Concepts generated outside of the brainstorming sessions.

Concepts	***Description***
Traditional harness	A traditional five-point harness is used.
Backpacker belt	A back packer belt is used in addition to a standard three-point belt.
Criss-cross belt	Two opposing standard three-point belts are used.
Height adjustment plate	A plate is used for the height adjustment of the head support.
Central adjustment strap	A central adjustment strap is used to tighten the harness.
Crotch buckle	The buckle is attached to the crotch strap and kept in position over the child's hips.

All the ideas were grouped according to their functionality, see Appendix E. 25 concepts were generated by combining the ideas from the categories "Shoulder positioning mechanism", "Hip positioning mechanism" and "Others" in all possible ways.

4.6 Concept selection

13 of the 25 concepts were eliminated using a Pugh matrix where the concepts were compared with the state of the art today. The use of a Kesselring matrix reduced the number of concept down to six. The remaining concepts were combined with the remaining ideas from the categories that were not system defining from the brainstorming sessions. These ideas formed attributes for the concepts in the categories budget, mid-range and luxury.

4.6.1 Pugh matrix

The combined concepts were evaluated using a Pugh matrix, see

Table 4.4. The criteria evaluated were safety, user friendliness and estimated comfort for the child. The concepts that were equal to or worse than the state of the art today were eliminated. Concept 21 included magnetic clothes to fasten the child which was not deemed doable and therefore also eliminated.

Table 4.4 Pugh matrix over the generated concepts.

	State of the art	*Concept 1*	*Concept 2*	*Concept 3*	*Concept 4*	*Concept 5*	*Concept 6*	*Concept 7*	*Concept 8*	*Concept 9*	*Concept 10*	*Concept 11*	*Concept 12*	*Concept 13*	*Concept 14*	*Concept 15*	*Concept 16*	*Concept 17*	*Concept 18*	*Concept 19*	*Concept 20*	*Concept 21*	*Concept 22*	*Concept 23*	*Concept 24*	*Concept 25*
Height adjustment		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	+	-	0	0	+
Tighten		-	-	-	0	-	+	-	-	-	+	+	0	0	0	0	0	+	+	0	0	0	0	0	0	0
Buckle		+	0	0	+	0	+	+	0	0	+	+	0	0	0	+	0	+	0	-	-	+	0	0	0	0
Place child in seat		-	0	0	+	+	-	+	0	0	+	-	0	0	0	0	0	+	+	+	+	+	+	+	+	+
Keep child in place		0	0	0	0	+	+	+	+	+	0	+	+	+	+	+	0	-	+	+	+	+	0	0	0	+
Force shoulders	*reference*	0	0	0	0	0	0	0	0	0	0	0	+	+	+	+	0	0	+	0	0	0	0	0	0	0
Force hips		0	0	0	-	0	0	0	0	-	0	0	0	0	0	-	0	0	0	-	-	0	-	0	0	0
Number of actions		0	0	0	+	-	0	0	0	0	+	0	0	0	0	+	0	+	+	-	-	+	+	0	+	+
Estimated safety		0	0	0	-	-	0	0	-	-	0	+	+	+	+	0	0	0	+	0	0	-	-	0	0	0
Risk of misuse		-	-	-	+	-	-	-	-	0	+	0	0	0	0	0	0	0	+	-	-	-	0	0	0	0
Estimated comfort		0	0	0	0	-	-	-	0	0	+	0	+	+	+	+	0	+	0	0	0	0	0	0	0	0
SUM:		-2	-2	-2	**2**	-3	0	0	-2	-2	**6**	**3**	**4**	**4**	**4**	**4**	0	**4**	**7**	-3	-2	**3**	-1	**1**	**2**	**4**
Doable?																						N				
Keep?		N	N	N	**Y**	N	N	N	N	N	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	N	**Y**	**Y**	N	N	N	N	**Y**	**Y**	**Y**

4.6.2 Kesselring matrix

The attributes of the CRSs were weighted and the remaining concepts were evaluated using a Kesselring matrix, see Table 4.5. The safety related categories were attributed the highest weight since they were ranked the highest by the users in the questionnaire. The concepts were evaluated according to the different categories and a score indicating closeness to the ideal was assigned for each category.

Table 4.5 Kesselring matrix

	Weight	***Ideal***	***Concept 4***	***Concept 10***	***Concept 11***	***Concept 12***	***Concept 13***	***Concept 14***	***Concept 15***	***Concept 17***	***Concept 18***	***Concept 23***	***Concept 24***	***Concept 25***
Buckle	4	5	3	4	3	3	2	2	3	4	3	1	3	3
Place child in seat	4	5	3	4	3	3	3	3	3	4	4	5	5	5
Keep child in place	4	5	3	4	5	5	5	5	4	4	5	5	5	5
Force shoulders	5	5	5	4	5	5	5	5	5	5	5	5	5	5
Force hips	5	5	2	5	5	5	5	5	2	5	5	5	5	5
Number of actions	4	5	4	4	3	3	3	3	4	4	3	2	3	3
Estimated safety	5	5	3	4	5	5	5	5	4	5	5	4	4	4
Estimated comfort	4	5	4	5	4	4	4	4	4	5	5	4	4	3
Ready for production	2	5	5	4	3	2	4	2	4	4	4	1	1	1
Risk of misuse	5	5	4	4	3	4	4	2	4	4	4	3	3	3
SUM:		*210*	*148*	*177*	*168*	*171*	*171*	*157*	*155*	*187*	*183*	*155*	*167*	*163*

The concepts with a total sum of less than 80.0 % (168) were eliminated. Concepts 10, 11, 12, 13, 17 and 18 were kept for further development and investigation.

4.6.3 Attributes

The ideas belonging to the categories system tightening, lock mechanism, height adjustment mechanism, facilitating placement of child and hip support that were found to be possible solutions to the remaining generated concepts were added to these in a mind map, see Appendix F. The attributes were then grouped based on the perceived value they would bring to the CRSs in the categories budget, mid-range and luxury, which can be seen in Appendix G.

4.7 Concept description

The ideas behind the different features of the remaining concepts were described as well as their attributes in the categories budget, mid-range and luxury.

4.7.1 Concept 10

Concept 10 has a positioning half shoulder, a three-point safety belt and a comfort bump. The idea is that the three-point belt facilitates fastening of the child by allowing fastening with one belt strap. Around the child's shoulders is a comfortable neck support cushion. The neck support cushion is used to guide the upper part of the three-point belt over the child's shoulder. Since children are prone to be out of position the shoulder that is not secured with the three-point safety belt is kept comfortably in place by the other end of the neck support cushion. When the child is not placed in the chair the ends of the neck support cushion are directed in an upwards and outwards direction so as to not be in the way when a child is placed in the seat. This gives the seat an inviting impression. To avoid submarining a bump in the CRS seating surface is placed between the child's legs on the seating surface. It is assumed that the hip belt keeps the child's hips in place vertically and laterally and the comfort bump acts by guiding the hip to the correct position longitudinally during normal use and keeps it there in case of an impact.

Figure 4.1 Concept 10 with a positioning half shoulder, a three-point safety belt and a comfort bump.

4.7.1.1 Budget

In its budget rendition, concept 10 has a central adjustment strap to tighten the system, a buckle placed on the side of the seating area and a height adjustment plate. A belt button is used to avoid that the belt tongue slides down the belt into the corner between the seating area and the side structure.

4.7.1.2 Mid-range

In its mid-range rendition concept 10 is equipped with a belt retractor, a height adjuster and hip and shoulder springs. The springs keep the neck support cushion and the hip belt out of the seat when the child is placed in the seat.

4.7.1.3 Luxury

In its luxury rendition concept 10 has a comfort retractor, the height is automatically adjusted by the system and hold-out retractors. A comfort retractor means that the child is allowed a small interval of movement to increase comfort while still keeping the child in a safe position.

4.7.2 Concept 11

Concept 11 has a Y-belt, a neck support cushion (Dalmatian) and a lap bar. The idea is that the Y-belt allows for easy fastening of the child since it lacks redirection of the belt in the belt buckle as in the five-point belt systems on the market today. A neck support cushion is used to guide the shoulder belts to a good position over the child's shoulders, close to the neck. The neck support cushion is not used as a load bearing structure but acts solely to guide the belts and provide comfort for the child. When the child is not placed in the seat the ends of the neck support cushion are directed in an upwards and outwards direction so as to not be in the way when a child is placed in the seat. This gives the seat an inviting impression. To keep the child's hips in place and to take force in case of an impact this concept uses a lap bar. The lap bar is secured to the CRS between the child's legs and has a structure that distributes the force over the child's hips.

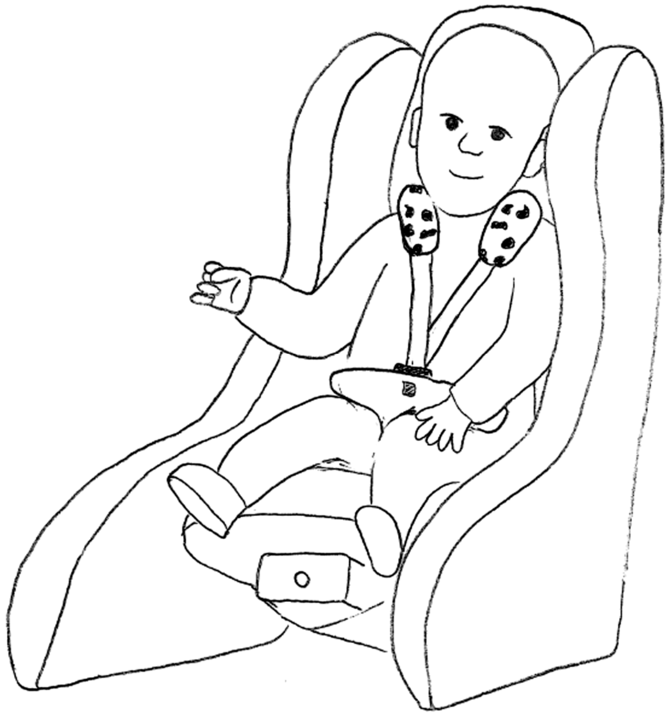

Figure 4.2 Concept 11 with a Y-belt, a neck support cushion (Dalmatian) and a lap bar.

4.7.2.1 Budget

In its budget rendition concept 11 has a central adjustment strap to tighten the system and a height adjustment plate.

4.7.2.2 Mid-range

In its mid-range rendition concept 11 is equipped with a belt retractor attached to both belts, a height adjuster and shoulder springs. The springs keep the neck support cushion out of the seat when the child is placed in the seat. A magnet is used to keep the belt tongues together during latching if there are dual tongues.

4.7.2.3 Luxury

In its luxury rendition concept 11 has a comfort retractor, after adjustment and automatic tightening. The height is adjusted automatically by the system. A comfort retractor means that the child is allowed a small interval of movement to increase comfort while still keeping the child in a safe position. The automatic tightening means that the system itself tightens the belt around the child's body.

4.7.3 Concept 12

Concept 12 has a five-point belt, a neck support cushion (Dalmatian) and a crotch buckle. The idea is that the neck support cushion guides the shoulder belts to a good position over the child's shoulders, close to the neck. The neck support cushion is not used as a load bearing structure but acts solely to guide the belts and provide comfort for the child. The five-point belt is already used in most RFCRSs on the market today and is therefore very close to production.

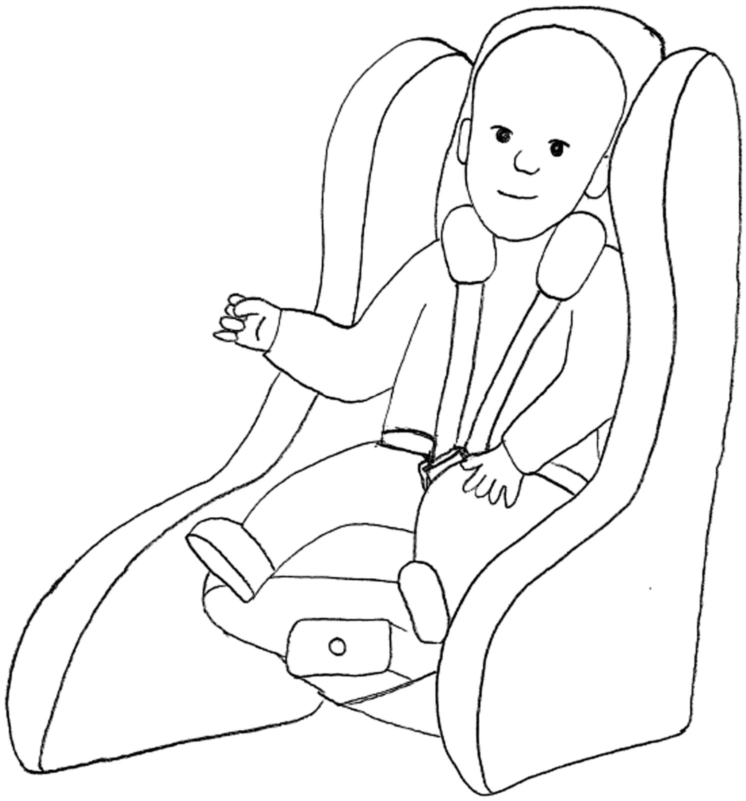

Figure 4.3 Concept 12 with a five-point belt, a neck support cushion (Dalmatian) and a crotch buckle.

4.7.3.1 Budget

In its budget rendition concept 12 has a central adjustment strap to tighten the system and a height adjustment plate. Belt buttons are used to avoid that the belt tongues slide down the belts into the corners between the seating area and the side structures. The lock itself has a roof to avoid that crumbs and dirt find their way into the lock mechanism and provides a visual barrier for the child to the release button. The belts are overlapping going into the belt buckle to allow for a narrower design.

4.7.3.2 Mid-range

In its mid-range rendition concept 12 is equipped with a belt retractor attached to both belts at the hips, a height adjuster and shoulder springs. The springs keep the neck support cushion out of the seat when the child is placed in the seat. A magnet is used to keep the belt tongues together during latching if there are dual tongues. The buckle can be slided back and forth between the child's legs to better fit children of different sizes.

4.7.3.3 Luxury

In its luxury rendition concept 12 has a comfort retractor, after adjustment and automatic tightening. The height is adjusted automatically by the system. A comfort retractor means that the child is allowed a small interval of movement to increase comfort while still keeping the child in a safe position. The automatic tightening means that the system itself tightens the belt around the child's body.

4.7.4 Concept 13

Concept 13 has a Y-belt with a neck support cushion (Dalmatian) and a crotch buckle. The idea is that the Y-belt allows for easy fastening of the child since it lacks redirection of the belts in the belt buckle as in the five-point belt systems on the market today. A neck support cushion is used to guide the shoulder belts to a good position over the child's shoulders, close to the neck. The neck support cushion is not used as a load bearing structure but acts solely to guide the belts and provide comfort for the child. When the child is not placed in the seat the ends of the neck support cushion are directed in an upwards and outwards direction so as to not be in the way when a child is placed in the seat. This gives the seat an inviting impression.

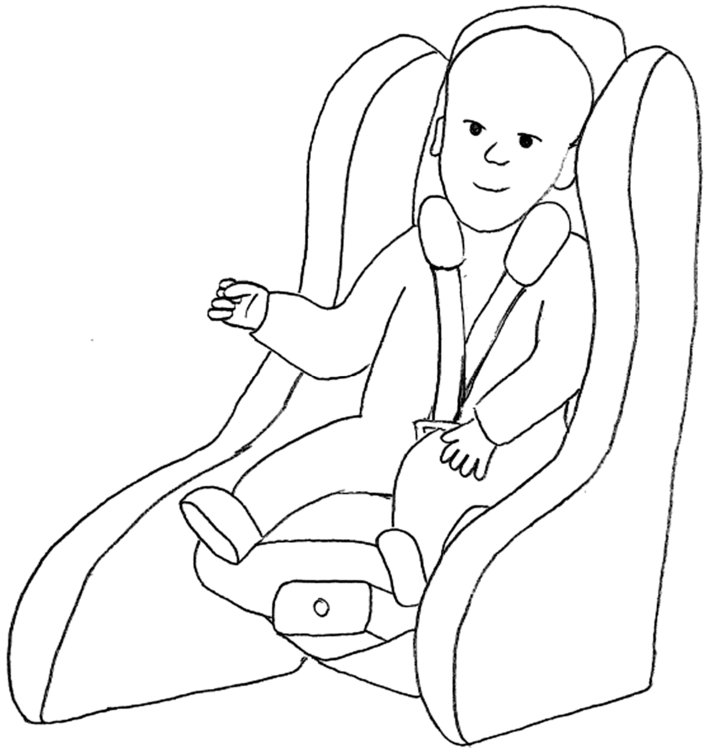

Figure 4.4 Concept 13 with a Y-belt with a neck support cushion (Dalmatian) and a crotch buckle.

4.7.4.1 Budget

In its budget rendition concept 13 has a central adjustment strap to tighten the system and a height adjustment plate. Springs are used to help tighten the system. The lock has a roof to avoid that crumbs and dirt find their way into the lock mechanism and provides a visual barrier for the child to the release button. The belts are overlapping going into the belt buckle to allow for a narrower design. The hip is kept in place longitudinally by using an insert.

4.7.4.2 Mid-range

In its mid-range rendition concept 13 is equipped with a belt retractor attached to both belts, a height adjuster and hip and shoulder springs. The springs keep the neck support cushion and the belt buckle out of the seat when the child is placed in the seat. A magnet is used to keep the belt tongues together during latching in case there are dual tongues. The buckle can be slided back and forth between the child's legs to better fit children of different sizes. The hip is kept in place by allowing the width to be adjusted by the user.

4.7.4.3 Luxury

In its luxury rendition concept 13 has a comfort retractor, after adjustment and automatic tightening. The height is adjusted automatically by the system. A comfort retractor means that the child is allowed a small interval of movement to increase comfort while still keeping the child in a safe position. The automatic tightening means that the system itself tightens the belt around the child's body. After inflation is used to inflate the seat around the child's hips and thereby keeping them in place.

4.7.5 Concept 17

Concept 17 has a backpack belt and a comfort bump. The idea is that a three-point safety belt facilitates fastening of the child by allowing fastening with one belt strap. An extra shoulder belt keeps the other shoulder in place and stops the child from getting out of position. To avoid submarining a bump in the CRS seating surface is placed between the child's legs. It is assumed that the hip belt keeps the child's hips in place vertically and laterally and the comfort bump acts by guiding the hip to the correct position longitudinally during normal use and keeps it there in case of an impact.

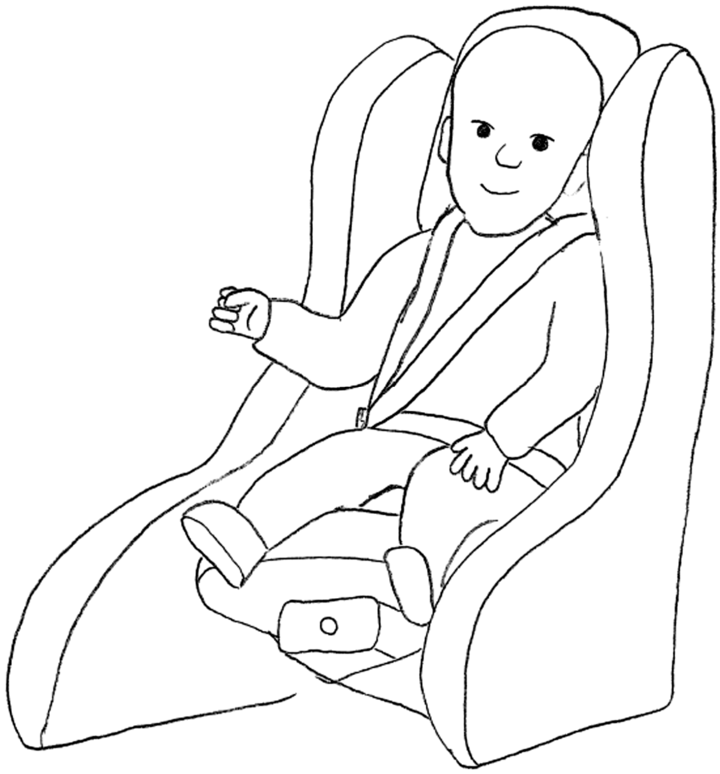

Figure 4.5 Concept 17 with a backpack belt and a comfort bump.

4.7.5.1 Budget

In its budget rendition concept 17 has a central adjustment strap to tighten the system and a height adjustment plate. A belt button is used to avoid that the belt tongue slides down the belt into the corner between the seating area and the side structure. The buckle is placed on the side.

4.7.5.2 Mid-range

In its mid-range rendition concept 17 is equipped with belt retractors attached to both belts and a height adjuster.

4.7.5.3 Luxury

In its luxury rendition concept 17 has a comfort retractor and after adjustment. The height is adjusted automatically by the system. A comfort retractor means that the child is allowed a small interval of movement to increase comfort while still keeping the child in a safe position.

4.7.6 Concept 18

Concept 18 has a criss-cross belt and a comfort bump. The idea is to take advantage of the easy fastening provided by the three-point belt combined with an extra diagonal shoulder belt to keep the child in place. The secondary belt does not necessarily need to be a three-point belt. To avoid submarining a bump in the CRS seating surface is placed between the child's legs. It is assumed that the hip belt keeps the child's hips in place vertically and laterally and the comfort bump acts by guiding the hip to the correct position longitudinally during normal use and keeps it there in case of an impact.

Figure 4.6 Concept 18 with a criss-cross belt and a comfort bump.

4.7.6.1 Budget

In its budget rendition concept 18 has a central adjustment strap to tighten the system and a height adjustment plate. Belt buttons are used to avoid that the belt tongues slide down the belts into the corners between the seating area and the side structures. The buckle is placed on the side.

4.7.6.2 Mid-range

In its mid-range rendition concept 18 is equipped with a belt retractor attached to both belts, a height adjuster and shoulder springs. The belt release button is placed separately from the buckles to allow for simultaneous release of both belts.

4.7.6.3 Luxury

In its luxury rendition concept 18 has a comfort retractor, automatic height adjustment and automatic tightening. The height is adjusted automatically by the system. A comfort retractor means that the child is allowed a small interval of movement to increase comfort while still keeping the child in a safe position. The height is adjusted automatically by the system. The automatic tightening means that the system itself tightens the belt around the child's body.

4.8 Final concept evaluation

A final concept evaluation was made to reduce the number of remaining concepts before prototype construction. The six selected concepts were evaluated using Pugh matrices in the categories budget, mid-range and luxury.

4.8.1 Selection of budget concepts

Concept 10 was used as a reference in the first Pugh matrix, see Table 4.6. It revealed two concepts, 13 and 18, to be equal to or better than the reference.

Table 4.6 First Pugh matrix of budget concepts.

Budget	*Concept 10*	*Concept 11*	*Concept 12*	*Concept 13*	*Concept 17*	*Concept 18*
Height adjustment	*reference*	0	0	0	0	0
Tighten		-	-	+	-	0
Release belt straps		-	-	0	-	0
Buckle		-	-	0	-	-
Place child in seat		0	-	-	0	+
Keep child in place		+	+	0	0	+
Number of actions		-	-	0	-	-
Ready for production		0	+	+	-	0
Misuse		0	0	0	0	0
SUM		*-3*	*-3*	*1*	*-5*	*0*

The reference and the two concepts that were equal to or better than the reference were further investigated in a second Pugh matrix, see Table 4.7. In order to ascertain that the result was independent of the used reference concept 13, which came out as the winner in the first Pugh matrix, was used as reference. In the second Pugh matrix concept 10 was graded better than the reference while concept 18 was worse. Since concept 10 and 13 had been close in both matrices it was decided to keep both.

Table 4.7 Second Pugh matrix of budget concepts.

Budget	Concept 13	Concept 10	Concept 18
Height adjustment	reference	0	0
Tighten		-	-
Release belt straps		0	0
Buckle		+	-
Place child in seat		+	+
Keep child in place		0	+
Number of actions		0	-
Ready for production		-	-
Misuse		+	0
SUM		1	-2

4.8.2 Selection of mid-range concepts

As for the budget rendition a comparison between the mid-range concepts were evaluated using a Pugh matrix, see Table 4.8, where concept 10 was used as reference. None of the other concepts was shown as better than the reference. Concept 18's score was equal to the reference and concept 13 was slightly negative. Concept 11 had a high negative value and was therefore not included in a second Pugh matrix.

Table 4.8 First Pugh matrix of mid-range concepts.

Mid-range	Concept 10	Concept 11	Concept 12	Concept 13	Concept 17	Concept 18
Height adjustment	reference	0	0	0	0	0
Tighten		-	0	0	0	0
Release belt straps		0	0	0	0	0
Buckle		-	-	-	-	-
Place child in seat		-	-	0	0	+
Keep child in place		+	+	0	0	+
Number of actions		-	-	0	-	-
Ready for production		-	-	+	-	0
Misuse		-	0	-	0	0
SUM		-5	-3	-1	-3	0

In a second Pugh matrix, Table 4.9, concept 18 was used as a reference. It showed that all the other remaining concepts were better than the reference. Concepts 10 and 13 had the highest scores and it was therefore decided to keep these.

Table 4.9 Second Pugh matrix of mid-range concepts.

Mid-range	Concept 18	Concept 12	Concept 13	Concept 17	Concept 10
Height adjustment	reference	0	0	0	0
Tighten		0	+	0	0
Release belt straps		0	0	0	0
Buckle		+	+	+	+
Place child in seat		-	0	0	0
Keep child in place		0	-	-	0
Number of actions		0	+	+	+
Ready for production		+	+	0	+
Misuse		0	+	0	0
SUM		1	4	1	3

4.8.3 Selection of luxury concepts

The luxury versions were also evaluated using a Pugh matrix, see Table 4.10, with concept 10 used as the reference. All concept apart from the worst, concept 11, were evaluated further.

Table 4.10 First Pugh matrix of luxury concepts.

Luxury	Concept 10	Concept 11	Concept 12	Concept 13	Concept 17	Concept 18
Height adjustment	reference	0	0	0	0	0
Tighten		0	0	0	0	0
Release belt straps		0	0	0	0	0
Buckle		-	-	-	-	-
Place child in seat		-	-	0	0	+
Keep child in place		+	+	+	0	+
Number of actions		-	-	0	-	-
Ready for production		-	0	-	-	0
Misuse		-	0	0	0	0
SUM		-4	-2	-1	-3	0

A second Pugh matrix was used where concept 18 was used as reference, see Table 4.11. Concepts 10 and 13 had the highest scores and it was decided to keep these.

Table 4.11 Second Pugh matrix of luxury concepts.

Luxury	Concept 18	Concept 12	Concept 13	Concept 17	Concept 10
Height adjustment	r	0	0	0	0

Tighten		0	+	0	0
Release belt straps		0	0	0	0
Buckle		+	+	+	+
Place child in seat		-	0	0	0
Keep child in place		0	-	-	0
Number of actions		0	+	+	+
Ready for production		+	+	0	+
Misuse		0	+	0	0
SUM		*1*	*4*	*1*	*3*

4.8.4 Summary of chosen concepts

It was decided to develop two main concepts, 10 and 13, with three different renditions for each concept to allow for a budget, a mid-range and a luxury version.

4.9 Function analysis of the attributes

The functionality of the different attributes belonging to the concepts was evaluated for concept 10 and 13.

4.9.1 Height adjustment analysis

For both concepts the budget versions consist of a height adjustment plate. The height adjustment can then be done by moving a positioner between different slots, see Figure 4.7. This is identified to be a simple solution for CRSs made in hard materials. However, in an inflatable structure the height position may not be kept between inflations since there is a high risk that parts will become unattached. Another way of solving this mechanism, as done by Axkid, is by use of retractors which more automatically adjust the height of the harness, without the use of slots and pins. Although Axkid uses two retractors, it should be possible to use only one centrally fitted retractor. The retractor must have a lock function to enable that the height position remains between uses.

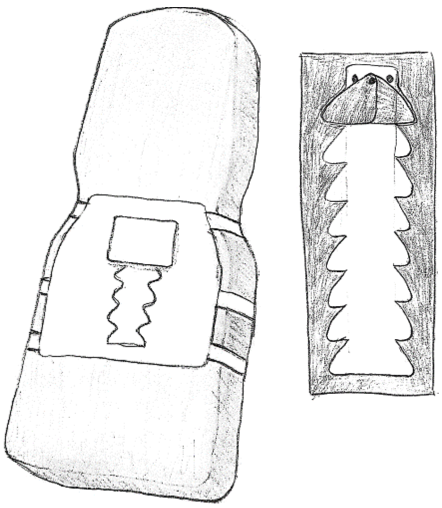

Figure 4.7 Possible principle for a height adjustment plate.

For the mid-range concepts a height adjuster is defined as the height adjustment mechanism. This can be placed in a hole in the seat back or on some height adjustment plate and the principle of this solution can be based on the height adjusters used in traditional front seat belts. The height adjusters can be angled to allow an adjustment of the seat harness for smaller or larger children. It is important to ensure that the solution will not be bulky when installed in the CRS. If the belts are coming out from the back on the sides the height adjuster can be installed on the side structure, see Figure 4.8.

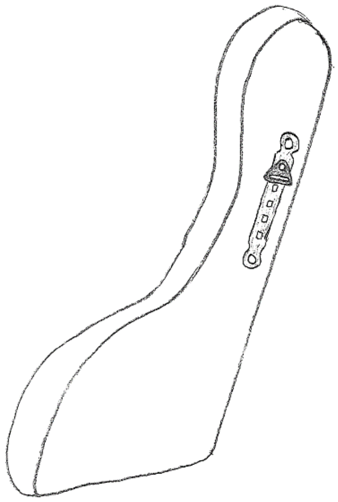

Figure 4.8 Height adjuster installed on the side structure.

Another alternative is that a separate strap is used for the height adjustment with a central adjuster on the back of the seat. The system will then be tightened through the Dalmatian on the back of the seat, or routed to the front. Another possible solution can be a crossing clip that consists of a clip that holds the two shoulder belt straps together at a desired height at the intersection of a hole in the seat back, see Figure 4.9. The straps could be attached at shoulder level and the system would therefore need to be tightened at the hips or by pulling of the shoulder straps. The neck cushion is used as the locking mechanism that is found in the central adjuster in other seats. A spring can be used to stop the Dalmatian from moving upwards using a crossing clip solution.

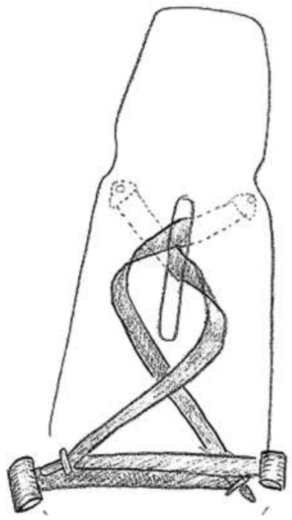

Figure 4.9 A clip is placed where the belt straps cross in a hole in the seat back. The neck support can be attached to the clip and positioned in this way.

Automatic height adjustment would be the ideal solution when it comes to user friendliness and is identified to be the luxury solution for the concepts. The user would only need to place the child in the seat and the seat would adjust the height automatically. However, the technology to do so is not there today or is too bulky to be implemented in an inflatable structure. It is also believed that the increased cost would not be motivated for the end user.

4.9.2 System tightening analysis

In the budget versions the systems can be tightened with a central adjustment strap, which is found to be the easiest and the most affordable solution. Pulling the strap should be done in the front between the child's legs where there is enough space for the user. For implementation in the CCS a channel for the central adjustment strap should be mandatory since pulling a strap over the surface will cause excessive friction on the drop stitch fabric, which will cause too high levels of wear on the surface.

The budget solutions with central adjustment straps are not suited for the CCS since these would also require a release button for the central adjustment strap that is hard to fit into the CCS. For other seats where a central adjustment strap is implemented it would be desirable to use a solution similar to Maxi-Cosi Pearl, where releasing the belt buckle causes the buckle to fall forward and automatically release the central adjustment strap.

Belt retractors are used in the mid-range and luxury versions. These are required by regulations to be emergency locked or automatically locked. According to the questionnaire, users do not feel safe if the child can pull out more belt. The belt retractors should therefore have a lock function to limit how much the straps can be pulled out and thereby work like an automatically locked retractor. In the luxury version a comfort retractor is used where the child is allowed a small interval of movement. The advantage is that the retractor function can be used during fastening but it acts as a normal CRS harness when the child is fastened.

The luxury versions have an automatic after adjustment that helps the user to tighten the system by slightly tightening the system after the user has stopped tightening. This pull should be gentle to not be uncomfortable for the child and sense the tension in the belt straps. This way the system is only tightened when needed and only to a predefined tension.

4.9.3 Lock mechanism analysis

The concept with a positioning half shoulder requires a separate release button since the space available between the child's hip and the side of the seat will be limited. It would also be too easy for the child to unbuckle itself, even unintentionally. The release button should be built-in in such a way that the child's hip is not injured in a side collision.

It is important to keep a roof over the lock mechanism to protect the locking mechanism for crumbs and dirt. The belt button can only be applied to concept 10, since there is a risk of the belt tongue sliding down into the corner between the side of the seat and the seating surface.

In concept 13 the shoulder belt straps can be placed overlapping going into the belt buckle, to achieve the part between the child's legs to be narrower. If the shoulder belt straps are not attached to each other magnetism can be used to make the belt tongues join. This way they are already joined when the user buckles the belt and multiple simultaneous tasks are avoided.

In order to get a closer fit and better adjustment possibilities a sliding lock can be used for the crotch buckle. A sliding lock cannot be used in the CCS since grooves for placement of such a function is not permitted.

4.9.4 Place child in seat analysis

A magnetic belt tongue can be used to create a magnetic bond between belt tongue and seat side. By this the belt is not in the way when the child is placed in the seat.

The side structures of the neck support cushion (Dalmatian or positioning half shoulder) should be lifted in an upwards and outwards direction so as to not be in the way when a child is placed in the seat to give it an inviting impression. Springs or rubber bands can be used to lift the side structures of the neck support cushion up and out in a welcoming position. Connected hinges can be used to make the neck support cushion flex in the desired angle relative to each other and in relation to the child. This will facilitate the placement of the child in the seat since the shoulder belt straps will be held out of the seat.

The crotch buckle should fall forward when the harness is not buckled, this can be achieved by using a spring, magnet or rubber band to avoid placing the child on the belt buckle when placing the child in the seat.

4.9.5 Hip adjustment analysis

To ensure that the child cannot move laterally in concept 13 an insert is used in the budget version to position the hips. In the inflatable seat the hip adjustment can be achieved by inflating a smaller air pocket around the child’s hips and thereby creating an adjustable size of the hip support. In a hard structure seat the hip adjustment can be included in the design of the hard structure, such as in Britax Multi-Tech.

In the concepts that do not have a crotch buckle a comfort bump in the seating area between the child’s legs prevents submarining. This anti-submarining device is kept stiff enough that it prevents the child from submarining but is still comfortable between the child’s legs.

4.10 Prototype construction

Based on the functionality analysis and discussions a selection of two final concepts were chosen for further development and physical prototypes were constructed.

4.10.1 Prototype definition

Two different complete systems were defined based on the previous findings. Due to limited resources and the level of complexity of the height adjustment mechanism it was decided that the height adjustment mechanism should not be visualized in the physical prototype. One way to illustrate this kind of solution is to have the shoulder belt strap passing over a shaft which is attached to a spring system. The springs in the system aims to force the shaft in an upward position which will keep the shoulder straps and neck support cushion in the highest position when the system is unbuckled. When the user buckles the child the straps will be pulled downwards towards the buckle. This motion should be enough to position the shoulder straps and the neck support cushion at the wanted level in relation to the height of the shoulder of the specific child. By this it is important to ensure that the spring force and the force on the belt retractor collaborates and are calibrated to meet the requirements of the system. A schematic sketch of this system can be seen in Figure 4.10.

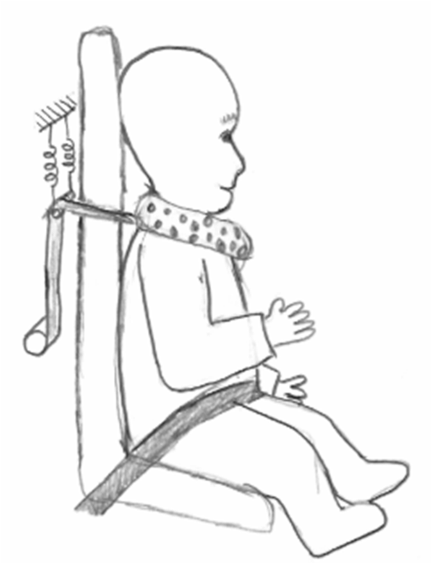

Figure 4.10 Schematic sketch of a possible height adjustment system.

Both of the two remaining concepts include a neck support cushion which has several functions. The cushion should allow a narrow fit between the neck of the child and the shoulder strap to minimize slack in the belt system. It should also be possible to guide the shoulder straps through the cushion, which can allow a vertical entry of the strap from the back of the chair to the front of the chair. It is important to limit the friction between the belt strap and the cushion to ensure that the tightening of the system is as easy as possible. In the concept with a positioning half shoulder this cushion is central since this is the mechanism that keeps the shoulder in the right position.

To ensure that the feeling and experience of the prototype is as good and reliable as possible some modifications were made, which are not part of the real concept. However, to produce a prototype with the real components was not possible due to limited resources. No CRS manufacturer use belt retractors today as a part of the harness, which limited the possibility of applying a belt retractor customised for CRSs into the prototype since there were no belt retractors for CRSs on the market at the moment of production. This was solved by use of a traditional belt retractor, produced for use in a passenger car, to illustrate the feeling of a belt retractor system in the CRS.

4.10.2 Prototype production

Two crash tested Britax Max-Way were prepared for implementation of the harness prototypes.

Two neck support cushions were sewn in a Dalmatian patterned fabric. The size of the cushion was made to fit children of approximately 2-3 years of age (Noelle, 2012) and then filled with hobby foam to make it comfortable and cosy. To ensure that the friction between the belt strap and the material inside the cushion was as low as possible, a part of a plastic bag was glued onto the hobby foam to create a channel with low friction for the belt strap.

The neck support cushions were sewn by hand to the fabric covering the neck support in Britax Max-Way.

On both prototypes, the ends of two 20 cm long elastic band was sewn to the crotch strap and in the near area of the chair for keeping the belt buckle in a forward position when it is not buckled.

4.10.2.1 Concept 10

To prepare for concept 10 the complete harness and belt tightening system was removed from one of the Britax Max-Way. A small plastic tube with a steel wire inside was placed along the outer edge of the neck support cushion. This was done to increase the stiffness of the neck support cushion and to make the link between the left and right sides of the cushion stronger. This enables that the unsupported side, without belt strap, is lifted and lowered in synchronization with the side with a belt strap.

A sketch of the belt arrangement was sent to Holmbergs for production, see Figure H.1. A customized belt tongue from Holmbergs that enabled fastening of one belt tongue into a buckle made for two belt tongues was printed in plastic.

A belt retractor made for implementation in a car was screwed to the hard plastic below the seating area. Since the screws penetrated the plastic into the seating surface they were covered with a piece of extruded polystyrene foam. The belt buckle was fastened to the metal bracket at the side of the seating surface, originally intended for hip belt fastening. The belt strap was then routed under the seat and up through the bracket on the other side. The belt strap was then routed through the belt tongue and the neck support cushion channel.

The belt strap from Holmbergs was stapled onto the belt strap on the belt retractor and the excess belt strap was cut off. The spring in the belt retractor was winded up to increase the pulling force exerted by the retractor to overcome the friction in the system.

A comfort bump was added by placing two layers of hobby foam of dimension 7 x 11 cm on top of each other behind the original position of the belt release button and taping them into position. A picture of the prototype can be seen in Figure 4.11.

Figure 4.11 Prototype of concept 10 with a positioning half shoulder, a three-point safety belt and a comfort bump.

4.10.2.2 Concept 13

In the other Britax Max-Way the harness was removed but the system tightening, a central adjustment strap, was kept. A sketch of the belt arrangement was sent to Holmbergs for production, see Figure H.2. The belt straps were pulled through the neck support cushion and connected to the central adjustment strap using the existing spreader bar. The crotch buckle was attached in the original position by use of a metal bracket. A picture of the prototype can be seen in Figure 4.12.

Figure 4.12 Prototype of concept 13 with Y-belt with a neck support cushion (Dalmatian) and a crotch buckle.

4.11 Prototype evaluation

There were nine participants at the evaluation session who all answered the questionnaire with their opinions and experiences regarding the three displayed CRSs. The first harness system was the positioning half shoulder, a three-point safety belt and a comfort bump, the second harness system was the unaltered Britax Multi-Tech II and the last one was the Y-belt with a neck support cushion (Dalmatian). A summary of the responses can be found in Appendix J.

Generally, the participants were most satisfied with the third prototype. Here no one had a really low answer and the majority answered above the mean of the scale. Many participants were positive to the mechanism which keeps the buckle out of the seating area and pointed out that the principle for keeping the shoulder belt straps away from the seating area was good but needed some modification to become a more user friendly system. Some participants were unsure about the safety level of the harness and mentioned that it does not seem as safe as a five-point harness. Overall the participants found this prototype to be the best solution and commented that it was easy to handle.

The second harness was presented as a reference system. Here the participants were rather unsatisfied, but not extremely unsatisfied. The parts with low scores were about the innovative feeling of the harness and if the harness had a premium feeling. The lowest ones were regarding the placement of the child in the seat and the fact that the harness will be in the seating area during placement. On the other hand most of the participants agreed with the statement that they feel confident that the child is secured in the chair and that the harness looks safe. However, there was a comment about the robustness of the harness where the participant mentioned that it seems easy for the children to get out of the harness by themselves. A comment stated the fact that even though the harness is classic and reliable, the harness is a bit boring and unpleasant.

Regarding the first concept, most unsatisfied were the participants regarding the questions about the safety level of the harness, for example if the harness looks safe and reliable, if the child will be able to get out of the harness by themselves and if they feel confident about how the child is secured in the seat. There were some general comments about how to access the buckle when a child is placed in the seat since the hip of the child will be in the way and will prevent an easy access. Other comments were about the safety level of the harness. Here some participants mentioned that only one shoulder is fastened and were sceptical to how this will affect the child in a rollover accident. Others highlighted the risk that the retractor would make it easier for the children to get out of the harness by themselves and that the retractor forced the user to use both hands to pull out the strap before fastening since the retractor will keep retracting the belt strap even before the belt is buckled. One participant answered that the retractor gave the harness an exclusive feeling.

5 Discussion

The focus group only contained seven participants. A good focus group should have eight to twelve participants to get the best combination of different opinions and experiences and a good conversation. If the recruitment had been more successful a larger focus group would have increased the input from the session. If more than twelve people would have been recruited it would have been interesting to split the group into smaller focus groups based on use patterns or user profiles, such as parents/caretakers, grandparents and others.

The first questionnaire that was sent out was in .docx format, which means that the respondents were required to be in possession of MS Word. This might have limited the number of respondents. The questionnaire was distributed by e-mail. Any person that did not get a direct e-mail from the researchers had received a forwarded e-mail from any of the direct recipients. This limited distribution was also limiting for the number of respondents. By posting the questionnaire in a forum that the target group visits could have led to a higher and wider scope of respondents. A higher number of respondents would have led to a better statistical sample. The majority of the respondents were a wide scope of employees at Volvo Cars, which could influence the results. During the study the assumption was made that the role as a parent or grandparent in regards to CRSs is bigger than that as a Volvo Cars employee.

From the answered questionnaires it was evident that some questions were hard to understand or not understood in the intended way. Although it was stated that the questionnaire concerned the harness in the CRS in the introduction to the questionnaire, some of the respondents had answered some of the questions with the car's safety belt in mind. In the question where the participants were asked to rank the importance of different properties when buying a CRS on a scale 1-10 it was evident that different people had interpreted the scale differently. 1 was either interpreted as the highest ranked or the lowest ranked by different people. This could have been avoided by stating that 1 was the highest ranked and 10 the lowest.

The most annoying part of the system was identified to be the height adjustment of the harness and more than half of the respondents of the first questionnaire thought that the buckle is in the way when placing the child in the seat. This has been kept in mind during the development process and identified as the most important areas for improvement in the new concepts. To ensure that this will improve the customer value of the product it is of high interest to keep the prototype principle as straight forward and simple to use as possible. The ideal solution is that all adjustments are automatically adjusted without the need of any additional actions. The defined spring system for the height adjustment is supposed to meet this requirement at a realistic level since the purpose of the system is to allow a height adjustment mechanism that is as automatic as possible. However, this system will need more development to ensure that the functionality and mechanism meet these requirements.

Another thing identified during the investigation process was that it is important that the CRS looks inviting even for the child. If the child wants to sit in the CRS, the fastening process of the child will be facilitated since a satisfied and happy child is often more cooperative than a disgruntled child. The neck support cushion, formed and designed as a Dalmatian, is one way to increase the inviting impression of the CRS. Another important part is to ensure that there is no part of the harness in the seating area and to make the neck support cushion automatically tilt upwards when the harness is unbuckled so the child can be placed in the seat without any obstacles. The main use of belt retractors is to even further facilitate the fastening process of the child since this allows a simple pull of the straps to release more belt straps and an automatic retraction of the unused belt strap. The aim of the belt retractor is thereby defined to work as a traditional belt retractor during the fastening process and then as a traditional harness when the child is buckled and restrained.

Both of the conceived concepts are considered to be implementable in the CCS with some adjustments and adaptations.

Due to limited resources, the functionality of the produced prototypes was not completely as expected, which may have affected the participants during the evaluation session. This was reflected in the questionnaire answers mainly concerning the concept with a positioning half shoulder, a three-point safety belt and a comfort bump, since this prototype was furthest away from the current system. The use of a traditional belt retractor limited the functionality of the length adjustment of the belt strap which probably affected the feeling and experience of the whole prototype. Furthermore there were several comments about the perceived level of safety of the prototypes, both regarding the belt retractor and the use of a three-point harness system, which were in line with the comments from the first questionnaire. The participants argued that the child would be able to cause slack in the system by pulling out more belt strap during the trip, which can easily be avoided by use of an ALR system which only allows the system to retract the belt strap when buckled. However, by use of an ARL system the child may be too strictly restrained and the movement allowed for the child will be very limited. By this, the optimal solution would be a compromise where the child is allowed movement within a specific interval and thereby not allowed to pull out the belt straps too far. Further development within this area is therefore necessary to obtain the optimal functionality of a belt retractor system for CRSs. Another comment about the first prototype was about the placement of the buckle, which is located at the inside of the chair next to the hip of the child. This placement may complicate the buckling process, which is in conflict with the aim of the prototype since it should be as user friendly as possible. Further development is therefore necessary to obtain an optimal system.

Regarding the other prototype most of the comments were positive and the respondents though that this was the best harness. Even this prototype had some comments about the fact that it only consists of a three point belt and the safety level was questioned. This may not be an issue since the harness will only be used in RFCRS, although it is important to ensure that the child will not be able to slip out of the harness during a roll-over accident or a side impact. However, the function of the defined hip support is to prevent all possible slip of the hip, but further investigation in this area is needed to ensure a safe harness for all types of accidents.

Generally, it can be stated that a five point harness is safer than a three point harness. However, in this case this may not be necessary. In both concepts a neck support cushion is present. This will not only make it more comfortable for the child, but the aim of this cushion is to allow a narrow belt position against the child's neck and to force the shoulder straps together and keep the position at the child's shoulders without any slip to the side. By this it is ensured that the shoulders will remain restrained and that the risk that the shoulder belts will slide off is eliminated. In case of an accident the child will thereby always be restrained at the shoulders and kept in position inside the CRS.

Every comments about the predicted safety level of the prototypes are important to note since the safety of the harness must be prioritized. Even though the previous analysis of the system shows that the system should be safe, the users' feelings are just as important as the facts since this will probably affect the buyer in a negative way. As stated earlier, it is of high importance to increase the perceived satisfaction of needs that the product offers or to reduce the product's use of resources to be able to increase the customer value of the product. By this a low predicted safety level of the product will negatively affect the customer value.

The legal requirements have not been a limiting factor in the development of the concepts in this project. During further development of these concepts the legal requirements must therefore be considered. Any patent infringement should also be investigated to ascertain that the market introduction can be done smoothly.

A next step in the development process is to evaluate the prototypes by a user study with children and their parents to even further investigate the properties and possible areas of improvements in a more realistic situation.

6 Conclusion

The most important factor of a user friendly system is identified to be that the system should be as intuitive and easy to use as possible. However, the first impression of the harness is stated as the most important one since the CRS is a rather expensive investment that the users will adapt to and learn how to use rather than buy a new CRS the old one is tricky to use. The procedure of fastening the child will be done so many times that the user will learn how to fasten the child without paying any attention to how to do it. Because of this, the user friendliness is a very important factor when the CRS is bought since the user will most probably keep the same CRS until the child no longer uses a CRS. It is also evident from the questionnaire results that two of the highest ranked aspects when choosing a new CRS were test results and recommendations from acquaintances. This makes it more important to implement a parameter measuring the user friendliness of the system in the analysis or the tests that are performed to raise this question as early as possible in the investment process.

A solution to keep the buckle out of the seating area when placing the child is present in the prototypes. This mechanism meets the goal of being a simple, intuitive and easy-to-handle solution since it automatically keeps the buckle away from the identified critical area by use of a simple elastic band. If the mechanisms are too complex the risk of misuse or no use at all is high since it will be seen as a time and energy consuming action, without any obvious benefits for the user. If the system is easy to use, the system will be correctly used and as long as the system is used properly it will be safe.

The use of a belt retractor is identified to be an optimal solution of the system tightening mechanism. This allows the system to automatically adjust the harness to prevent any slack in the system in combination with an easier fastening procedure by an automatic increase of the length of the belt straps. By this the central adjuster is no longer needed. The allocation of this mechanism was identified in the first questionnaire to be a big issue for some users since this is hidden under the clothing in some of the CRSs. The aim of the belt retractor is to favour the fastening process and to act as a traditional harness when fastened. Although the optimal solution may be to allow a small movement of the child to increase the comfort for the child, this will need more investigation before implementation.

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8 Appendices

Appendix A Presented scenarios at focus group session

Some scenarios were presented at the focus group session to facilitate and support the discussion.

- A warm summer day when you just want to go a short distance home from pre-school
- A warm summer day on the way to the beach
- A rainy and windy day in October
- A cold winter day. The children are wearing large winter clothes and you are about to go to a nearby sledding hill. (How differs this situation compared to a ride to the grocery store?)
- A cold winter day. You are about to go on a longer ride up north for a week of skiing. (How differs the departure if it is dark outside compared to daylight? How differs the arrival if it is dark outside compared to daylight?)
- First sunny day in March when you are about to have a cosy picnic, but maybe comes back home when it is dark and colder outside.
- The day when you realize that the children have grown and the height of the belt/neck support needs to be adjusted - how long do you see this before you adjust it? Do you need to remove the entire CRS? What do you consider to be an acceptable solution, how advanced it may be to adjust?

Finally some possible issues were presented.

- The child unbuckle itself and are unbuckled in the back seat. How do you avoid this? Why does this happen?
- The child gets out of the harness by itself – how do you affect this? Why do you think the child acts like this?
- Does the inclination of the CRS affect if the child is trying to get out of the harness?
- If the belt system has acted like a traditional retractable seat belt, do you think that this would have a positive impact on the child?
- The child vomits when you are on a longer journey. What is the biggest problem? With a focus on the harness, something worth mentioning?

Appendix B Questionnaire (in Swedish)

Vilken modell av bilbarnstol har du störst erfarenhet av?

Skriv ditt svar här…

Om du inte kan namnet kan du utgå från exempelmodellerna nedan. Välj den stol du har störst erfarenhet av, alternativt den stol som mest efterliknar den stol du har störst erfarenhet av.

 Acta Graco Comfort S	 Axkid Minikid	 BeSafe iZi Kid X3
 Britax Max-Way	 Britax Multi-tech II	 Britax Hi-way II
 Klippan Triofix	 Maxi-Cosi Pearl XP	 Maxi-Cosi Mobi XP

I vilken bilmodell är din bilbarnstol oftast placerad?

Skriv ditt svar här...

Var i bilen är din bilbarnstol oftast placerad?

Skriv ditt svar här...

Hur nöjd upplever du att du är med följande hos selen i din bilbarnstol?

	1 Mycket missnöjd	2	3 Missnöjd	4	5 Okej	6	7 Nöjd	8	9 Mycket nöjd	10	Ingen uppfattning
Hur nöjd är du i helhet med selen i din bilbarnstol?	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
När du satt barnet i stolen											
Få tag i bältena	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Få tag i bälteslåset	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
När du ska knäppa bältet											
Hopföring av låstungor	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fastknäppning av låset	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
När du ska justera selen											
Justera höjd på selen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Antalet höjdlägen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Dra åt selen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hitta mekanismen för att släppa ut mer bältesband	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Släppa ut mer bältesband	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
När barnet är fastspänt											
Trygg med hur barnet sitter fast i stolen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Knäppa upp selen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Har du några andra tankar kring selen i barnstolen eller kommentarer till dina svar?

Skriv ditt svar här...

	Dagligen	Någon gång i veckan	Någon gång i månaden	Någon gång om året	Mer sällan/ Aldrig	Ingen uppfattning
Hur ofta använder/använde du bakåtvända bilbarnstolar?	☐	☐	☐	☐	☐	☐
Hur ofta har du problem med att:						
- barnet klagar på att sitta i stolen?	☐	☐	☐	☐	☐	☐
- barnet krånglar vid fastsättning?	☐	☐	☐	☐	☐	☐
- barnet kränger sig ur selen?	☐	☐	☐	☐	☐	☐
- barnet knäpper upp bälteslåset?	☐	☐	☐	☐	☐	☐
- barnet kräks i bilbarnstolen?	☐	☐	☐	☐	☐	☐
Hur ofta:						
- använder du stolens inbyggda bälteshållare? (se bild)	☐	☐	☐	☐	☐	☐
- drar du åt bältesbandet över barnets höfter?	☐	☐	☐	☐	☐	☐
- glömmer du att knäppa fast barnet?	☐	☐	☐	☐	☐	☐
- tar du loss klädseln för tvätt?	☐	☐	☐	☐	☐	☐
- tvättar du selen och dess delar?	☐	☐	☐	☐	☐	☐
Hur ofta justerar du:						
- bältesbandens längd?	☐	☐	☐	☐	☐	☐
- stolens lutning (om möjligt)?	☐	☐	☐	☐	☐	☐
- nackstödets position?	☐	☐	☐	☐	☐	☐
- axelbältets höjd?	☐	☐	☐	☐	☐	☐

Bälteshållare, från vänster: BeSafe: magnet i sida och bältesmuddar; Britax: gummihål i sidan för bältestungor; Maxi-Cosi fjädrar håller bälten från stolsrygg

Övriga kommentarer:

Skriv ditt svar här…

Ranka de egenskaper du anser vara viktigast vid köp av bilbarnstol. Ranka alternativen nedan (1-11, där 1 är viktigast).	
välj	Storlek på stol
välj	Testresultat
välj	Bekantas rekommendationer
välj	Försäljarens rekommendationer
välj	Expertrekommendationer (ex NTF, forskning, Volvo…)
välj	Hur bra stolen passar i din bil
välj	Uppskattad komfort för barnet
välj	Användarvänligheten: fastsättning av stol i bil
välj	Användarvänligheten: justering av bälte/höjd efter barnets storlek
välj	Användarvänligheten: fastsättning av barn i stol
välj	Pris

Andra viktiga egenskaper:

Skriv ditt svar här…

Besvara följande frågor med ja eller nej.	Ja	Nej	Ingen uppfattning
Om bältesbanden inte är i kontrastfärg jämfört med stolen, är det ett problem att inte bältesbanden syns?	☐	☐	☐
Föredrar du att höjden på nackkudden och axelbältena justeras ihop?	☐	☐	☐
Kan en magnet vara till hjälp för att hålla ihop bältestungorna vid fastsättning?	☐	☐	☐
Önskas en möjlighet att justera avståndet mellan axelbanden?	☐	☐	☐
Hade det varit bra med en varning för uppknäppt lås?	☐	☐	☐
Är det ett problem att inte axelkuddarna sitter på plats?	☐	☐	☐
Skulle rullbälten underlätta fastsättning av barnet?	☐	☐	☐
Tror du att barnet skulle reagera positivt på rullbälten under färd?	☐	☐	☐
Upplever du att axelbanden är i vägen när du sätter ner barnet i stolen?	☐	☐	☐
Upplever du att bälteslåset är i vägen när du sätter ner barnet i stolen?	☐	☐	☐

Hur tror du att barnet skulle reagera på rullbälten under färd?

Skriv ditt svar här…

Har du några övriga kommentarer gällande selen i stolen?

Skriv ditt svar här…

Tack för hjälpen!

Appendix C Questionnaire results

The participants were asked which RFCRS they had the most experience of, see Table C.1. Two of the participants answered more than one type of CRS. One of the participants answered Maxi-Cosi CabrioFix and another one answered Britax Baby-safe which both are infant carriers.

Table C.1 Model of RFCRS that the users had most experience of.

Rearward facing CRS	***Number***
Acta Graco	3
Axkid Kidzone	1
Axkid Minikid	1
BeSafe iZi Kid X3	5
Brio Zento	2
Britax	1
Britax Baby-safe	1
Britax Hi-way	7
Britax Max-way	3
Britax Multi-Tech II	11
Folksam RFCRS	1
Maxi-Cosi	2
Maxi-Cosi CabrioFix	1
Maxi-Cosi Mobi	12
Older Volvo RFCRS	4
SUM	***55***

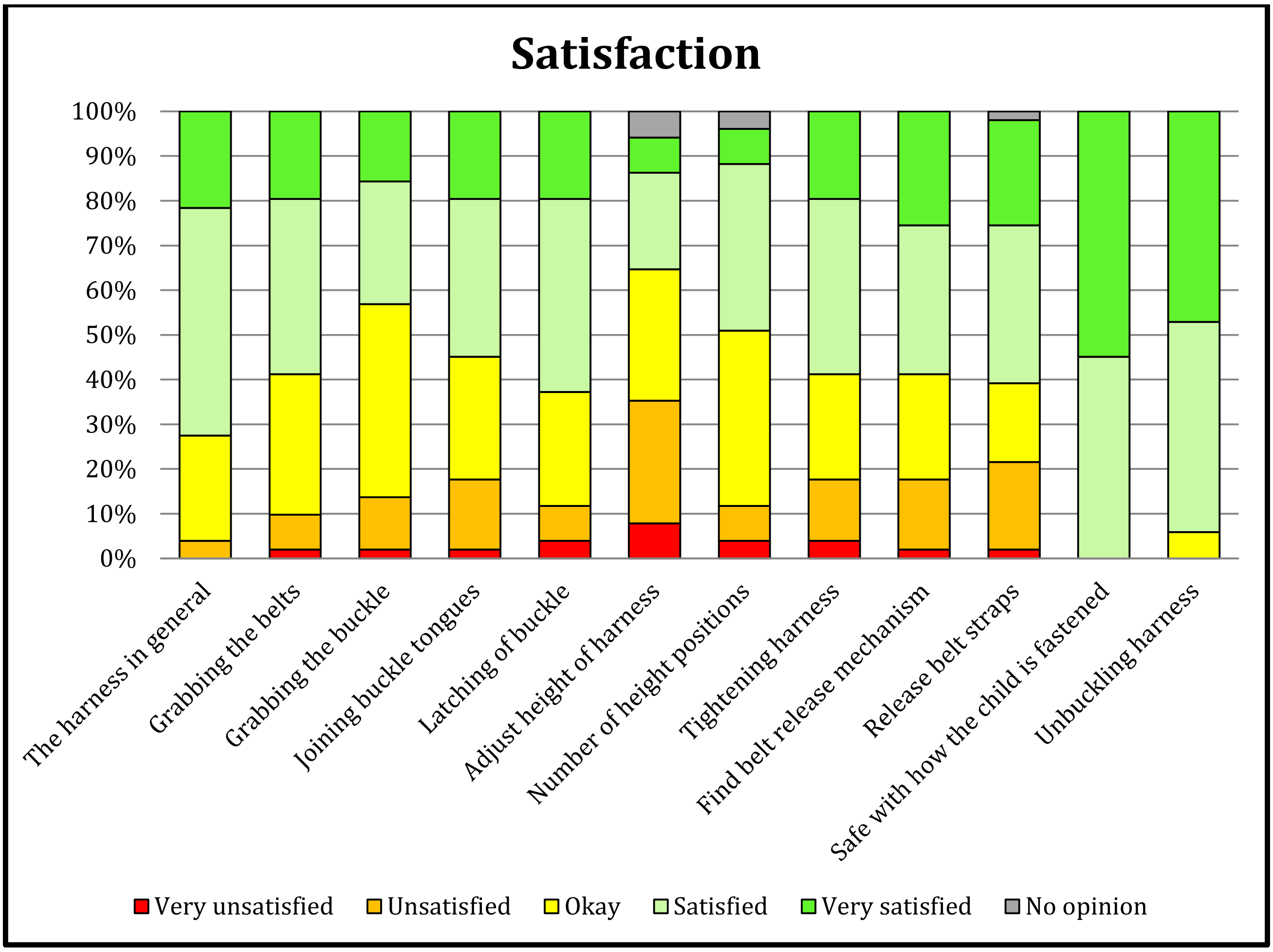
The participants were also asked where in the car the CRS was placed, see Table C.2. The total number of positions outnumbers the number of participants since several participants gave more than one position or had more than one CRS.

Table C.2 Position of the rearward facing CRS.

Position in car	***Number***
Front	20
Rear	32
No information	5
SUM	***57***

The satisfaction with the harness was investigated using the Volvo scale from one to ten where 1-2 is very unsatisfied, 3-4 is unsatisfied, 5-6 is okay, 7-8 is satisfied and 9-10 is very satisfied, see Table C.3.

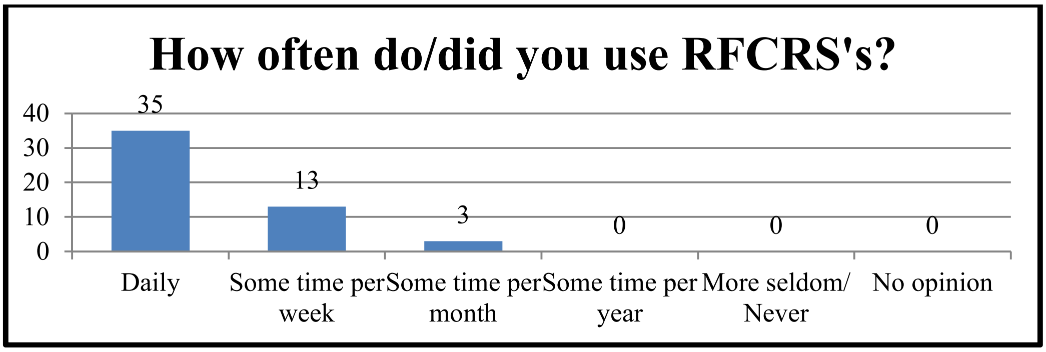
Table C.3 User satisfaction with different aspects of using the harness evaluated using the Volvo scale.



Britax Multi-tech II and Maxi-Cosy Moby were the most common RFCRS's. The users of these systems were examined separately to compare the two systems. It was seen that Maxi-Cosi Moby users had a higher average score of satisfaction. However, the number of answers for either CRS is too low to draw any definite conclusion.

The users were asked about their frequency of use, see Table C.4. Of the 51 respondents 68.6 % were daily users, 25.5% were weekly users and 5.9% were monthly users.

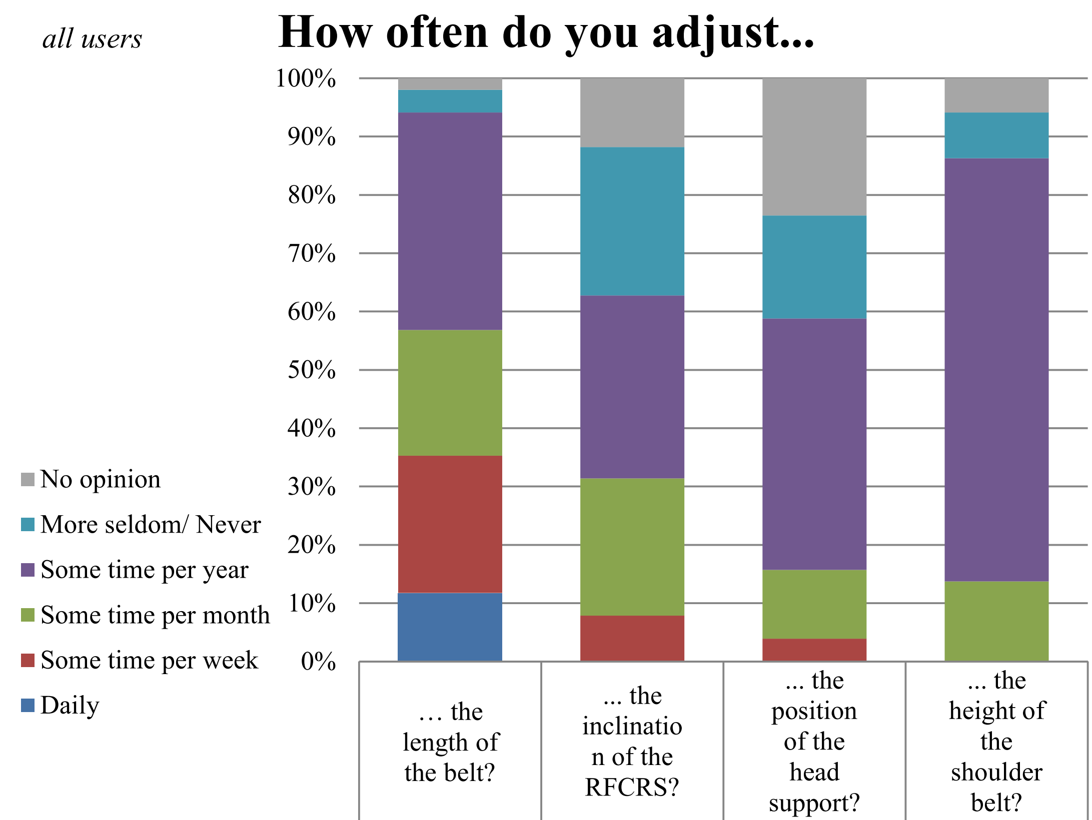
Table C.4 Number of users by frequency of use.



The occurrence of different situations was investigated by asking the participants about the frequency of encountering different problems. Since this frequency is dependent on the frequency of use of the RFCRS this fact is taken in consideration below. In

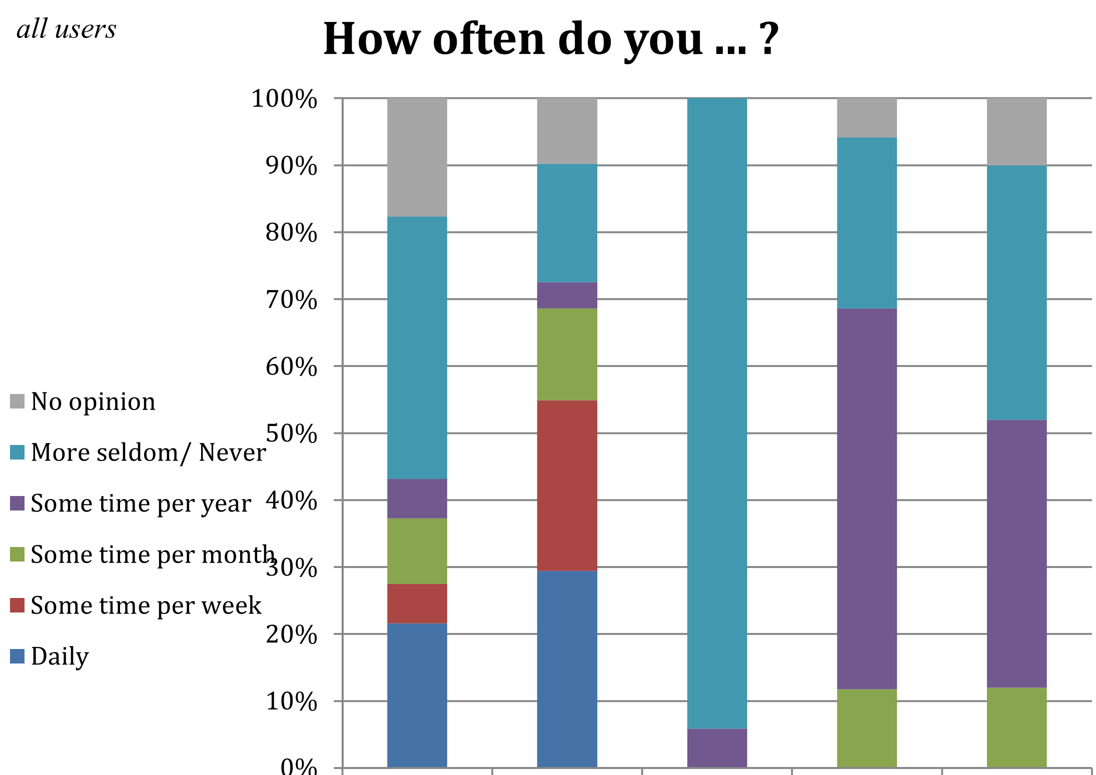
Table C.5, Table C.6 Frequency analysis of different behaviours among all the questionnaire participants.Table C.6 and Table C.7 the occurrence of all users are represented.

Table C.5   Frequency of encountering problems among all the questionnaire participants.



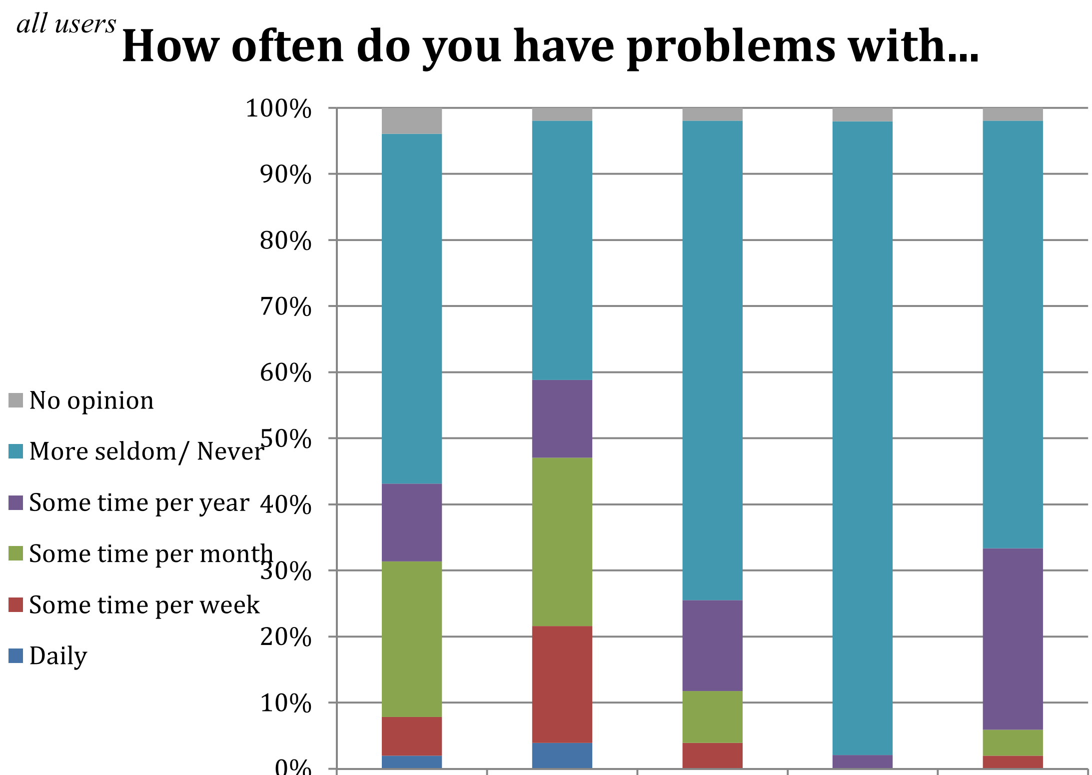
	… the length of the belt?	... the inclination of the RFCRS?	... the position of the head support?	... the height of the shoulder belt?
No opinion	1	6	12	3
More seldom/ Never	2	13	9	4
Some time per year	19	16	22	37
Some time per month	11	12	6	7
Some time per week	12	4	2	0
Daily	6	0	0	0

Table C.6 Frequency analysis of different behaviours among all the questionnaire participants.



	Use the built-in belt holder	Tighten the harness over the child's hips	Forget to fasten child	Remov e the cover to wash	Wash the harness and its parts
No opinion	9	5	0	3	5
More seldom/ Never	20	9	48	13	19
Some time per year	3	2	3	29	20
Some time per month	5	7	0	6	6
Some time per week	3	13	0	0	0
Daily	11	15	0	0	0

Table C.7 Frequency of adjustments of different parts of the RFCRS among all the questionnaire participants.



	... the child complaining about sitting in the RFCRS?	... the child giving trouble during fastening?	... the child getting out of the harness?	... the child unbuckling the harness buckle?	... the child vomiting in the RFCRS?
No opinion	2	1	1	1	1
More seldom/ Never	27	20	37	47	33
Some time per year	6	6	7	1	14
Some time per month	12	13	4	0	2
Some time per week	3	9	2	0	1
Daily	1	2	0	0	0

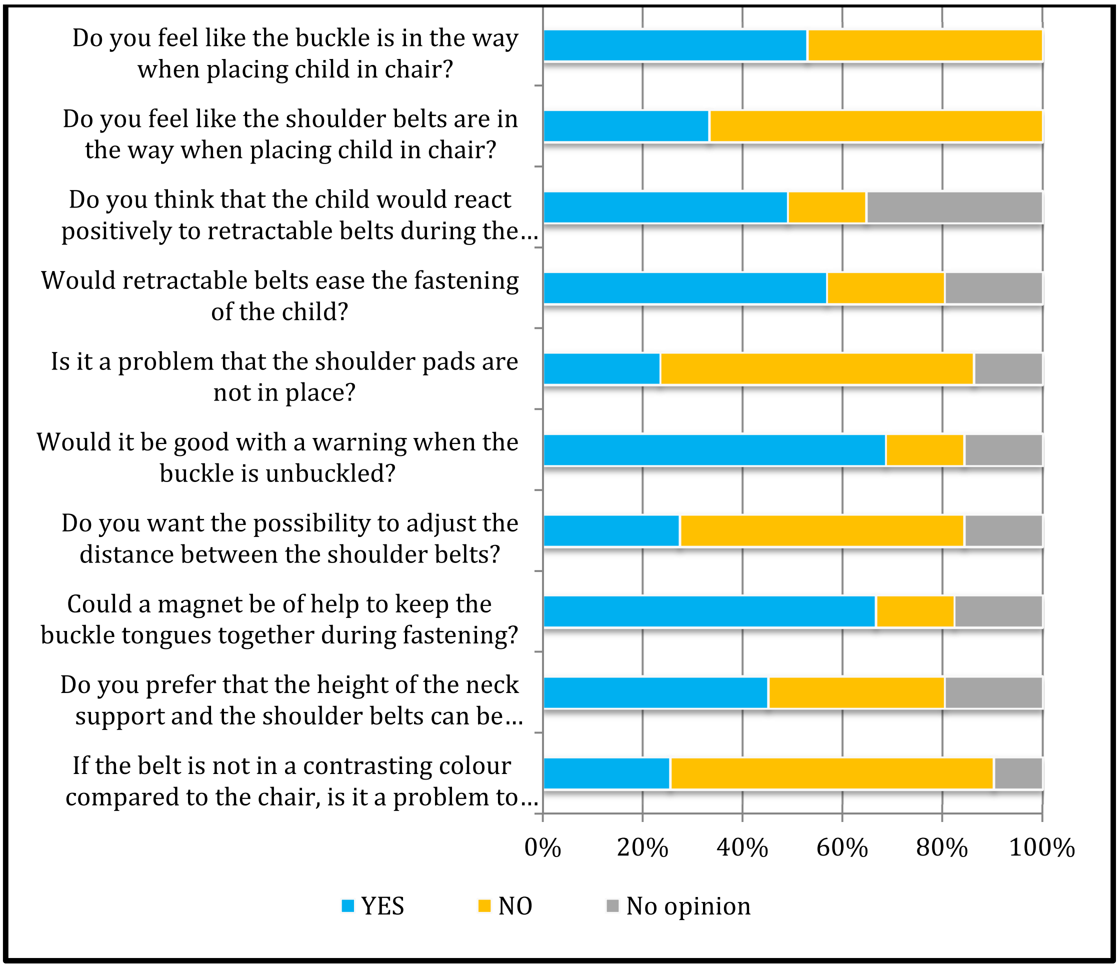
The participants were asked to rank the properties of the chair that they thought were important when buying a RFCRS, see Table C.8. There was space to add additional properties that the participants found important.

Table C.8 Ranking of importance of different properties when buying a RFCRS.

	Size of chair	***Test results***	***Recommendations from acquaintances***	***Recommendations from retailers***	***Expert recommendations (e.g. NTF, research, Volvo...)***	***How well the chair fits in your car***	***Estimated comfort for the child***	***User friendliness: attaching chair in car***	***User friendliness: adjustment of belt/height to the size of the child***	***User friendliness: attaching child in chair***	***Price***
1 & 2	7	32	3	2	33	11	7	5	1	1	1
3 & 4	6	7	11	1	8	19	21	4	10	14	7
5 & 6	6	5	4	6	4	3	13	15	11	20	8
7 & 8	13	1	12	7	3	9	5	13	16	9	13
9, 10 & 11	16	4	19	33	2	8	4	13	12	5	20
No opinion	3	2	2	2	1	1	1	1	1	2	2

The respondents' attitude to different aspects and adjustments of the RFCRS was investigated with yes and no questions, see Table C.9.

Table C.9 Attitude questions answered with yes or no.



Appendix D Child anthropometry

Stature

Table D.1 Supine stature [cm], boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	53.5	64.2
6-8.9 months	64.7	76.7

Table D.2 Supine stature [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	51.3	61.2
6-8.9 months	64.6	74.5

Table D.3 Supine stature [cm], both sexes (Pheasant, 1996)

	5th %-ile	*50th %-ile*	*95th %-ile*
Newborn	46.5	50.0	53.5
0-6 months	51.0	60.0	69.0
6-12 months	65.5	71.5	77.5

Table D.4 Stature [cm], boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
3.0-3.9 years	94.8	110.7
4.0-4.9 years	100.2	116.7

Table D.5 Stature [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
3.0-3.9 years	92.2	109.2
4.0-4.9 years	101.8	115.6

Table D.6 Stature [cm], boys (Pheasant, 1996)

	5th %-ile	*50th %-ile*	*95th %-ile*
3 years	91.0	99.0	107.0
4 years	97.5	105.0	112.5

Table D.7 Stature [cm], girls (Pheasant, 1996)

	5th %-ile	*50th %-ile*	*95th %-ile*
3 years	89.5	97.0	104.5
4 years	96.5	105.0	113.5

Sitting shoulder height

For children aged 0-18 months Steenbekkers does not include data on sitting shoulder height. This measurement can be calculated by using given measurements.

$$Sitting\ shoulder\ height = supine\ crown\ buttock\ length - (supine\ stature - supine\ shoulder\ height)$$

Table D.8 Supine crown-buttock length [cm], boys (Steenbeckers 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	36.0	44.3
6-8.9 months	43.5	51.7

Table D.9 Supine crown-buttock length [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	36.8	43.0
6-8.9 months	44.2	50.4

Table D.10 Supine shoulder height [cm], boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	39.4	49.5
6-8.9 months	46.5	59.3

Table D.11 Supine shoulder height [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	37.6	48.3
6-8.9 months	46.6	56.5

Table D.12 Calculated supine buttock-shoulder height, boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	21.9	29.6
6-8.9 months	25.3	34.3

Table D.13 Calculated supine buttock-shoulder height, girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	23.1	30.1
6-8.9 months	26.2	32.4

Table D.14 Sitting shoulder height [cm], boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
3.0-3.9 years	32.4	39.1
4.0-4.9 years	32.4	40.5

Table D.15 Sitting shoulder height [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
3.0-3.9 years	30.6	38.5
4.0-4.9 years	33.5	40.2

Table D.16 Sitting shoulder height [cm], boys (Pheasant, 1996)

	5th %-ile	*50th %-ile*	*95th %-ile*
3 years	31.0	35.0	39.0
4 years	32.0	36.0	40.0

Table D.17 Sitting shoulder height [cm], girls (Pheasant, 1996)

	5th %-ile	*50th %-ile*	*95th %-ile*
3 years	29.5	33.5	37.5
4 years	31.5	36.0	40.5

Hip breadth

Table D.18 Hip breadth [cm], boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	10.7	14.7
6-8.9 months	13.3	18.4

Table D.19 Hip breadth [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
0-2.9 months	11.0	15.7
6-8.9 months	13.2	18.7

Table D.20 Seated hip breadth [cm], boys (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
3.0-3.9 years	17.8	23.1
4.0-4.9 years	18.5	24.0

Table D.21 Seated hip breadth [cm], girls (Steenbekkers, 1993)

	3rd %-ile	*97th %-ile*
3.0-3.9 years	17.5	22.4
4.0-4.9 years	19.3	24.2

Table D.22 Hip breadth [cm], boys (Pheasant, 1996)

	5th %-ile	*50th %-ile*	*95th %-ile*
3 years	17.5	19.5	21.5
4 years	18.0	20.0	22.0

Table D.23 Hip breadth [cm], girls (Pheasant, 1996)

	5^{th} %-ile	50^{th} %-ile	95^{th} %-ile
3 years	17.5	19.5	21.5
4 years	18.0	20.5	23.0

Thigh thickness

Table D.24 Thigh thickness [cm], boys (Steenbekkers, 1993)

	3^{rd} %-ile	97^{th} %-ile
0-2.9 months	3.7	6.8
6-8.9 months	4.2	8.1

Table D.25 Thigh thickness [cm], girls (Steenbekkers, 1993)

	3^{rd} %-ile	97^{th} %-ile
0-2.9 months	3.1	6.6
6-8.9 months	4.7	8.0

Table D.26 Thigh thickness [cm], boys (Steenbekkers, 1993)

	3^{rd} %-ile	97^{th} %-ile
3.0-3.9 years	6.0	9.2
4.0-4.9 years	6.7	9.6

Table D.27 Thigh thickness [cm], girls (Steenbekkers, 1993)

	3^{rd} %-ile	97^{th} %-ile
3.0-3.9 years	6.7	9.3
4.0-4.9 years	6.5	9.6

Appendix E Idea generation

Table E.1 The ideas are grouped according to functionality.

Shoulder positioning mechanism
Y-belt
Liseberg
Positioning half shoulder
The Dalmatian
Traditional harness
Backpacker belt
Criss-cross belt
Hip positioning mechanism
Hip car belt
Lap bar
Hip claws
Fold-out pins
Comfort bump
Crotch buckle
System tightening
Crotch pull
Belt retractor
Universal retraction
After adjustment
Hip retraction
Automatic tightening
Spring
Comfort retractor
Central adjustment strap
Height adjustment mechanism
ARH
Automatic height adjustment
Height adjustment plate
Lock mechanism
Weight lock
Belt button
No thigh buckle
Side button
Separate button
Overlapping belts
Sliding lock

Magnetic lock
Lock roof
Facilitating placement of child
Vertical hold-out
Hip springs
Shoulder springs
Hold-out retractors
Hip support
After inflation
Hip air bags
Impact material
Temperature material
Adjustable hip width
Others
Arm holder
Turn the seat
Fastening jacket
Parachute
Magnetic clothes
The Door
Net

Table E.2 Generated concepts through possible combination of the ideas.

	Y-belt	Liseberg	Positioning half shoulder	The Dalmatian	Traditional harness	Backpacker belt	Criss-cross belt	Hip car belt	Lap bar	Hip claws	Fold-out pins	Comfort bump	Crotch buckle	Fastening jacket	Parachute	Magnetic clothes	The Door	Net
Concept 1	■								■									
Concept 2	■									■			■					
Concept 3	■										■							
Concept 4	■												■					
Concept 5		■						■										
Concept 6		■							■									
Concept 7		■								■		■						
Concept 8		■									■							
Concept 9		■											■					
Concept 10			■									■						
Concept 11				■					■									
Concept 12				■						■			■					
Concept 13				■	■								■					
Concept 14				■							■							
Concept 15	■			■									■					
Concept 16					■								■					
Concept 17						■						■						
Concept 18							■					■						
Concept 19														■				
Concept 20															■			
Concept 21																■		
Concept 22	■												■				■	
Concept 23					■								■				■	
Concept 24					■							■					■	
Concept 25					■							■					■	■

Appendix F Possible attributes for each concept

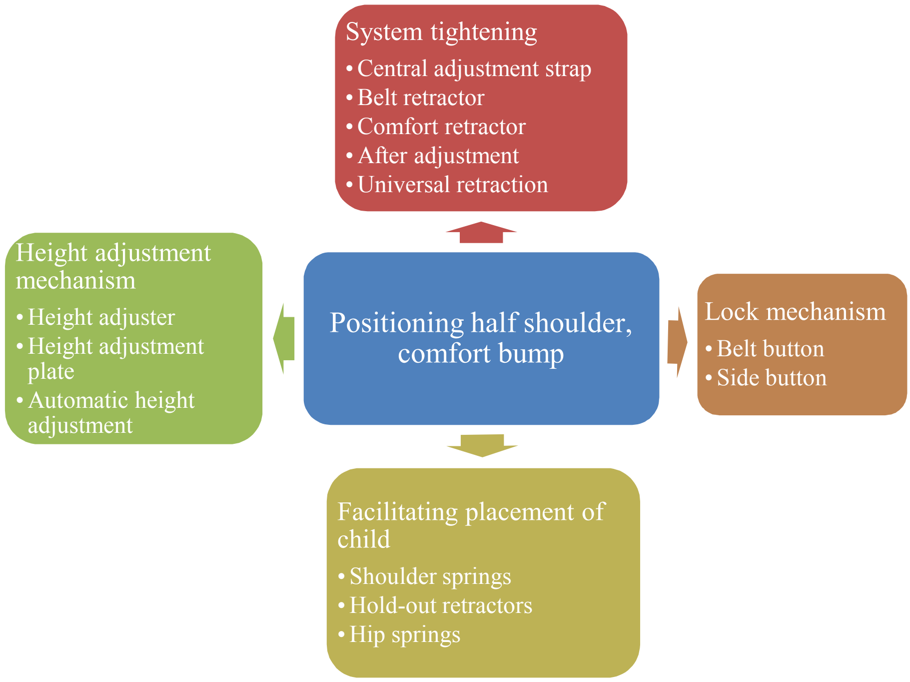


Figure F.1 Possible attributes for Concept 10.

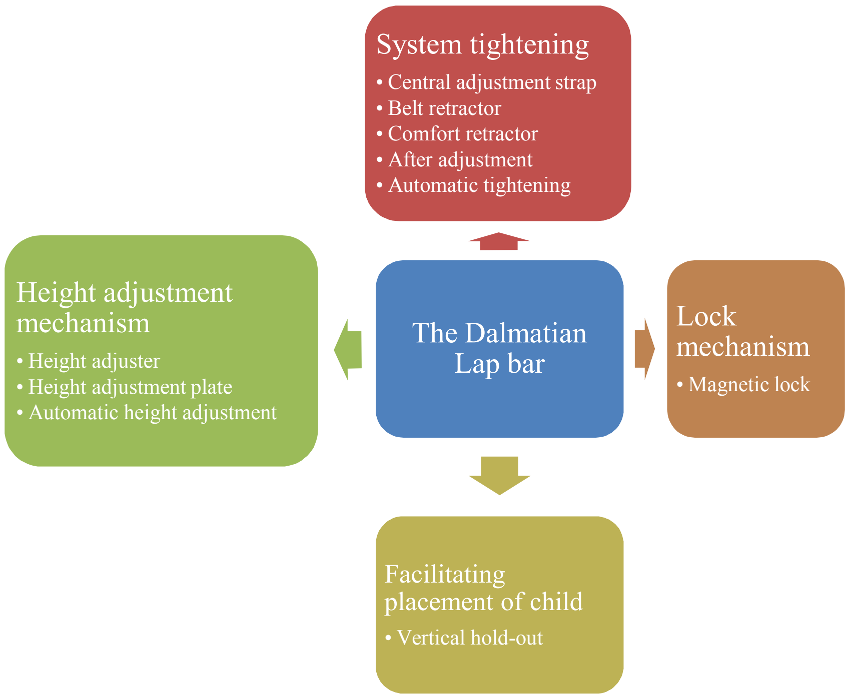


Figure F.2 Possible attributes for Concept 11.

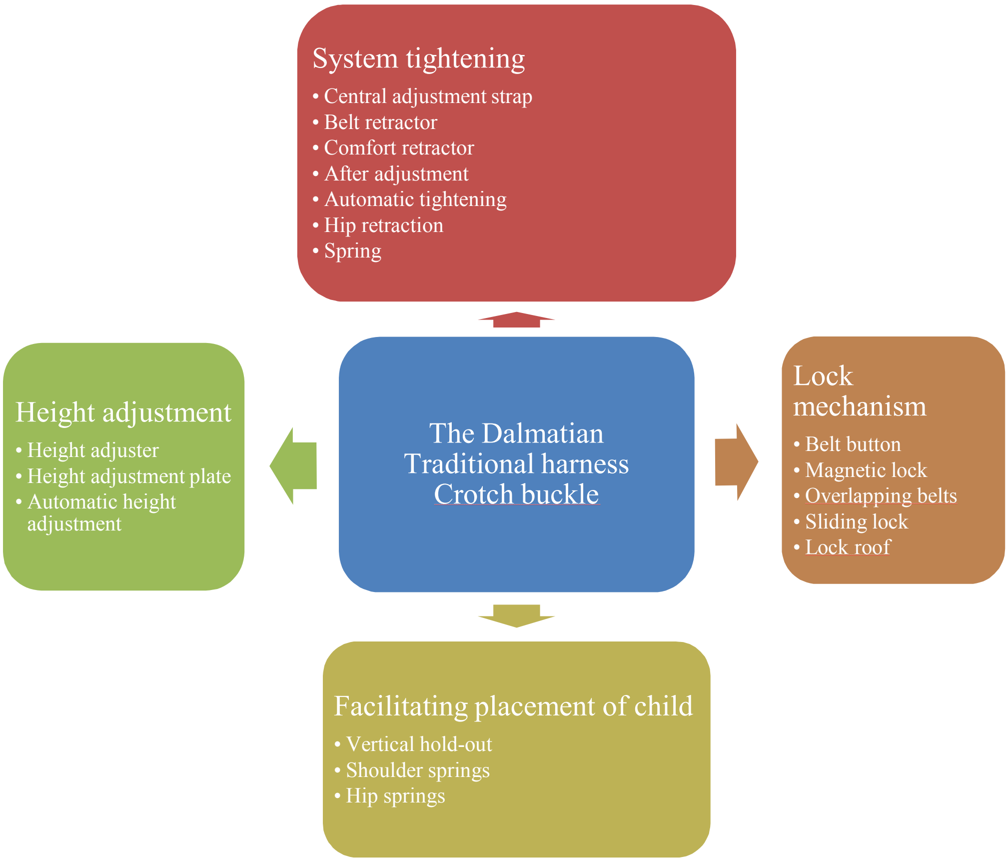


Figure F.3 Possible attributes for Concept 12.

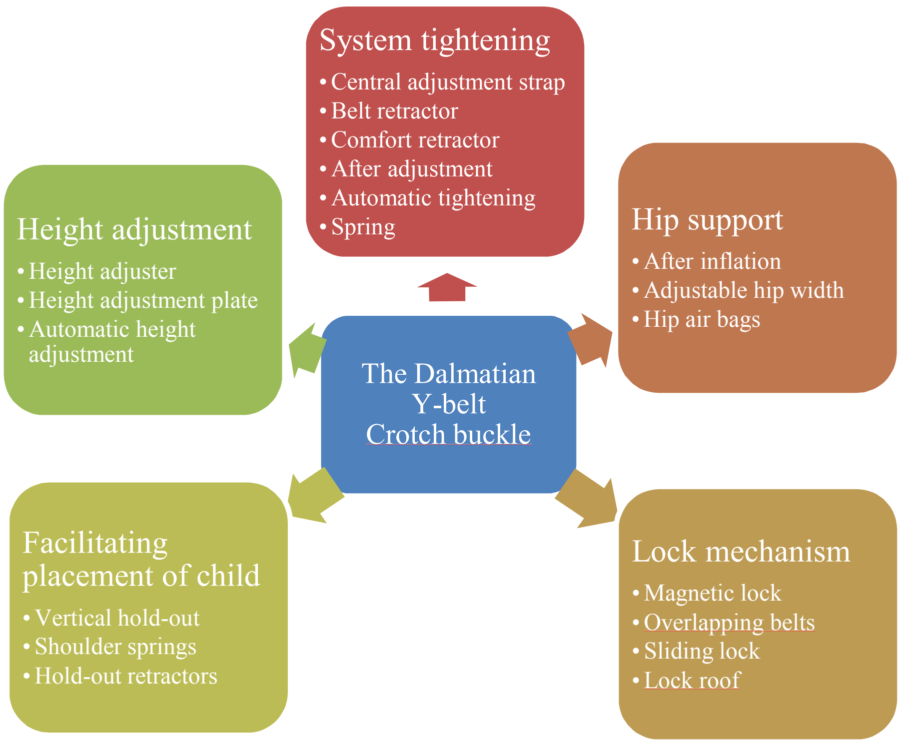


Figure F.4 Possible attributes for Concept 13.

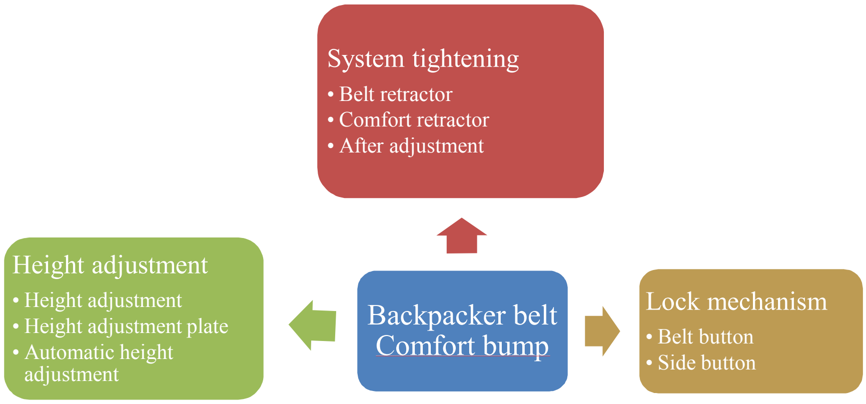


Figure F.5 Possible attributes for Concept 17.

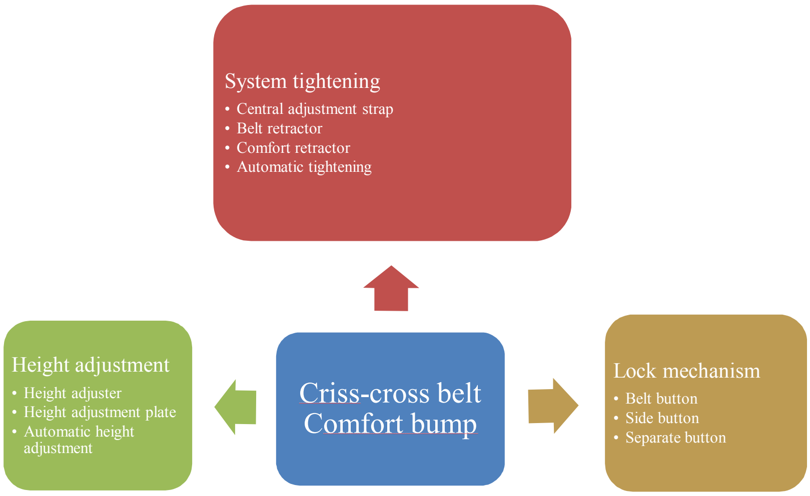


Figure F.6 Possible attributes for Concept 18.

Appendix G Concept attributes distribution between budget, mid-range and luxury

Table G.1 Distribution of attributes for concept 10 with a positioning half shoulder and a comfort bump.

CONCEPT 10	***Budget***	***Mid-range***	***Luxury***
System tightening	Central adjustment strap	Universal retraction, Belt retractor	Comfort retractor, After adjustment
Lock mechanism	Belt button, Side button		
Height adjustment mechanism	Height adjustment plate	Height adjuster	Automatic height adjustment
Facilitating placement of child		Shoulder/hip springs	Hold-out retractors

Table G.2 Distribution of attributes for concept 11 with a Y-belt, a neck support cushion (Dalmatian) and a lap bar.

CONCEPT 11	***Budget***	***Mid-range***	***Luxury***
System tightening	Central adjustment strap	Universal retraction, Belt retractor	Comfort retractor, After adjustment, Automatic Tightening
Lock mechanism		Magnetic lock	
Height adjustment mechanism	Height adjustment plate	Height adjuster	Automatic height adjustment
Facilitating placement of child		Vertical hold-out	

Table G.3 Distribution of attributes for concept 12 with a five-point belt, a neck support cushion (Dalmatian) and a crotch buckle.

CONCEPT 12	***Budget***	***Mid-range***	***Luxury***
System tightening	Central adjustment strap, Spring	Belt retractor, Hip retraction	Comfort retractor, After adjustment, Automatic Tightening
Lock mechanism	Belt button, Side button, Overlapping belts	Magnetic lock, Sliding lock	
Height adjustment mechanism	Height adjustment plate	Height adjuster	Automatic height adjustment

Facilitating placement of child		Shoulder/hip springs, Vertical hold-out	

Table G.4 Distribution of attributes for concept 13 with a Y-belt with a neck support cushion (Dalmatian) and a crotch buckle.

CONCEPT 13	***Budget***	***Mid-range***	***Luxury***
System tightening	Central adjustment strap, Spring	Belt retractor	Comfort retractor, After adjustment, Automatic Tightening
Lock mechanism	Overlapping belts, Lock roof	Magnetic lock, Sliding lock	
Height adjustment mechanism	Height adjustment plate	Height adjuster	Automatic height adjustment
Facilitating placement of child		Shoulder/hip springs, Vertical hold-out	Hold-out retractor
Hip support	Insert	Adjustable hip width	Hip air bags, After inflation

Table G.5 Distribution of attributes for concept 17 with a backpack belt and a comfort bump.

CONCEPT 17	***Budget***	***Mid-range***	***Luxury***
System tightening	Central adjustment strap	Belt retractor	Comfort retractor, After adjustment
Lock mechanism	Belt button, Side button		
Height adjustment mechanism	Height adjustment plate	Height adjuster	Automatic height adjustment

Table G.6 Distribution of attributes for concept 18 with a criss-cross belt and a comfort bump.

CONCEPT 18	***Budget***	***Mid-range***	***Luxury***
System tightening	Central adjustment strap	Belt retractor	Comfort retractor, After adjustment
Lock mechanism	Belt button, Side button	Separate button	
Height adjustment mechanism	Height adjustment plate	Height adjuster	Automatic height adjustment

Appendix H Belt sketches

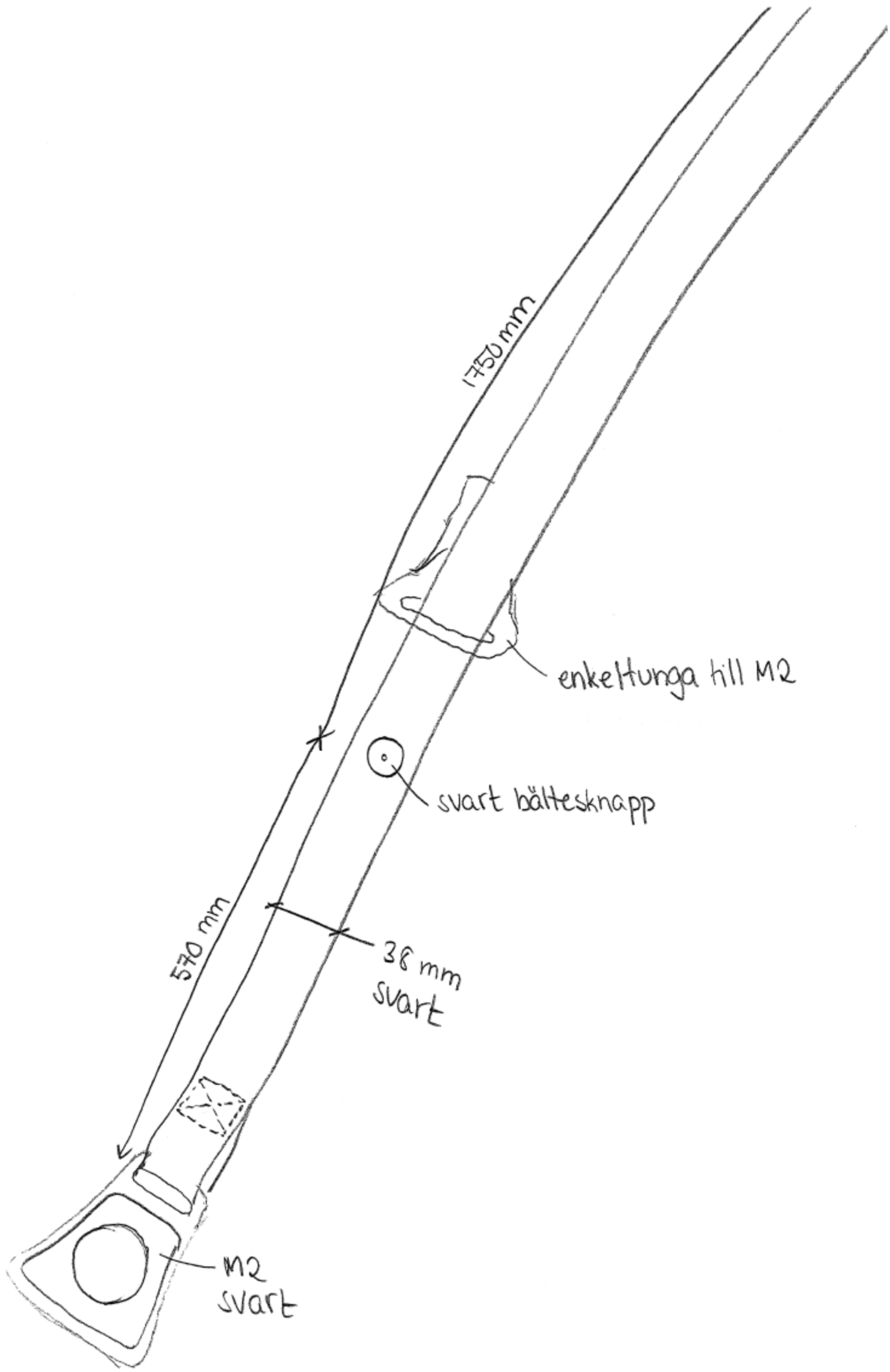


Figure H.1 Belt arrangement sketch for concept 10.

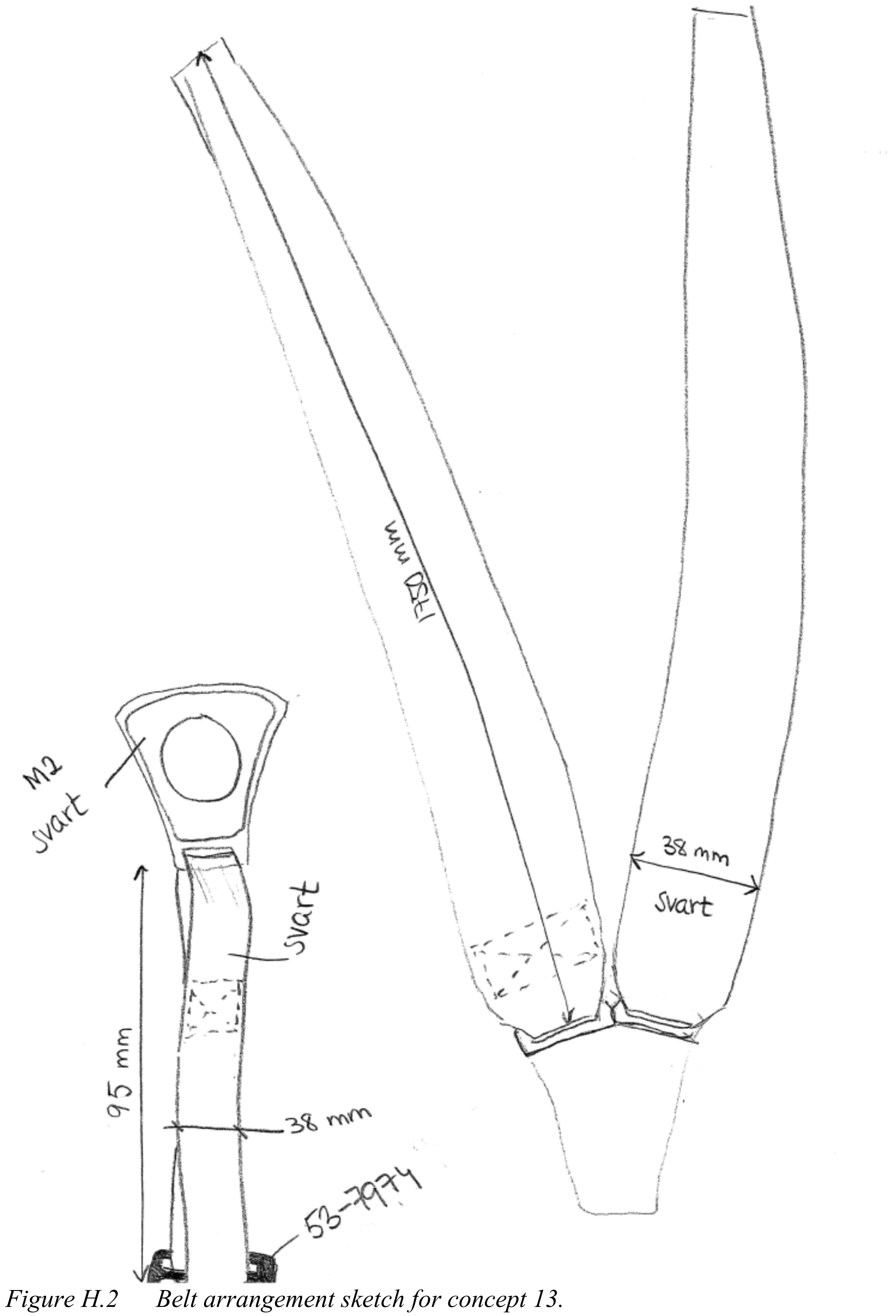


Figure H.2 Belt arrangement sketch for concept 13.

Appendix I Evaluation questionnaire (in Swedish)

	1	2	3	4	5	6	7	8	9	10	Ingen uppfattning
	Instämmer inte alls								Instämmer helt		
Selen ser inbjudande ut	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Selen ser bekväm ut	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Selen ser säker ut	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Selen känns ny och innovativ	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Selen har en premiumkänsla	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
När jag placerar barnet i stolen riskerar jag inte att sätta barnet på selen	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Antalet moment för att sätta fast barnet är få	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Selen försvårar för barnet att kränga sig ur under färd	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
När jag knäpper loss barnet underlättar stolen att hålla selen borta från sittytan	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Jag känner mig trygg med hur barnet sitter fast	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Övriga kommentarer:

Appendix J Evaluation results

Table J.1 Evaluation result of the first prototype harness presented at the evaluation session.

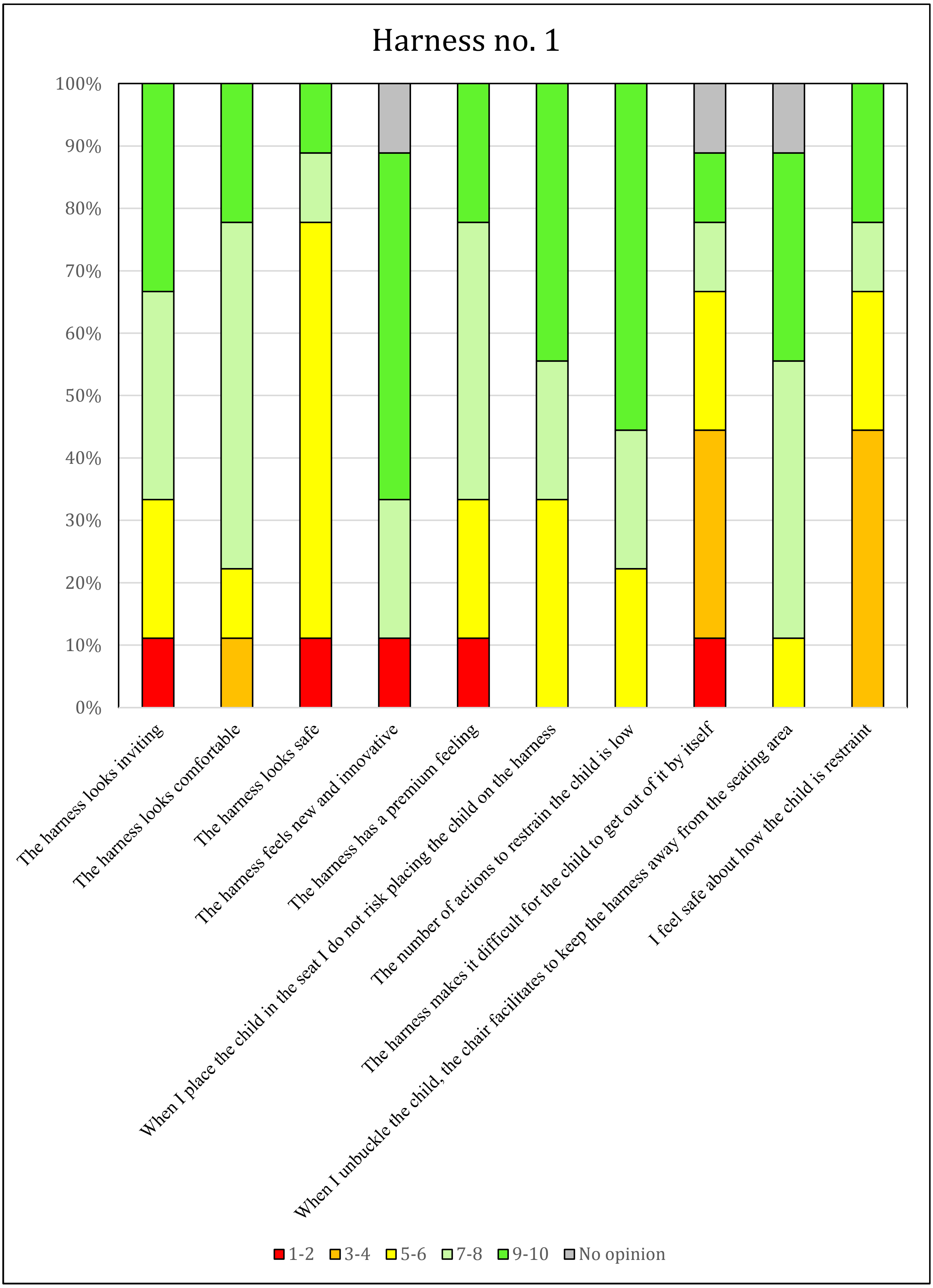


Table J.2   Evaluation result of the reference harness presented at the evaluation session.

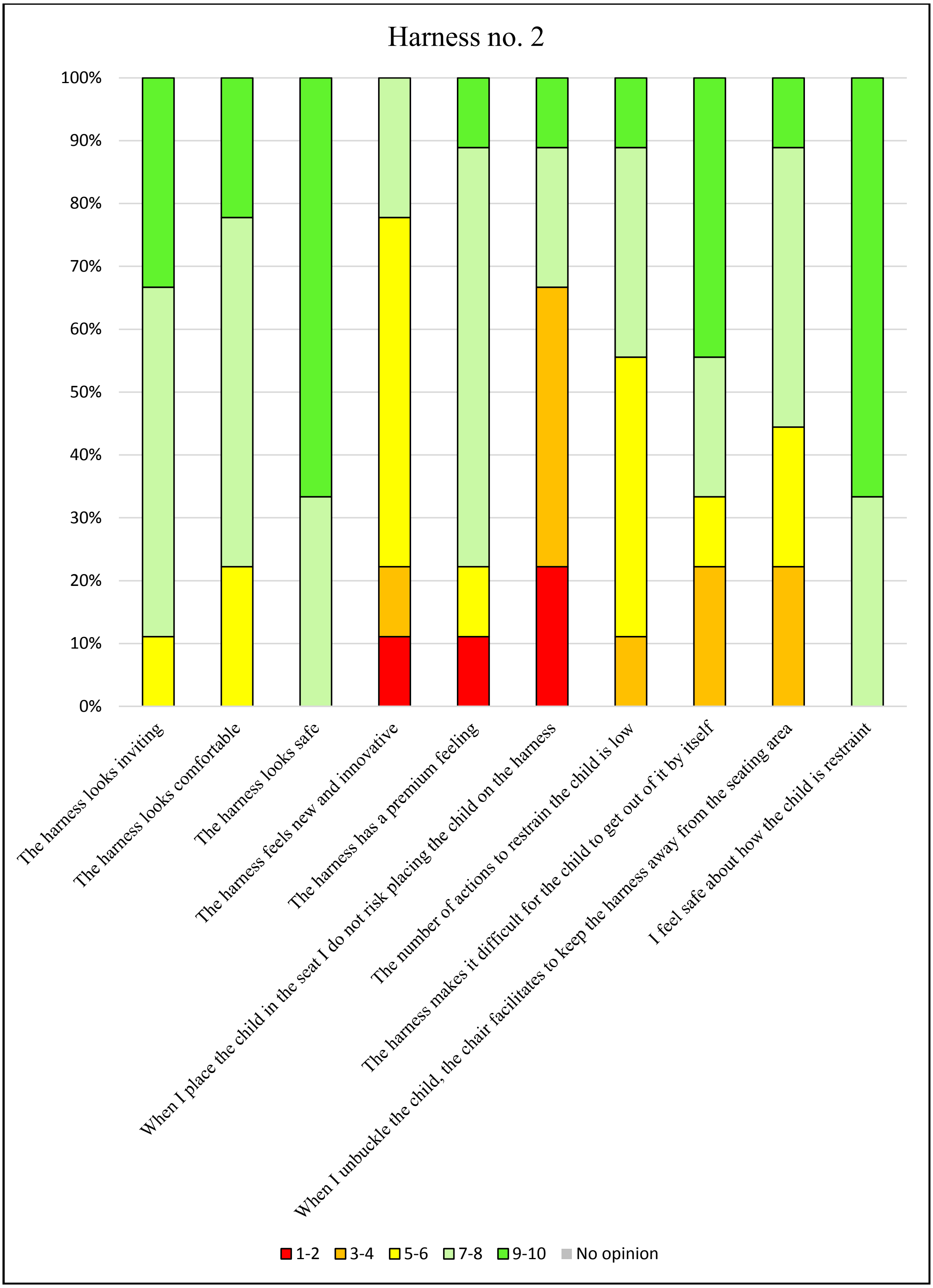


Table J.3 Evaluation result of the first prototype harness presented at the evaluation session.