REAR SIDE AIRBAG OF THE FUTURE
And about its purpose to protect the passenger

FRAMTIDENS SIDOAIRBAG FÖR BAKSÄTET
Och om dess syfte att skydda passageraren

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I certify that all material in this Bachelor Degree Project, which is not my work has been identified and that no material is included for which, a degree has previously been conferred on me.

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Abstract
This project aims to develop a rear side airbag and to investigate how the passenger in the rear seat is in need of protection in a side impact.

It was found from the literature study that the head of children and thorax of adults are the most exposed body regions in side impacts. The side collision test done with a barrier by LINCAP (Lateral Impact, New Car Assessment Program) was found to produce the highest force on the rear-seated dummy, in comparison to the same test by IIHS (Insurance Institute Highway Safety), and that a high combined pelvic force results in a lower rating of the vehicle.

The objective of the airbag concepts is to offer protection area to the most exposed body regions. The airbags are designed with the presumption that the occupant uses a seat belt and a pretensioner to limit the forward motion of the body, with the rationale that this enables design of airbags with reasonable manufacturing costs.

The three new concepts of airbags were: thorax; thorax/pelvis and thorax/pelvis extended. From sled tests with the three new airbag concepts, it was found that an airbag, compared to no airbag, reduces the risk of injury at thorax by 70 percentage units and the force on pelvis is considerably reduced in a side impact. The thorax bag showed a reduction of the rib deflection compared to no airbag, but a high force on the pelvis motivates a protection area of pelvis. The tests with the two larger bags thorax/pelvis and thorax/pelvis extended resulted in a better protection of thorax, abdomen and pelvis than without airbag. Problems with positioning the pelvis area of the bags was noticed but not solved and may be a task in further investigations.
Foreword

This Bachelor Degree Project has been held at the School of Technology and Society, University in Skövde, during the spring term in 2011. Autoliv submitted the assignment of the project and the work has mainly been carried out at the company, Autoliv Sweden AB in Vårgårda. The aim has been to develop a rear side airbag and to investigate the purpose with an airbag in the rear seat. There are several people to thank for their help during the project, and specially:

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1. Introduction
This chapter introduces the objectives of the project and gives an introduction to aspects related to side impacts in vehicles. A brief presentation about the work at Autoliv in Vårgårda is given as well as an overview of the report structure.

1.1. Background
According to the World Health Organisation over 1,2 million people dies each year on the world’s roads (Peden et al., 2004). About 20 to 50 million people suffer severe injuries. Stuke et al. (2010) show there are 9000 vehicle occupants that die in side impact collisions each year in USA. The Insurance Institute for Highway Safety (IIHS) demonstrate in one of their newsletters that the fatal injuries in side impact collisions represent about 27% of the deaths in traffic in year 2009 in the USA (IIHS, 2011). Collected information from Sweden, France and UK the European Enhanced Vehicle-safety Committee (EEVC) shows that in car collisions with fatal injuries, there are 22% to 26% that is related to side impact collisions (EEVC, 2010).

One important reason for side impact collisions to be more dangerous than frontal collisions is that there is lesser material that can absorb the energy from the impact and protect the occupants (IIHS, 2011).

To protect the passengers in the front and rear seats, the cars may be equipped with side airbags, as standard or optional devices. The purpose with the airbags is to protect the passengers’ head, chest and pelvis during a side impact. National Traffic Safety Administration (NHTSA) point out that if all of the cars in USA would be equipped with side airbags there could be 700 to 1000 lives saved each year in side impact collisions (NHTSA, 2010).

Federal Motor Vehicle Safety Standards (FMVSS) set out regulations about car safety and how well the vehicles need to protect the crash test dummy in crash tests being performed. To be allowed to sell the car in USA, the minimum level of safety needs to be fulfilled but it is up to the vehicle manufacture to ensure that the vehicles pass the tests (GAO, 2005).

The organisations that perform crash tests are NCAP (New Car Assessment Program), which is established in USA, Europe, China, Japan, Korea and Australia and IIHS (Insurance Institute for Highway Safety). Both organisations perform crash tests on the vehicles that are expected to be the most popular ones in the year. Vehicles are rated for their performance in the crash tests and the results are published through Internet and brochures. The consumers can then use these ratings as a guideline in their choice of buying a new car. The rating system also works as an encouragement for manufactures to improve the vehicle safety (GAO, 2005).

1.2. Autoliv Sweden AB
In the project of developing the next generation rear side airbag, the work was performed at Autoliv in Vårgårda, Sweden. Autoliv (Auto Lindblad in Vårgårda) was established by Lennart Lindblad in 1953 and is now a worldwide leading company in automotive safety. They develop, manufacture and market safety equipment for vehicles such as airbags, seat belts, safety electronics, anti-whiplash systems, seat components and integrated child seats. Autoliv is spread around the world in thirty different countries and sell their products to vehicle manufactures around the whole world (Autoliv, 2009).

1.3. About the challenge
Bilston et al. (2010) demonstrate that the safety in the rear seat has not been as developed as in the front seat. In a study of vehicles involved in accidents from year 1993 to 2007, it is found that children between the ages nine to fifteen are more protected in the rear seat, while the adults are more protected in the front seat.

In older vehicles the occupants are more protected in the rear seat since the front seat is more exposed in the more common frontal impacts. Given that there have been several safety
improvements in the front seat, it is now stated to be safer for an adult in the front but still safer for the children, in the ages nine to fifteen, in the rear seat. The safety equipments in the front seat are developed to protect adults and the aggressive airbags can easily harm the children, as they do not have the same height as the adult occupant (Bilston et al., 2010).

The most common safety equipment in the rear seat is the side curtain that protects the head of the occupants. There are not many rear side airbags on the market today, and the most common ones are the thorax airbags, that protects the chest at the occupant (Stuke et al., 2010). In a full-scale test, with and without a thorax airbag, it was demonstrated that the average rib deflection was decreased by 50% in cases where an airbag was mounted (Bohman et al. 2009).

Schneider et al. (2005) state that the injury levels may be further reduced with the combination of a side curtain to protect the head and a side airbag that protects both thorax and pelvis.

1.4. The purpose
The purpose of the project was to develop a new rear side airbag that protect the occupants in the rear seat. The activities involved in the project were meant to be useful for Autoliv, where the project was running. The aim of the work was to generate:

- A summary of what is expected for the rear seat safety in the future
- A benchmark review over the existing rear seat airbags on the market today
- A product that meets the discovered demands
- A validation of the product with simulation, sled or full-scale test
- A comparison between the existing crash test dummy with the coming one

By gathering data from crash test reports and reports about traffic collisions; the intention of the work was to investigate who and what parts of the body that is in need of protection in the rear seat.

The project also aimed to study crash tests to see how the ratings of the rear seat affect the overall rating and what is expected of rear seat protection in the future to receive a maximum rating.

1.5. Limitations
The restraints for this project are:

- Only study crash tests performed by the organisations in the USA since they perform the toughest crash tests.
- The knowledge about the rear seat is limited, hence some assumptions will have to be made to gather more information, and afterwards it shall be possible to verify if the assumptions reasonable or not.
- The task is limited to the rear seat.
- The availability of external parts, such as original airbags, doorframes, seats and trim parts, is limited.
- To develop a side airbag that was possible to sell at a reasonable price, which would not be possible if an airbag include all kinds of cases.

1.6. Structure of the report
The first chapter Introduction gives a brief presentation of the objectives and background of the challenges of the project. Figure 1.1 explains the working procedure of the project and the structure of the report.
The second chapter contains the theory background of the issues considered in the project. The third chapter covers the creative methods used and the Front-End Process that was used as an overall method during the project. The fourth chapter presents the results from the collected data and resumes the information about the problem. The fifth chapter explains the development of the new airbag concepts. The sixth chapter includes the final analyses of the concepts and recommendations for further work.
2. Theory background

This section informs about the main issues concerning crash tests and car safety. The crash test institutes, the regulations, the crash test dummies and the abbreviated injury scale are further explained in this chapter.

2.1. About the airbag

According to the 2nd law of motion of Newton all moving objects have momentum, which is the product of the mass and the velocity of an object. This means that an object will continue to move at its present speed and direction unless there is an outside force influencing upon it. While travelling in a car there are many different masses moving at the same time and if there is a collision these masses will continuing moving at the same speed and direction as just before the collision. Stopping an object’s momentum requires force acting over a period of time. When a car crashes, the force required to stop any mass travelling inside the car is very great because the car's momentum has changed instantly while the occupants has not. To prevent serious harm in such crash, the restraint system aim to slow down the occupants’ motion (Brain, 2011).

The aim of the use of an airbag is to slow down the speed of the occupant without causing an abrupt stop to his or her motion. As a collision typically is over within milliseconds there is not much time for the airbag to perform such task. Often there is just a small space between the occupant and the intruding vehicle and that space reduces with time, forcing the need of an aggressive and fast deployment of the airbag (Brain, 2011).

Figure 2.1. A side airbag deployed, mounted in the seat.

The airbag consists of three main parts:
- The bag, which is made of a nylon fabric. It can also have a layer of silicon to make the bag more air tight, preventing a prematurely loose of the gas.
- A sensor that tells the bag when to inflate. When a collision occurs accelerometers around the car notice the change of speed and send signals to a main system in the middle of the car. This device then sends a fire signal to the airbag sensor if the force is big enough to be considered a crash. The airbag will then deploy, see figure 2.1. Normally it takes about 5-10 ms from the first touch of the collision object until the airbag have deployed.
- An inflator, which will produce nitrogen gas to fill up the bag.

Even though the whole process of noticing a crash situation, send a fire signal to the airbag and finally fill the bag with gas lasts for only ~30 ms, that additional time is enough to help prevent serious injury (Brain, 2011).

2.2. Anthropometric Test Devices

Anthropometric Test Devices (ATD’s), also known as crash test dummies, are tools for regulators and crash test organisations to test the safety systems in vehicles. ATD’s are designed to be biofidelic (humanlike) in their impact response with human physical characteristics such as size, shape, mass, stiffness and energy absorption. The development of
the responses of the dummy has mainly derived from crash simulations with human cadaver (Verriest, 2009).

In the work to receive correct injury predictive data, the crash test dummy must be biofidelic, i.e. act like a human in the tests. There are various parameters for the different body regions to compute. Head injuries may be caused by acceleration, chest injuries may be caused by rib deflection and leg fractures may be caused by force and moments. Physical responses related to such injuries need to be detected by the dummy to foresee the injuries that may affect the occupants in a side impact (WorldSID Task Group, 2006).

In the USA the standard dummy used in the different crash tests for side impacts is the SID-IIs (Small Side Impact Dummy). The SID-IIs anthropometry represents the size and weight of a small adult (5th percentile female) or what is equalized as a twelve or a thirteen years old child. The sitting height is 780 ±8 mm and the total weight is 44,52 kg. It is capable of measuring over 100 data channels for injury assessments of the head, neck, arm, abdomen, pelvis and leg (Humanetics ATD, 2011).

The World SID 5th percentile dummy is currently being validated and is not yet in use. This new ATD have improved biofidelic properties as the spine is designed to simulate the shear motion between the upper and lower torso. It also has a coordinate system that can provide the test engineer with data of the interaction between the car and the dummy. The total of 128 measurement channels provides more crash data than the earlier generations of side impact dummies (Barnes et al., 2005).

2.3. Abbreviated Injury Scale
The Abbreviated Injury Scale (AIS) is a standard scale used to classify the intensity of an injury. A higher number on the scale indicates a more severe injury where the scale goes from one to six, see table 2.1 (Cavanaugh, 2002).

| AIS 1 | Minor |
| AIS 2 | Moderate |
| AIS 3 | Serious |
| AIS 4 | Severe |
| AIS 5 | Critical |
| AIS 6 | Unsurvivable |

Table 2.1. The abbreviated Injury Scale.

Each body region has a classification for the different levels of injury and there is a separate category for a skeletal injury or a soft tissue injury (Cavanaugh, 2002). The scale is used to evaluate the probability of injury in crash tests and when injuries from real world crash data are categorized.
Figure 2.2. Body regions to protect in a side impact.

The names of the different body regions that the risk of injury is measured at are seen in figure 2.2.

2.4. The performers of the crash tests
The National Highway Traffic Safety Administration (NHTSA) started the New Car Assessment Program (NCAP) in 1979 to perform crash tests on vehicles to rate them on their crashworthiness. The car is rated on a scale of five stars, where one is the worst and five is the best. These ratings are then used as a guideline for consumers in their choice of buying a safe car. Today the NCAP programs are established in Europe, China, Japan, Korea and Australia, and they all share the vision to encourage the manufacturers to provide better protection for various occupants in a broad range of accidents (NHTSA, 2007a).

The other organisation in USA that performs crash tests is Insurance Institute for Highway Safety (IIHS). They were established in 1959 by three auto insurance institutes to increase the safety on the roads. They have performed frontal crash tests since 1995 and side impact tests since 2003, to inform consumers about the safety in the car regarding the occupant protection (IIHS, 2011).

In this project, the focus will be on IIHS and the US NCAP program. The side impact test by US NCAP is named LINCAP (Lateral Impact New Car Assessment Program).

2.5. FMVSS 214 regulation
The Federal Motor Vehicle Safety Standard (FMVSS) is a regulation that was amended in 1990 to assure occupant protection in a dynamic test that simulates a severe right-angle collision. The FMVSS 214 aims to make passenger cars less vulnerable in side impacts and especially aims to reduce fatality risk to the nearside occupant when a car is struck in the door
area by another vehicle. The demands in this regulation are to be considered as a minimum level of security and are required of the manufactures if they want to sell their cars in the USA. The regulation states the side impact tests, with a moving deformable barrier (MDB) and an oblique test with a pole, and also the acceptable injury values are described in the regulation (GAO, 2005).

The test, concerning the rear seat occupant, is the side impact test with a MDB. The weight of the MDB is set to 1368 kg and the velocity is declared to be 54 km/h in a 27 degrees crab angle into the vehicle (NHTSA, 2007b).

NHTSA (2007b) describes that a smaller occupant in the rear seat is more vulnerable to chest injuries than a larger occupant and therefore is the SID-IIs, which represents a 5th percentile female, placed in the rear seat. A summary of the allowed values for injury criterion is listed in table 2.2.

Table 2.2. Injury regulations by NHTSA for the SID-IIs dummy in side impact test.

<table>
<thead>
<tr>
<th>Head region</th>
<th>SID-IIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Head Injury Criteria &lt; 1000</td>
</tr>
<tr>
<td>Chest</td>
<td>Lower spine acceleration &lt; 82 m/s²</td>
</tr>
<tr>
<td>Pelvis</td>
<td>Force limit of 5525 N</td>
</tr>
</tbody>
</table>

New Car Assessment Program (NCAP), in USA, uses a higher speed in their tests and Insurance Institute for Highway Safety (IIHS) is using a larger weight and a higher bumper on the MDB than the regulation requirements in FMVSS 214. Therefore it is possible for the injury values in these tests to be superior the values set by the regulation. If the injury measures are higher than the regulation, the car is rated with a low grade but it could still be approved to be sold in USA.

2.6. LINCAP

In the LINCAP test there are two crash test dummies placed in the car. In the front seat there is an ES-2re (European Side Impact Dummy with Rib Extension) and in the rear seat a 5th percentile female dummy, SID-IIs. The MDB is moving with a speed of 61 km/h, in a 27 degrees crabbled angle, into the vehicle (see figure 2.3). The weight of the barrier is 1368 kg and hits the car with its centre at the hip of the driver (Carhs, 2010).

Figure 2.3. A side impact test by LINCAP.

The MDB is imitating the front of a passenger car and is placed 28 cm over the ground with a height of 56 cm (Kim et al., 1998). Because of the relative low height above ground, the barrier may hit the sill at a passenger car, resisting the barrier to do a larger intrusion at the door. With a total height of about 84 cm, the barrier may not directly hit the head of the occupant.
In LINCAP’s rating of a vehicle, the whole test is containing a frontal impact, side impact, rollover test and a view over the available safety features. The rear seat is concerned in the side impact test with the MDB and is calculated together with the front seat in an overall side impact rating. In the overall side impact rating the front and rear seat is valued even and the dummy in the rear seat is evaluating the risk for injury on the head and pelvis. From the risk of injury, that is including the head injury criterion (HIC) and the sum of acetabular and iliac force in the pelvis, the joint probability risk of injury is calculated. The probability of AIS 3+ injury for the head and AIS 2+ for pelvis is calculated; see equations and descriptions in appendix 1.

2.7. IIHS

In the side impact test by IIHS, the impact angle of the barrier is 90 degrees to the car’s side. The weight of the barrier is 1500 kg and travels with a velocity of 50 km/h. In the front and the rear seat there are two SID-IIs dummies placed at the impact side, see figure 2.4 (Teho & Lund, 2011).

![Side impact test with a MDB by IIHS.](image)

The MDB is imitating the front of a SUV or a pickup truck with its height of 76 cm and 38 cm above the ground (IIHS, 2008a). The barrier hits above the sill of a passenger car and straight into the doors, producing a great impact force. Cause of its total height of about 114 cm, it may also hit the dummies in the head.

In the IIHS’s rating of the car it is given the score Good, Acceptable, Marginal or Poor. The car is rated in relation to how crashworthy it is by the categories front, side, rear, rollover and electronic stability control. In the evaluation of the rear seat, where a SID-IIs dummy is placed, the body regions head and neck, shoulder, torso, pelvis and left femur are included in the rating of the rear occupant’s safety (IIHS, 2011).

In the overall side rating there are three groups: injury measures from the dummy, head protection and B-pillar deformation. The B-pillar is the pillar located behind the front row in the vehicle. The ratings by IIHS are further described in appendix 2.

2.8. The children in side impacts

Bilston et al. (2010) explain that the safety in the rear seat has not been developed as much as in the front seat. The front crashes are still the most common accidents and that is the main reason for the focus on front impact protection. In a study of vehicles involved in accidents between 1993 and 2007, it is found that children between the age nine to fifteen are more protected in the rear seat, as side impact crashes are less common, while the adults are more protected in the front seat (Bilston et al., 2010).

The most expelled body part of the children in side impacts appears to be the head. As they suffer from serious head damages the outcome often is a fatal injury. Information about how
children response in motor vehicle crashes can be used to further improve the safety initiatives (Nance et al., 2010).

In a study of rear-seated children in side impact, there were 231 children, in the age fourteen years old or younger, involved in 186 motor vehicle crashes. The data was collected from the CIREN database and the years 1991 to 2002 were selected. It showed that side impacts resulted in a higher outcome of AIS 2+, AIS 3+, AIS 4+ and AIS 5+ injuries than compared to frontal crashes. The children have a lower sitting height, which result in increased threat of contact with the interior door panel (Orzechowski, 2003).

Bohman et al. (2009) demonstrate in a study that children in the year four to twelve received AIS 3+ injuries to the head in most cases of side impacts. Maltese et al. (2007) did a study among children in the ages four to fifteen years old. In the research it was investigated where the different body regions of the children hit the door. The children were seated without booster seat but with seatbelts. The area where the head appears to hit the side of the door is the rear half window from the windowsill up to the centre of the window, see figure 2.5 (Maltese et al., 2007).

![Figure 2.5. The impact points of the head at the door.](image)

Bohman et al. (2009) is mentioning that a forward motion can be more controlled if the seat belt and a pretensioner are used and that the protection area of the side airbag could be narrowed, avoiding the need of an enormous covering area.

### 2.9. The adults in side impacts

From real world crashes, collected from NASS in the years 1997 to 2004, there were 7812 occupants in side crashes. Among the front seated occupants, it was 4282 that suffered from chest injuries. That makes the chest the most frequent injured body part, followed by the abdomen and the head. The occupants that suffered from injuries in more than one body area had, in the most cases, injuries at the head and the chest (Yoganda et al., 2007).

---

1 Separate fabric rapped foam block
Bohman et al. (2009) showed that thorax is the most frequent injured body region among rear-seated adults. In collected data from NASS-CDS from the years 1994 to 2007, the occupants (thirteen years and older) involved in side impacts were considered. Most of the occupants (59%) suffered from an AIS 3+ injury to the thorax; several rib fractures and maybe an internal bleeding. The head and pelvis injuries are found on second and third place, according to how frequent an AIS 3+ injury occurred (Bohman et al., 2009).

2.10. Out-Of-Position tests

The airbag is meant to protect the occupants in collisions, but in some cases of real-world accidents there have been cases where the airbag caused injuries to Out-Of-Positioned occupants. Out-Of-Position is a situation where the occupant is not seated regular in the seat as in figure 2.6 as an example. NHTSA has numbers that tells that 3000 lives has been saved by airbags as of May 1998 in USA but also that 99 people has been killed by a deploying airbag, because of an Out-of-Position (OOP) (Morris et al., 1998).

The risk that occurs in an OOP is when the passenger blocks the deploying airbag and the pressure in the airbag becomes greater than usually necessary to split the module cover. There will then be a great force on the region of the occupant blocking the airbag’s path. The other risk of injury is when the airbag is outside its module and is inflating. If a passenger is in the airbag’s path, there could be a large membrane force on the passenger (Morris et al., 1998).

There is a report by the Technical Working Group (2003) about procedures how to measure the risk of injury for an occupant by a deploying airbag. The risk of injury is not allowed to exceed a 5% risk for AIS 4 injury for the head and the thorax, and a 5% risk for AIS 3 injury for the neck. The neck is given a lower tolerance risk of injury since it is believed to be the most critical part of the body in an OOP risk from deploying side airbags. The risk of injury is decreasing while the size of the occupant is increasing. The ones that seem to be in the largest risk region in the deploying airbags path, and used in the OOP tests, are small women and children while the newborn and up to 2 years old children are supposed to be better protected as they are placed in a child restraint (Technical Working Group, 2003).

The positions to be tested are worst-case scenarios according to the side airbag, shown in figure 2.6.

Figure 2.6. The positions for testing the side airbags with a dummy with the size of a three years old child, according to the Technical Working Group.

The test of OOP is not a regulation or a law, but a recommendation of procedures by the Technical Working Group that NHTSA is asking for. It is up to the manufactures to test the dummies in out of position situations and inform about if the airbag has passed the procedures. Up to this date no child has ever suffered an fatal injury in an out of position situation in the rear seat (Technical Working Group, 2003).
3. Method

The overall design method used for the project is The Front-End Process where the seven activities are described in this chapter. The other methods used in the project are also presented and described.

3.1. The Front-End Process as an overall focus

Ulrich and Eppinger (2008) describe a concept development process called The Front-End Process. The idea is to visualise the activities that a development team is passing in their way from a product opportunity to the final product. Ulrich and Eppinger (2008) demonstrate the activities in a certain order but inform that it is very rare that a project finish each activity before the next one is started. Instead it is more common that the activities are overlapping and that the process may be iterative. The activities in the Front-End Process are shown in figure 3.1.

![Figure 3.1. The activities in The Front-End Process by Ulrich and Eppinger (2008).](image)

Identify customer needs

The first action described is to identify customer needs. The purpose of this part is to make sure that the product has its focus on, and is built up from, customer needs. By identifying the customer needs the product specification will be easier to understand and correctly developed (Ulrich and Eppinger, 2008).

To be clear about the main goal and what the project group is aiming for, it is helpful to set up a design brief at the beginning of the work. The purpose of the design brief is to identify a goal, explain the circumstances, set up the limitations and compose criteria for the product opportunity (Cross, 2008).

Establish target specification

In order to establish the product specifications there are four steps to follow. The first step is to arrange a list of metrics. The second step is to gather the competitors’ products and specifications in a benchmark to be clear about how the market looks like. After that, the ideal and marginally acceptable values are set for the product. The last step is to reflect on the result and the process (Ulrich and Eppinger, 2008).

Cross (2008) informs about the product specifications and that a specification should be presented in a range between limits if possible.

Generate product concepts

By dividing the activity of generating product concepts into several steps, there is a bigger chance that a larger spectrum of alternatives/possibilities are covered. These steps are:

- Clarify the problem and divide it into sub-problems until it is fully understood.
- By searching externally there are several sources where to find inspiration and ideas from the ones that already invented and explored the area.
- By searching internally the knowledge within the project group are used to generate ideas in different group methods.
• In order to organize the thinking in the group it is useful to explore systematically with combination tables and similar methods. (Ulrich and Eppinger, 2008)

This activity is further specified in section 5.1 Concept generation.

Select product concept
To select a final concept among the product concepts there is a number of alternatives to do so. The methods described by Ulrich and Eppinger (2008) are: (1) external decision, (2) product champion, (3) intuition, (4) multivoting, (5) pros and cons, (6) prototype and test and (7) decision matrices. The methods are a way to select concept by letting the customer chose, letting the product team choose, selected by intuition, voting on the concepts, selection by a list of the positive and negative things, each concept is build as a prototype and tested or by using decision matrices where the specifications are weighted.

Cross (2008) explains that a choice made by intuition is not as good as if a choice can be more rational. This to feel more secure when there are several persons and activities that are affected by the choice.

Test product concept
Concept testing is very much like concept selection in the way that both aim to reduce the number of concepts. One of the ideas is to look for how the concept may be improved to better meet the customer needs. (Ulrich and Eppinger, 2008)

Cross (2008) mentions that improving the concept could mean two things: it is either a way to reduce the cost for the producer or a way to improve the value for the customer.

The activity about testing the concepts are further specified in chapter 5.3.1 Test planning.

Set final specifications
When a final concept is selected, it is time to set the final specifications. The first set of specifications, pointed out from the customer needs, may be exceeded or unfulfilled. Therefore the specifications need to be defined once more, for the new selected concept. This is done in the same way as described earlier in the section Establish target specification (Ulrich and Eppinger, 2008).

Plan downstream development
As a final activity it is suggested to create a detailed development plan to organize all the involved people and their different tasks. The purpose with planning is to manage the resources of time and money to reach for a high quality and a low cost product (Ulrich and Eppinger, 2008).

One of the ways to visualise the planning is a Gantt chart. In a Gantt chart the activities in the project are presented in a vertical column where a horizontal bar represents the start and end of each activity. A Gantt chart does not show how the activities depended on each other but in which way the tasks are done and if they are parallel or sequential (Ulrich and Eppinger, 2008).

Perform economic analysis
Ulrich and Eppinger (2008) explain that an economic analyse is an activity that is performed during the whole development phase. The four steps to be used in the activity are (1) put up a financial model of the cash flows, (2) perform a sensitivity analysis to look for internal and external factors that may affect the project, (3) use the sensitivity analysis to understand project trade-offs and make the changes in the project if a gain is expected, and (4) how decisions in the project interact with the firm, the market and how factors from the society may interact with the project (Ulrich and Eppinger, 2008).

The methods for the activity Perform economic analysis were not used in the project. To set the limits of the project, the economic analyse was left to be analysed in a further work.
Benchmarking of competitive products
To create a successful product that is positioned in a new product place, a benchmarking is useful to find how the competitive products solve the problem. The idea is that a benchmark is meant to offer new ideas about the product and the design. By looking for competitive products in more than one activity of the Front-End Process there a larger spectra is covered (Ullrich and Eppinger, 2008).

The benchmark used in this project is further specified in chapter 5.1.6 Comparison of the size.

Build and test models and prototypes
Models could be built in many aspects and in several activities of the development process. One reason to build a model is to more easily demonstrate the ideas by the team and to set the design of the product (Ullrich and Eppinger, 2008).

This activity is further specified in chapter 5.1 Concept generation.

3.2. Working methods used In the project

Analysis of the crash tests by US NCAP and IIHS
In the comparison between the side impact tests that affect the rear seat, the test reports from the two test institutes IIHS and US NCAP were collected. The test reports were collected at their homepages (IIHS, 2011 and NHTSA, 2011). The studied tests were the side impact test with a moving deformable barrier, with a SID-IIs placed in the rear seat. The test reports were limited to the ones that had been performed in the years 2010 and 2011.

FARS-data from NHTSA
The FARS (Fatality Analysis Reporting System) encyclopedia offers public data from real cases in USA by NHTSA. The search was narrowed down to fulfil the purpose of each researcher analyzing the documents. The years that were selected were 2005 to 2009, to use the latest data available. For this project the search criteria were listed as following:

Age: All
Sex: Male or Female
Restrain use: All
Airbag deployment: All
Initial impact angel: Side impacts that appear at 2 o’clock to 4 o’clock and 8 o’clock to 10 o’clock.
Injury severity: Fatal injuries. Only the ones who died were included.
Seating position: Second rear seat left or right side and third rear seat left or right side.

High temperature tests
The airbags need to be tested in a higher temperature to be sure that it manages various kinds of climates. Three airbags of each concept were tested with both upper limit gas and nominal gas, to be sure of the strength since the effect of the gas may vary. The airbag modules were placed in a test lab for two hours, to reach to the expected temperature of +85° Celsius, before fired off. The purpose with the tests was to ensure airbag reliability.

Sled Tests
A number of sled tests were performed to validate the new airbag concepts. The sled test aimed to imitate the full-scale test performed and presented by LINCAP. The sled tests were performed at the crash track at Autoliv in Vårgårda.
4. Results from the Pre-Study

A pre-study was done in the work of developing a rear side airbag to protect the occupants in a side impact. The study intended to answer the questions about how the rear side airbag should be developed and protect the rear-seated occupant.

The questions to be answered in the pre-study were:

- What is the difference between the crash tests regarding the rear seat and what is necessary to protect in the tests?
- Which load case to use in the upcoming sled tests?
- How does the existing rear side airbags protect the occupants?
- How is the situation for the rear-seated occupant in real life?

The questions were pointed out from the formulated tasks in the chapter 1.4 The purpose. The questions are answered by collecting information and data about the different subjects.

From the pre-study, the specifications for the airbag concepts were not presented in a range of limits, as suggested in the chapter Front-End Process as an overall focus. The specifications were instead presented in how the area of the rear side airbag should cover the occupant, according to the found information from the pre-study.

4.1. A comparison between IIHS and LINCAP

4.1.1. Comparison of the parameter results

Among the vehicles from 2010 and 2011, the cars tested by both LINCAP and IIHS were compared in table 4.1. LINCAP is only studying the index of head injury criteria (HIC) and the combined pelvic force in the side collision, while IIHS also calculates the result from thorax, abdomen and the upper leg. In table 4.1 it was only the common parameters that were compared.

<table>
<thead>
<tr>
<th>Car model</th>
<th>HIC</th>
<th>Combined pelvic force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IIHS</td>
<td>LINCAP</td>
</tr>
<tr>
<td>2011 BMW 528i</td>
<td>184</td>
<td>190,5</td>
</tr>
<tr>
<td>2011 Chevrolet Cruze</td>
<td>146</td>
<td>327</td>
</tr>
<tr>
<td>2011 Ford Fiesta</td>
<td>119</td>
<td>245,9</td>
</tr>
<tr>
<td>2011 Hyundai Sonata</td>
<td>166</td>
<td>199</td>
</tr>
<tr>
<td>2011 Jeep Grand Cherokee</td>
<td>78</td>
<td>121,2</td>
</tr>
<tr>
<td>2011 Kia Sorento</td>
<td>120</td>
<td>181</td>
</tr>
<tr>
<td>2011 Toyota Sienna</td>
<td>202</td>
<td>107</td>
</tr>
<tr>
<td>2011 Volkswagen Jetta</td>
<td>313</td>
<td>405</td>
</tr>
<tr>
<td>2010 Ford Mustang</td>
<td>796</td>
<td>2735</td>
</tr>
<tr>
<td>2010 Honda Insight</td>
<td>290</td>
<td>435</td>
</tr>
<tr>
<td>2010 Kia Soul</td>
<td>102</td>
<td>355,1</td>
</tr>
<tr>
<td>2010 Kia Forte</td>
<td>237</td>
<td>606,6</td>
</tr>
<tr>
<td>2010 Mazda 3</td>
<td>280</td>
<td>333</td>
</tr>
</tbody>
</table>

The bold numbers in table 4.1 point out the highest obtained values in the comparison between IIHS and LINCAP. The Chevrolet Cruze was the only vehicle that had a side airbag in the rear seat.

As a result from table 4.1 it is clear that the side impact test performed by LINCAP resulted in higher values on the side impact dummy in most cases. LINCAP received the highest index of HIC in twelve cases and nine in the combined pelvic force, of the thirteen available common test results.
4.1.2. Differences between the Moving Deformable Barriers

Some significant difference between the two organisations in the side impact test with the Moving Deformable Barrier (MDB) is the size, weight, shape, impact angle and velocity as described earlier in the chapter 2.5 LINCAP and 2.6 IIHS. While LINCAP is using a lower MDB to imitate a passenger car, the IIHS is imitating a SUV or a pickup truck in the side impact test, see figure 4.1 (GAO, 2005).

![Figure 4.1. Illustration of how the MDB varies between IIHS, to the left, and LINCAP, to the right.](image)

Because of the altered heights above ground, there will be a different impact of the MDB into the vehicle. While the barrier used by LINCAP will most likely hit the sill of the car, the barrier used by IIHS will most likely hit above the sill and just the door. Figure 4.2 shows the position of the head of the two crash test dummies used in the tests, compared to the two barriers used by IIHS (to the left) and LINCAP (to the right). The head of the dummy that is placed in vehicle is at the same height as the MDB by IIHS, while the MDB from LINCAP hits the dummy under the head, see figure 4.2.

![Figure 4.2. The heights of the MDBs; the IIHS barrier to the left and the LINCAP barrier to the right.](image)

The shape of the front is differing between the two barriers where IIHS, to the left in figure 4.3, has angled corners, while IIHS, to the right in figure 4.3, has sharp edges. Both barriers are made of aluminium with a honeycomb structure, to imitate a deformable front of a vehicle (IIHS, 2008).
Figure 4.3. An overview from above, on the different shapes with the MDB from IIHS to the left and LINCAP to the right.

As described in chapter 2 about the organisations’ side impact tests, there is a difference between the velocity and the weight of the MDB. A higher speed has a big influence to the impact and produces potentially more injury and damage. The kinetic energy is calculated as in equation 4.1, where the energy for tests by LINCAP and IIHS are calculated in equation 4.2 and 4.3. The 36% greater energy in the crash test by LINCAP than IIHS is calculated in equation 4.4.

\[ E_K = \frac{1}{2}mv^2 \]  \hspace{1cm} (4.1)

\[ E_{LINCAP} = \frac{1}{2}1368kg \times (61km/h)^2 \] \hspace{1cm} (4.2)

\[ E_{IIHS} = \frac{1}{2}1500kg \times (50km/h)^2 \] \hspace{1cm} (4.3)

\[ \frac{E_{LINCAP} - E_{IIHS}}{E_{IIHS}} \times 100 = 36\% \] \hspace{1cm} (4.4)

These differences are likely to be one reason for the different results from IIHS and LINCAP.

4.1.3. What to protect in the side impact test by LINCAP?
As the LINCAP test is the one that results in a higher force on the SID-IIs, a study of their tests from 2010 and 2011 was done in the project. All of the tested vehicles in 2011 and 2010 (with the SID-IIs placed in the rear seat) had a side curtain in the rear seat to protect the head, except for Ford Mustang and Hyundai Genesis from 2010. The only vehicle with a thorax/pelvis airbag was Chevrolet Cruze. The parameter results and the ratings of the rear seat in the vehicles are shown in table 4.2. The letter in the Segment column, in table 4.2, indicates the size of the cars. B is for small cars, C is for medium cars, D is for large cars, E is for exclusive cars, S is for sport coupes, M is for multipurpose and J is for off-road vehicles.
Of the 36 vehicles eleven of them were not rated with a maximum score of five stars. The eleven highest values for the combined pelvic force and HIC index are marked with a bold style. From the table it is shown that the eleven highest values for combined pelvic force is also the ones that did not earn a maximum score, and received a lower rating of the rear seat. The eleven highest values for HIC index are not necessary the same vehicles that did not earn a maximum score. Within the group of vehicles that did not earn the highest rating, all car segment types were represented indicating that the car segment did not influence the final rating.
To receive a maximum rating in the side impact test by LINCAP with a MDB, both head and pelvis need to be protected as mentioned in chapter 2.5 LINCAP. Since almost all vehicles have an inflatable curtain that covers the side of the rear seat, the head of the SID-IIIs is more or less protected in the test, but not the hip.

4.2. How come some cars get a lower rating than others?
A comparison of 30 vehicles, tested by LINCAP, of the model year 2011, was made in the project. The comparison was done to see how the difference in size of the vehicle and the size of the compartment might result in a lower rating of the rear seat. The values were categorized by the rating of the rear seat in the vehicles, one to five stars.

The comparison of the rear-seated occupant’s height of the hip-point is shown in figure 4.4. The height of the hip-point is measured from the ground level to the rear-seated dummy’s hip-point. From figure 4.4 it is demonstrated that a higher location of the hip-point does not necessarily lead to a higher rating of the rear seat. The five-star rated vehicles are represented in a large spectrum from a low to a high location of the hip-point.

Figure 4.4. Comparison of the heights of the hip-point of the rear seated occupant and the rating obtained.
Figure 4.5 shows how the rating of the rear seat depends on the sill top heights in the vehicles. As seen in the figure, it is a large spectrum covered by the five-star rated vehicles. The height of the sill does not seem to affect in how well protected the rear seated occupant is.

A comparison of the distance from rear door trailing edge to impact centreline of the barrier is shown in figure 4.6. From the figure it is shown that the rating of the vehicle may not be affected by how wide or narrow the rear door is.
In figure 4.7, it is shown that vehicles with various lengths were rated with five stars. The length of the car may not affect the rating of the rear seat in the crash tests since the five-star rated vehicles are represented from shorter to longer vehicles.

![Vehicle length at centerline](image)

Figure 4.7. Comparison of the vehicles’ length and the rating obtained.

A comparison of the wheelbase of the 30 vehicles is shown in figure 4.8. The figure shows that vehicles with a five-star rating are represented by both shorter and wider wheelbases. The ones who did not earn a maximum rating were within the same interval as the ones who obtained a five star rating.

![Vehicle wheelbase](image)

Figure 4.8. Comparison of the vehicles wheelbase and the rating obtained.
The distance from the dummy’s arm to the door tells something about the size of the compartment and how wide the rear seat is. The measurements of the compared vehicles are shown in figure 4.9. Among the five-star rated vehicles there was a varying distance, reaching from the lowest to the highest among the compared vehicles.

Figure 4.9. Comparison of the distance from the dummy’s arm to the inner door panel and the rating obtained.

The measurement from the hip-point to the door indicates how far away from the door the occupant is seated. Figure 4.10 shows the different distances, hip-point to the door, among the compared vehicles. The measurements from the five-star rated vehicles were represented in a wide range of dimensions and did not show at any preferred distance to achieve a maximum rating.
Figure 4.10. Comparison of the distance from the dummy’s hip-point to the inner door panel and the rating obtained.

The penetration at the occupant hip point is measured at the exterior of the vehicle and compared to the vehicle’s rating in figure 4.11. The figure shows that the maximum rated vehicles were represented among both the ones with a larger intrusion and those with a minor intrusion.

Figure 4.11. Comparison of the maximum penetration at occupant hip point and the rating of the vehicle and the rating obtained.
None of these parameters seemed to affect how the vehicles were rated, which point out that all kinds of vehicles may be in need of a side airbag in the rear seat. There may still be some parameters that were not found in the test reports that affect the protection of the dummy during a side impact.

4.3. Benchmarking of the existing thorax and thorax/pelvis airbags
In the search for the existing rear side airbags, the purpose was to find information about how the airbags were mounted in the car, the size it had and how it got rated in the crash tests. The mounting of the side airbag depends on what the rear seat looks like in cars today. The purpose was to find out what the majority of the rear seat looks like and whether the airbags are mounted in the seat or at the wheelhouse. The database Autoliv GoBench was used to search for available rear side airbag modules.

The inflators in the available airbag modules are shown in figure 4.12.

![Inflators](image1)

ASH 1 Renault Laguna
AHS 25 (Hyundai Genesis)
HSI, Thorax (Fiat Croma, Fiat Stilo)
NASI2 (Seat Exeo)
NASI V2 (Volkswagen Passat, Audi A6)
SHI - 12/25 V038 (Mercedes CLS)
SPI 2 (Audi A8)
SPI - 2 (Volkswagen Tiguan)
SPI - 2/10 (Peugeot 308, Volkswagen Golf)

Figure 4.12. The inflators found in the existing rear side airbags.

The dimensions and the type of inflator are listed in appendix 3.

The existing rear side airbags are both of thorax and thorax/pelvis types. Each airbag is shown in figure 4.13. The sizes of the airbags are not comparable in the figure since they have been scaled down to fit and are here intended just to show different shapes. The overall dimensions of the airbags are seen in appendix 3.
The available rear side airbags are lined up in appendix 4 where it is pointed out if they have a coated or uncoated material and also the location of the airbag module. The coated fabrics have a thin layer of silicone to offer a better strength and to be airtight. The results from crash tests of the vehicles and the supplier of the airbag modules are also shown in appendix 4.

Among the cars that were compared in the benchmarking, found in Autoliv GoBench, most had the airbags mounted in the rear seat bolster, i.e. in the side of the rear seat. It was not all of the vehicles that were tested by IIHS or LINCAP. Of the tested vehicles, all of them were rated with a maximum grade in the rear seat except Volkswagen Passat, which only scored 4 stars in LINCAP’s test.

The height of the airbags varied between were 420 to 580 mm and the width varied between 270 to 410 mm. Five out of seven available airbags had coated fabrics, which has the effect to provide more strength and to be airtight, but is more expensive than uncoated material. The existing rear side airbags were later compared to the new airbag concepts to see how they varied in protection area.
4.4. The rear-seated occupant

FARS (Fatality Analysis Report System) is a database where all traffic accidents that occur in the USA where someone died within a month from the crash is reported. FARS data was collected from the years 2005 to 2009, which was the latest data, and it was found that 3000 rear seat occupants were involved in a fatal side impact during this time. The fatal injured were categorized by age in figure 4.14. From the percentage in the figure it is shown that 34% of the fatalities were in the ages zero to fourteen years old. This group is noticed since the occupants in these ages may have a lower seating height than the adults, and are not as protected by the side curtain as the adults.

![Pie chart showing age ranges of fatal injuries from 2005 to 2009.](image)

Figure 4.14. Ages of the fatal injured in side impact collision in the years 2005 to 2009.

The most frequent impact angles found in the FARS data was occurring at three and nine o’clock as seen in figure 4.15 (where twelve o’clock is a frontal impact and six o’clock is a rear impact). Maltese et al. (2007), on the other hand, found in a study of the Crash Injury Research and Engineering Network (CIREN) database that 88% of the side impacts had a direction of 30 degrees forward of a pure lateral, which is positioned ten and two o’clock. The difference between the two studies is that Maltese et al. (2007) was only including the rear-seated occupants in the ages four to fifteen, while the study done in this project included all ages.
In figure 4.16 it is shown that 43% of the fatal injured were seated with no restraint system and 32% of the occupants were wearing a lap and shoulder belt that is mounted in every vehicle.

From the FARS data it is noticed that the children, from zero up to fourteen years old, represent a large percentage of the fatally injured. In these ages there is no further protection than child restraint systems and seat belts. Since the head is a frequent body region exposed to
injury for children in side impacts, as showed by Bohman et al. (2009), there is an area beneath the side curtain that may need to be covered by a side airbag.

An angled side impact or a hard breaking by the driver may result that the occupant’s body will be moving forward and will be positioned outside the protection area of the side curtain. A study of children, seated in the rear seat with a belt and different kinds of child restraints was done. By pulling the belt it was locked and the child was told to lean forward. This visualised about how far the child’s body would reach in a breaking situation, see figure 4.17.

Figure 4.17. An illustration on how the children’s body is moving forward in a breaking, where the left one is seated on a booster with back and the right child is seated on a booster without back.

The area of impact points will be wider as a result of these situations. The belt is the only effective safety equipment that is used to keep the occupant in place and to reduce the impact points at the door panel in an angled side impact or in a breaking.
5. The development and the tests of the airbag concepts

In this chapter there are four activities presented. The chapter contains the development of the airbag concepts and the activities where the airbags were tested in several ways to meet the expected and newfound demands.

Figure 5.1 presents a view over of the different tasks that were performed in the project, as major steps in the development of a new concept of a rear side airbag.

The major steps were (1) concept generation where three airbag concepts were developed; (2) a high temperature test to check the reliability of the airbag; (3) a sled test and (4) an Out-Of-Position test.

The size and shape of the new airbag concepts were inspired by existing airbags to take advantage from previous manufacturer’s design aspirations, but was redesigned to match the purpose of the project. A thorax/pelvis airbag from Autoliv was used as a base line to form the new side airbags.

5.1. Concept generation

By borrowing a car from a vehicle seller, it was possible to carry out a concept generation session where three airbags were formed from when the dummies were seated in the vehicle compartment. Prototypes were cut and sewn and the protection area was tested in the vehicle with the dummy. The shapes of the airbags were established by placing a SID-IIs and a Hybrid-III 6 years old in the rear seat. The SID-IIs was placed approximately like the one in the side impact test performed by LINCAP and described in the test report by NCAP (2010).

There were various variants of side airbags tested in the workshop to find out how they could be protecting the rear-seated dummy. The aim was to protect the body parts of the dummy, found to be the most exposed body regions among children and adults but keeping the airbag as small and easy as possible.

In the chapter 3.1 Front-End Process as an overall focus, there was four steps described for the activity Generate Product Concepts. The steps that were used in this project were a search internally and a search externally. Using an earlier developed rear side airbag as an initial point, the already explored ideas were used. The things to keep from the existing airbag were the position of the inflator and to use the contours of the airbag as a base line when creating the new ones. When searching internally, the ideas generated in the project group were about how several concepts with various safety performances could interest customers with different intentions.

The way of selecting product concepts is mentioned in chapter 3.1 where Ulrich and Eppinger (2008) mention intuition and building and testing prototypes as a way to make the decisions. The decisions about the shape and size of the airbags were done in collaboration with an engineer at Autoliv and the experience and intuition from the people at the company where given large attention. The decisions were done by building prototypes to see how they acted in the compartment with the dummy.
5.1.1. Positioning the SID-IIs
The placement of the dummy was done according to LINCAP procedure to establish the design of the airbag so that it protects the expected body parts. With a centred location of the driver seat, the angle of the seat was measured at the headrest posts to be 8,9°. The length from left knee to driver seat back was 222 mm, chest to seat back was 434 mm and nose to seat back was 475 mm.

![Figure 5.2 Positioning of the SID-IIs in the vehicle where the left figure is from the concept generation in the project and the right picture is from full-scale test by LINCAP.](image)

The measurements from the side of the dummy to the side of the door were: H-point to door 168 mm, arm to door 133 mm, head to side window 372 mm and head to side header 236 mm.

5.1.2. Existing thorax/pelvis airbag
The existing rear side airbag by Autoliv (seen in figure 5.3) that was used during the concept generation had an overall length of 520 mm and a width of 330 mm.

![Figure 5.3. The existing rear side airbag that was used as an initial point when creating the new airbag concepts.](image)

The airbag was placed in the rear seat and filled with air to see what part of the dummy that was protected. From the shape of the airbag it was possible to see how the new ones could be improved.
5.1.3. Thorax airbag concept
One of the three side airbag concepts that were formed during the workshop was a small thorax airbag, see figure 5.4.

![Figure 5.4. The thorax airbag tested in vehicle and compared in size to the original bag.](image)

The most frequent exposed body part of adult occupants in side impact is thorax. A smaller side airbag will only protect thorax in a side impact. The overall dimensions for the side airbag were 420 mm in length and 350 mm in width. The shape was established by shortening the existing airbag and cut a radius around the dummy’s thorax area, while the upper part was kept.

5.1.4. Thorax/pelvis airbag concept
The new thorax/pelvis airbag was intended to offer a larger protection area than the existing one. The shape of the outline was almost the same as the existing one but an increased height and area for pelvis was added, see figure 5.5.

![Figure 5.5. The thorax/pelvis airbag tested in the vehicle and compared in size to the original bag.](image)

The overall dimensions of the thorax/pelvis airbag were 570 mm in length and 360 mm in width. The height and the width of the upper half were increased by 20 mm to improve the volume and offer a better protection. The airbag aim to offer protection to the exposed thorax region and also the pelvis area, found to be important to protect to achieve the highest rating in the side impact tests.
5.1.5. Thorax/pelvis extended airbag concept
Since the most exposed body part of children is the head, an airbag that protects their head from hitting the windowsill was developed, see figure 5.6. The large thorax/pelvis airbag is also supposed to protect the hip and the chest of adults.

![Figure 5.6. The extended thorax/pelvis airbag tested with two dummies and compared in size to the original bag](image)

The extended thorax/pelvis airbag is meant to cover the area all the way up to the side curtain, to protect the child occupant’s head where the side curtain does not protect. The overall dimensions of the large thorax/pelvis airbag were 650 mm in length and 440 mm in width. The airbag was developed during several steps where the outline was increased to cover up enough area of the door interior.

5.1.6. Comparison of the size
The existing side airbags and the ones that were designed in the workshop were compared in a chart, to see how the size varied and where the new ones were placed compared to the existing ones (see figure 5.7). The chart shows the view over how the length and width vary and also on how the new concepts were improved. The rear side airbags in the chart are the ones from the chapter 4.3 Benchmarking of the existing thorax and thorax/pelvis airbags were thirteen vehicles were found, equipped with rear side airbags.

Benchmarking is mentioned as one activity in the chapter Front-End Process as an overall process, and to be used as a method to bring up new ideas about the product and the design.
The blue circles point out the three new airbag concepts. The extended thorax/pelvis bag (number one) has an obvious larger length and width than the existing ones in the rear seat. With a larger airbag and volume comes a larger protection area, but it requires a bigger inflator to fill the large volume. The thorax/pelvis bag (number two) is among the wider ones and has an increased height to offer a better protection area to pelvis. The thorax bag (number three) was among the smallest to offer specific protection of thorax in a side collision. A smaller airbag is a cheap alternative; because of the use of lesser fabrics and that a smaller volume requires a smaller, and hence cheaper, inflator.

5.2. High temperature test
The high temperature test in +85°C Celsius is used to evaluate the strength of the bag. Three airbags of each concept were tested with both upper limit inflators and nominal inflators to be sure of the strength, since the amount of gas may vary with temperature and by batch. In a normal distribution curve, the upper limit gas is positioned beyond three standard deviations. Upper limit inflators are more powerful than the nominal one and only used for this test where the strength of the bag is evaluated in extreme conditions. If the airbag stands the extra pressure of heat, the bag may be considered strong enough to be used in a car and that the bag keeps its permeability performance during storage and when trigged in high temperatures.

All airbags had the same seams around the ventilation hole, as seen in the picture to the left in figure 5.8. The thorax bag and the thorax-pelvis bag had a ventilation hole of 40 mm in diameter, which resulted in only one seam around the hole. The extended thorax-pelvis bag had a ventilation hole of 30 mm in diameter, which resulted in two seams left around the ventilation hole.
The extended thorax/pelvis bags were intact after the high temperature test and the outer seams remained intact. The ventilation holes in the thorax and the thorax-pelvis bag were torn (see figure 5.8).

The solution of the torn ventilation hole was that one extra seam was sewn around the 40 mm hole.

5.3. Sled tests
The new airbag concepts were tested in a sled test to see how well they protect the rear-seated occupant and the different body regions. The airbag concepts were analyzed and the results are presented in the result chapter of this report.

5.3.1. Test planning
To validate and to further understand how the airbags perform, a set of 35 sled tests were planned.

The idea was to make the wagon accelerate like in the full-scale test by LINCAP, to validate the new airbags with a similar pulse and an approximate similar force on the dummy. These sled tests are referred to as correlation tests. The parameters that were possible to adjust in the test method, to achieve the same force on the dummy, were (1) the velocity of the sled, (2) the dimensions of the iron bars, (3) the trig time, (4) the distance between the sled and the trig system, (5) the positioning of the dummy and (6) the foam behind the door panel.

As mentioned in the chapter 3.1 Front-End Process as an overall focus, the sled tests are a way to test the performance. The sled tests were done to evaluate how well the airbags perform and what could be improved to meet the customer needs.

Three types of dummies were used during the tests: (1) the SID-IIs, (2) the new WSID5 (World Side Impact Dummy, 5th percentile female) and (3) a Hybrid-III with the size of a 6 years old child. The SID-IIs is the dummy used in the LINCAP tests today and the results from the new airbags may be compared to full-scale tests by the organisation. The Hybrid-III will be used to obtain crash data about children and their need for greater protection. The WSID5 is, as described earlier, expected to be the next dummy to be used in different rating tests for the rear seat. Therefore it is interesting to see how the dummy responds in the tests with the different airbag types, and to find out if there are any differences between the SID-IIs and the WSID5.

5.3.2. The preparation and the correlation of the sled test
Collected parts of the rear seat in a Chevrolet Cruze and a half body in white from the vehicle was used for the sled test (see figure 5.9).
In the side collision test by LINCAP, the angle of the car and the barrier is 27° relative to the crash track. The dummy response comes from the reaction of the intrusion of the barrier to the side of the car and this impact angle is calculated to be about 10° relative to the car’s coordinate system. Therefore the static sled test in this method was placed with a 10° angle relative to the impact sled.

Since almost all of the new vehicles on the market today have a side curtain that covers the rear seat, an inflatable curtain from Autoliv was used in the tests (see figure 5.10). The purpose with an inflatable curtain is to protect the head of the front and rear seated occupants in a side impact. It will not have any influence on the results of the side airbag other than the test with the 6 years old where the head accelerations are counted. In all other cases the focus will be on the rib deflections, spine acceleration and pelvis forces and not the head.

The iron bars are placed in the front of the sled, seen in the picture to the left in figure 5.11. The wagon, in the right picture in figure 5.11, will hit the bars on the sled and make it accelerate. Depending of the dimensions of the bars in addition to the wagon’s velocity, the acceleration of the sled is determined. Thinner bars give a slower and minor acceleration and a crash that is not as aggressive. Thicker bars give a higher energy interchange and a slope of the acceleration curve that is more drastic than with thinner bars.

According to Per Andersson, Engineer at Autoliv Sweden AB
The trig time is the time from the first contact between the sled and the iron bars, to when the airbag gets the “fire” signal. In the test, the signal comes from when a reflector, mounted on the yellow sled, passes a sensor by the side of the track. Changing the trig time, the airbag will go off sooner or later, and it will affect in which time period the dummy interacts with the airbag.

The distance between the trig system and the sled is another way of adjusting the time for the “fire” signal.

The distance between the dummy and the door will be affected when the body hits the pane. The positioning of the dummy has to be identical to the test by LINCAP, if not the credibility of the test is lost and further testing will not have any real case reference. These measures between the dummy and the vehicle interior were collected from NHTSA (2010).

Placing foam behind the door panel adjusts the hardness of the impact of the body regions. To adjust the deflection of the ribs and the force on pelvis the upper part of the door panel was filled with soft foam, and the lower part with high-density foam.

The results from the correlation tests were after 17 tests similar enough to the full-scale test by LINCAP. The parameters that were changed during the correlation tests were the padding in the door (see figure 5.12), the position of the trig system, the velocity of the sled, the dimensions of the iron bars, the angle of the rear door (see figure 5.13) and the position of the airbag module (see figure 5.14).
The angle of the door was changed from an intruded position to a straight position.

The position of the bracket that holds the airbag, behind the bent seat in the left picture and a glimpse of the bracket and the airbag to the right of the seated dummy.

The position of the original airbag module was the same as in the vehicle, calculated by measures from CAD-data. The car model used in the sled series is a European car with a European seat. The European model does not have any rear side airbag and the rear seat has a different design to the one in USA. These differences might have some influence on the test results.

5.3.3. Tests with the new concepts
An airbag was mounted on the bracket by the side of the seat before each test, see figure 5.14. The dummy was positioned and measured to sit in the same position as in the full-scale test. The dummy was painted on the five ribs, pelvis and the shoulder in order to mark the impact place on the airbag. Photos were taken of the sled, the dummy and the iron bars before and after each test. To evaluate and analyze the sled tests they were recorded by four cameras; one top view, one perpendicular view, one front view and one angled view with zoom. All raw-data collected by the dummy was evaluated and plotted in graphs and the comparisons were put together. To evaluate the results further, Excel was used to normalize the values and simple graphs were created to visualize the differences and the similarities between the concepts and the different dummies.
During the tests of the three new concepts, smaller changes of the airbag module were done such as (1) the size of the ventilation hole, (2) position of the bracket that is placed by the seat and where the airbag module is mounted on. These changes were done to evaluate the effects and were an attempt to optimize the offered protection by the airbags.

To evaluate the obtained results, the pelvis acceleration values were normalized to the original bag, which was given the value of 1. A higher value than 1 indicates a worse result than the original bag and a lower value indicates an improvement of the concept compared to the original bag. The reason the values were normalized was that the test method did not offered enough high pelvis forces and any other comparison would be misleading. The comparison did only show if the results were better or worse than the original bag. It was not possible to make any conclusions of potential risk of injury from the normalized comparison.

5.3.4. Thorax airbag results
The differences between the two tests with the thorax airbag were a reduced diameter of the vent hole, from 40 mm to 30 mm (see figure 5.15). The change was done to make the airbag keep the pressure for a longer time, but it also increased the pressure in the bag. The increased pressure resulted in a higher force on the ribs than the earlier test with a bigger vent hole.

![Image of thorax airbag](image)

Figure 5.15. The reduced dimension of the ventilation hole on the thorax airbag, from 40 mm to 30 mm.

The conclusion from the comparison of the pelvis acceleration, see figure 5.16, was that the thorax bag did not offer any protection for the pelvis and resulted in high pelvis acceleration values. The rib deflections were lower than in the test without any bag and than the original bag.

![Pelvis Acc Thorax bag](image)

Figure 5.16. Comparison of the normalized values for the pelvis acceleration for the thorax/pelvis extended airbag.
The test with the WSID5 showed that the thorax bag did not perform as good as the original bag, but compared to the test without any airbag there is a bigger effect with a thorax airbag than in the tests with SID-IIs.

The results from the sled tests with the thorax airbag points out the effect of a reduced rib deflection than in the test without any airbag. The high pelvis acceleration and high pubic force motivates the need of a thorax/pelvis airbag in the rear seat.

5.3.5. Thorax/pelvis airbag results
The change from the first test with the thorax/pelvis airbag and the second test was a straightened position of the bracket, the vent hole and the inflator. The airbag offered a satisfying protection of the ribs, but there was a high force on iliac and acetabulum. From changing the angle of the bracket, the aim was to place the airbag in a better position where the pelvis area was covered more properly, see figure 5.17. The ventilation hole was reduced from 40 mm to 20 mm and the gas inflator was one step less powerful. The reduced vent hole and the smaller gas inflator was an attempt to make the airbag softer and keep the air for a longer time.

Figure 5.17. The varying angle of the airbag to offer a better protection of pelvis.

The thorax/pelvis bag performed better than the original bag looking on the rib deflection but was similar on the pubic acceleration. Compared to the test without any airbag there is an advantage of using the thorax/pelvis airbag, as seen in figure 5.18.

Figure 5.18. Comparison between the normalized values for the pelvis acceleration for the thorax/pelvis airbag.
The tests with WSID5 showed good results using a thorax/pelvis airbag compared to the test without any bag (as seen in figure 5.18), but the results for the new concept is slightly higher than the original bag with WSID5.

The thorax/pelvis airbag shows the need for an airbag, in comparison to the test without any bag. The attempt to straighten up the airbag to optimize the protection area of pelvis did not lead to any better result in the sled test. The original bag does not perform much worse than the new concept.

5.3.6. Thorax/pelvis extended airbag results
The thorax/pelvis extended airbag was tested in two tests with the SID-IIs and the WSID5. The changes from the two tests were the same as in the tests with the thorax/pelvis airbag where the bracket was placed in a more straightened position. The change of position was made to force the airbag to deploy closer to the back of the seat in order to offer a better protection of pelvis. The inflator was adjusted one step less powerful to reduce the pressure in the airbag. The main problem with the airbag was that it had trouble protecting the chest; it did not push the arm away upward and forward as smaller airbags do. The airbag inflated above the arm (see figure 5.19) and then kept pushing the arm toward the ribs, causing high rib deflection values.

![Figure 5.19. The arm of the dummy is caught in the deployment of the thorax/pelvis extended airbag.](image)

![Pelvis Acc Thorax/Pelvis EXT bag](image)

The normalized values, figure 5.20 show that the pelvis acceleration is very similar to the original bag. For adults the thorax pelvis bag offers a protection just as good as the thorax pelvis extended bag.
5.3.7. Results Hybrid-III 6 years old
The Hybrid-III 6 years old, was tested with the thorax/pelvis extended airbag and with a child booster, to see how well the airbag protect the head of the dummy. The dummy was also tested with and without the inflatable curtain, without any side airbag. From these tests it was noticed that the inflatable curtain, used in the tests, did offer a protection of the dummy’s head.

The tests with the thorax/pelvis extended airbag and Hybrid-III 6 years old dummy did show a lower value for the HIC index than the other tests with the dummy (seen in figure 5.21). Compared to the results with only the inflatable curtain the value was reduces by a third, indicating that the protection offered by the thorax/pelvis extended make a difference for the head injuries of the children.

![Hybrid-III 6 years old, HIC index](image)

Figure 5.21. HIC index for the Hybrid-III 6 years old with four different setups.

The thorax/pelvis airbag was also tested, to see how well an airbag without the extra protection area above the windowsill. From figure 5.22 it is showed from the two bars to the left that the thorax/pelvis extended airbag did offer a better protection to the child’s head than the thorax/pelvis airbag.

5.3.8. The risk of thorax and abdomen injury for the SID-IIs
The values from the tests with the SID-IIs were compared to the existing risk curves from a full-scale test with a SID-IIs. The WSID5 had no such validated risk curves; therefore will the results from the tests with the WSID5 will not be evaluated into a risk factor. The normalized values for each concept, presented earlier in chapter 5.3.4 to 5.3.6, only tell if they performed better or worse and do not tell anything about the risk.

Figure 5.22 shows the risk of AIS 3+ and AIS 4+ injury for thorax for each, performed with a SID-IIs dummy, with the airbag concepts. For each bar there is a letter, T for thorax airbag, T/P for thorax/pelvis airbag and T/P E for thorax/pelvis extended.
Figure 5.22. The injury values for the airbag concepts in the tests with the SID-IIs.

The results show that all the bag concepts clearly reduce the risk of AIS3+ and AIS4+ injuries compared to the original bag and in the test without any airbag. About the results from the sled tests

5.3.9 About the results
The thorax/pelvis extended airbag, tested with the Hybrid-III 6 years old, is shown to the left in figure 5.23. The mark at the upper part of the bag indicates where the child’s head hit the bag in the test. The thorax/pelvis airbag is shown in the middle in figure 5.23 and the marks on the airbag show that it covered the body regions from the shoulder to the hip. The marks on the thorax airbag indicate that the bag had a protection area of all of the ribs and also the shoulder, seen to the right in figure 5.23.

It was discovered that the time for maximum deflection of the ribs and the peak values for pelvis did not occur at the same time in the sled tests. The problem with the airbag concepts
was that the airbag did not had enough gas left by the time of the pelvis force peak to provide a satisfying protection, while thorax was showing good values (seen in the upper and lower graphs to the left in figure 5.24). The other way around showed that when the pressure in the bag was high enough until the impact of pelvis, there was a too high pressure for thorax (seen in the upper and lower graphs to the right in figure 5.24).

Figure 5.24. The graphs for the ribs and pelvis of the dummy in two tests.

The first (1) peak in figure 5.24 is caused by the airbag while inflating and pressing on the dummy. The second (2) peak in figure 5.24 is from when the gas has drained and the dummy hits through the bag and into the door panel. When these two peaks are at the same height there is an optimized situation. A higher pressure in the bag will push up the first peak and then lower the second, and the other way around. When the two peaks are at the same height, there may also be an unstable situation in real life, because of several parameters that may affect the airbag in different ways to lower the pressure. The way to solve this is to make the first peak higher than the second, making it more stable. The aim is to spread out the energy from the impact and let the body regions that tolerate a higher force than others to take a larger hit.
5.4. Out-Of-Position Tests
The seating positions that have been selected by the technical working group are not any ordinary seating positions but worst-case positions relative to the side airbag. The airbags that were chosen for the Out-Of-Position tests were the airbags that offered the best protection of the dummy in the sled tests. The chosen ones were:

- Thorax airbag with a P 12 inflator, 40 mm vent hole and placed in an original position.
- Thorax/pelvis airbag with a P 14 inflator, 40 mm vent hole and with the lower hole for the bracket moved forward.
- Thorax/pelvis extended airbag with a P14 inflator, 30 mm vent hole with the upper hole of the bracket moved forward.

For this project there were two positions to be tested. Forward facing and rearward facing with the Hybrid III 3 years old dummy, see figure 5.25. These two positions are known to be the most harmful ones and the purpose with the OOP-testing was to get a hint of how these bag perform in such tests. Normally the car manufacturer demands the OOP tests but in this stage the bag is still under development and therefore the OOP is just used for further evaluation and more positions were not required for this project. The test setup was done by the recommendations of the side airbag OOP Injury Technical Working (Technical Working Group, 2003).

![Figure 5.25. The OOP setup with the Hybrid III 3 years old dummy, forward facing on booster to the left and reward facing on knees to the right.](image)

Each test was photographed before and after the airbag was fired off and also recorded. The collected data was put together in a spreadsheet in order to compare the obtained values to the reference values, see table 5.1. The values in table 5.1 are from the test that resulted in the highest values on the dummy. The values indicate how many percentage of the acceptable value that was reached in the test.
Table 5.1. Results from the airbag concepts in the OOP-tests.

<table>
<thead>
<tr>
<th>TEST PROPERTIES</th>
<th>HIGHEST VALUE</th>
<th>Detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorax P12 forward facing</td>
<td>288%</td>
<td>LN Extension moment</td>
</tr>
<tr>
<td>Thorax P12 forward facing</td>
<td>424%</td>
<td>LN Extension moment</td>
</tr>
<tr>
<td>Thorax Pelvis EXT P14 forward facing</td>
<td>91%</td>
<td>UN Twist moment</td>
</tr>
<tr>
<td>Thorax Pelvis EXT P14 forward facing</td>
<td>95%</td>
<td>LN Tension</td>
</tr>
<tr>
<td>Thorax Pelvis EXT P14 forward facing</td>
<td>80%</td>
<td>UN Twist moment</td>
</tr>
<tr>
<td>Thorax Pelvis P14 forward facing</td>
<td>131%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax Pelvis P14 forward facing</td>
<td>118%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax Pelvis P12 forward facing</td>
<td>127%</td>
<td>LN Extension moment</td>
</tr>
<tr>
<td>Thorax Pelvis P12 forward facing</td>
<td>99%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax P12 rearward facing</td>
<td>75%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax P12 rearward facing</td>
<td>111%</td>
<td>Thorax deflection</td>
</tr>
<tr>
<td>Thorax Pelvis EXT P14 rearward facing</td>
<td>80%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax Pelvis EXT P14 rearward facing</td>
<td>74%</td>
<td>LN Twist moment</td>
</tr>
<tr>
<td>Thorax Pelvis P14 rearward facing</td>
<td>66%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax Pelvis P14 rearward facing</td>
<td>56%</td>
<td>LN lateral moment</td>
</tr>
<tr>
<td>Thorax Pelvis P12 rearward facing</td>
<td>60%</td>
<td>Spine acceleration</td>
</tr>
<tr>
<td>Thorax Pelvis P12 rearward facing</td>
<td>76%</td>
<td>Spine acceleration</td>
</tr>
</tbody>
</table>

The neck is the body region that is in focus in the OOP-test with the Hybrid-III 3 years old. The forces on the upper and lower neck are measured in several directions to determine if the bag is too harmful for the occupant.

From the results of the testing it is clear that the values from the tests with the thorax bag highly exceed the limit for acceptable. The high values of the spine will also need further investigation and more research is needed to fully understand the behaviour of the spine in order to create a bag that is less harmful in OOP. Solutions to lower the high values may be to change the shape of the bag, change the inflator and the vent hole.
6. Discussion

The chapter discusses the results as well as the work process and methods utilised in the project.

About the results

The aim of the project was earlier described in chapter 1.3 The Purpose.

- A summary of what is expected of the rear seat safety in the future
- A benchmark review over the existing rear seat airbags in the market today
- A product that meets the discovered demands
- A validation of the product with simulation, sled or full-scale test
- A comparison between the existing dummy with the coming one

The outcome from the project resulted in:

- The summary of what is expected of the rear seat safety in the future gives that the new WSID5 will be integrated in the future crash test. Also more focus will be on the children as they are the most frequent occupants in the rear seat. These conclusions were made together with Autoliv Research employees and Douglas Stein, Autoliv representative at NHTSA in USA.
- The results of the benchmark are presented in appendix 3 and 4. The comparison between the existing rear side airbags and the new concepts is shown in chapter 5.1.6 Comparison of the size.
- Three airbags concepts were generated with different purposes to protect the rear-seated occupant.
- The concepts were tested in the sled test and they all need further improvements to be optimized.
- The SID-IIs and WSID5 were compared by the results in the sled tests. WSID5 follows the obtained curves of the SID-IIs but they are generally marking lower values and the spine acceleration was affected by the deployment of the bag, which was not observed by the SID-IIs. The rib deflections were less sensitive on the WSID5 than on the SID-IIs.

The side impact test with a MDB by LINCAP is found to be the more aggressive in comparison to the same test by IIHS. The higher velocity of the sled in the test by LINCAP, compared to the lower in IIHS, resulted in a 36% higher kinetic energy. The airbag in vehicles is a way to save lives, but the velocity has a big influence on how severe the injuries in a collision may be.

Combined force on pelvis is found to be the only common factor that causes a downgrade in the rating of the cars by LINCAP. Different parameters were investigated but no common thread was found to make any conclusions on what may cause these higher pelvis forces or a lower rating. There are a lot of possible reasons that may result in a higher force on the dummy, but these are not found in the test reports. The stiffness of the B-pillar and the thickness of the door are examples of parameters that also may affect the intrusion, but not available from the test reports.

Of the collected FARS-data, 34% were children and youths between the ages zero to fourteen. Adults and children need protection of different body regions. During the project it was clear that a side airbag has its limitations when it comes to an optimized protection area. The airbag will only give optimal protection when the child is seated on a booster and with a seat belt.

In the case with the thorax/pelvis airbag there was a problem with the positioning of the pelvis part of the airbag. The attempts to straighten up the airbag, to optimize its position, did not lead to any remarkably better position. The results from the bag were still satisfying but a bigger protection area of pelvis would make this rear side airbag even more motivated. The problem with positioning the lower part of the airbag is seen in figure 6.1 from when the airbag was tested in the high temperature test.
The airbag leave a gap between the seat back and the lower part of the airbag.

The airbag may offer a better protection area with a new design of the lower part.

About the work
The possibility to have a place at the office at Autoliv in Vårgårda did bring a lot of inputs to the project and made it possible to reach a lot further in the work than if it would have been held at the University in Skövde. With the possibility to involve a lot of employees from Autoliv, there were inputs from several departments and an utilisation of the experience from different directions.

In the project there were a lot of decisions to be made. Since there was a limit of knowledge in the project group about some of the choices, a lot of faith was put into the more experienced people at the company. The group members were still allowed to discuss alternative solutions and offer new inputs in some of the work that perhaps sometimes were done by routine.

The planning method *Visible Planning* (Hines et al., 2005), used at Autoliv, could have been used in a more effective way to take advantage of the positive things it offers. Since the final activity in the project was changed in several occasions, from a full-scale test into a sled test, the activities to reach the final task were changed numerous times. All activities involved in the project were not fully understood in the beginning, basically because of the complexity in the tests and evaluations in the work of developing an airbag. However, better understanding of relevant issues was achieved as different activities were carried out along the project.

The Front-End Process, as an overall method in the project, was a useful way to categorize the activities in the project. From the different formulated tasks in the Front-End Process, it was possible to relate the activities in the project to the different methods learned during the education at the University in Skövde. In some times of the project it was hard to make use of all the proposed methods in the chapter *Front-End Process as an overall method*. The work in the project followed the ordinary work at the company and the methods from the Front-End Process were not always used. The Front-End Process methods are considered as supporting when carrying out typical product development projects, but since the work in this project was a bit specific compared to ordinary product development projects, and indeed very intense in nature, the need for further methods was not always necessary, or possible to employ due to time pressure.

There was a rescheduling of the plan in several occasions, due to long queues to the different tests and sometimes more alert projects that had to be moved forward in the queue. At these occasions it was necessary to find the next thing to work with, and not just wait for your turn. There was also a problem in receiving original rear side airbags as they were made in Mexico. An order was made but never delivered and it was necessary to reuse old bags for the correlation tests. The reuse did not affect the results notably as the reused bags were in good condition. It could have been worse if the used bags were more burnt or deformed in earlier tests. The original bag was developed in Korea, which gave some extra work while trying to get some helpful information from them.
7. Recommendation

This section highlights what can be done for further developments of the rear side airbag and the protection of the rear seated passenger.

In a further work there are some things needed to be sorted out for developing the rear side airbag of the future.

- High pelvis values are the only common link found to lower the rating of the rear side in LINCAP tests. A protection for the pelvis could be a good insurance for higher rating. The reasons for the high combined pelvic force in the crash tests was however not found and further data about the vehicles may need to be collected to find the real cause.

- The collection of the existing rear side airbag was not fully completed and further useful data may be collected to learn about the rear side airbags on the market.

- How to protect the rear-seated occupants could be further studied and about how the stiffness of B-pillar (the B-pillar is the pillar placed behind the first seat row), thickness of the door etc. affect the rear-seated occupant in a side impact.

- The acceleration of the intruded door and how it affects pelvis and thorax could be investigated further to obtain a more reliable test method.

- How to combine a side curtain and a side airbag for the maximum area of protection for the smallest cost can be studied further. There are a few design changes that could be made to spare the fabrics and to optimize the bag concepts.

- The challenge with positioning the pelvis part of the airbag was not solved and by improving the protection area of pelvis there may be an improvement of the concepts.

- The rear seat has a different crash course of events than the front seat. The big difference found is that in the rear seat the thorax has the first impact and then the pelvis. Hence, a rear side airbag will need to be tuned differently to give a good protection for both body parts.

- An economic analysis on the concepts may be done to calculate the cost for each concept and what could be done to minimize the cost or add value for the customer.

- The results from the OOP-tests showed that all concepts need further work to pass the tests. The highest force on the dummy was generated by the thorax bag, indicating that the size of the airbag do not necessary affect the outcome from the tests negatively.
References


IIHS (2011) Vehicles that earn good test ratings for side-impact protection greatly reduce risk of dying for drivers in real-world crashes URL: www.iihs.org (Acc. 110122)


NHTSA (2007b) FMVSS No. 214 Amending Side Impact Dynamic Test Adding Oblique Pole Test URL: http://www.nhtsa.org (Acc. 110122)


Appendix 1

Probability of risk for AIS 3+ injury for the head, where $\phi$ is the cumulative normal distribution, is calculated as in equation 10.1.

$$P_{Head}(AIS3^+) = \Phi\left(\frac{\ln(HIC_{10}) - 7.45231}{0.73998}\right) \quad (10.1)$$

Probability of risk for AIS 2+ injury for pelvis where $F$ is the sum of the acetabular and iliac force, is calculated as in equation 10.2.

$$P_{Pelvis}(AIS2^+) = \frac{1}{1 + e^{6.3055 - 0.0694 \times F}} \quad (10.2)$$

The joint of probability for serious injury for the SID-IIIs is then calculated as in equation 10.3.

$$P_{join} = 1 - (1 - P_{Head}) \times (1 - P_{Pelvis}) \quad (10.3)$$

To calculate the relative risk for injury, the $P_{join}$ is divided with 0.15, that is a 15 percent baseline injury risk. From the risk of injury, the rear seat is given a rating from 1 to 5 stars, see table 2.3.

Table 10.1. The star rating, depending on the relative risk for injury.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Relative Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 stars</td>
<td>&lt; 0.67</td>
</tr>
<tr>
<td>4 stars</td>
<td>&lt; 1.00</td>
</tr>
<tr>
<td>3 stars</td>
<td>&lt; 1.33</td>
</tr>
<tr>
<td>2 stars</td>
<td>&lt; 2.67</td>
</tr>
<tr>
<td>1 star</td>
<td>$\geq 2.67$</td>
</tr>
</tbody>
</table>

The force on the head and pelvis are both used to calculate the relative risk and it is necessary to receive a low force on both body regions to receive a high rating.
In the body region rating, the lowest value for the parameter from the dummy, gives the final rating for that body region, see table 2.5 to 2.7. (IIHS, 2008b)

Table 10.3. Head and neck rating by IIHS.

<table>
<thead>
<tr>
<th>Injury Measure</th>
<th>Good</th>
<th>Acceptable</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIC (15 ms)</td>
<td>0 - 623</td>
<td>624 - 779</td>
<td>780 - 935</td>
<td>&gt;935</td>
</tr>
<tr>
<td>Neck Tension (kN)</td>
<td>0 - 2.1</td>
<td>2.2 - 2.5</td>
<td>2.6 - 2.9</td>
<td>&gt;2.9</td>
</tr>
<tr>
<td>Neck Compression (kN)</td>
<td>0 - 2.5</td>
<td>2.6 - 3.0</td>
<td>3.1 - 3.5</td>
<td>&gt;3.5</td>
</tr>
</tbody>
</table>

Table 10.4. Torso rating by IIHS.

<table>
<thead>
<tr>
<th>Injury Measure</th>
<th>Good</th>
<th>Acceptable</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak deflection (mm)</td>
<td>N/A</td>
<td>N/A</td>
<td>51-55</td>
<td>&gt;55</td>
</tr>
<tr>
<td>Average deflection (mm)</td>
<td>0 - 34</td>
<td>35 - 42</td>
<td>43 - 50</td>
<td>&gt;50</td>
</tr>
<tr>
<td>V*C (m/s)</td>
<td>0 - 1.00</td>
<td>1.01 - 1.20</td>
<td>1.21 - 1.40</td>
<td>&gt;1.40</td>
</tr>
<tr>
<td>Deflection rate (m/s)</td>
<td>0 - 8.20</td>
<td>8.21 - 9.84</td>
<td>9.85 - 11.48</td>
<td>&gt;11.48</td>
</tr>
<tr>
<td>Shoulder deflection</td>
<td>&gt;60 mm, downgrade of one rating category</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10.5. Pelvis and leg rating by IIHS.

<table>
<thead>
<tr>
<th>Injury Measure</th>
<th>Good</th>
<th>Acceptable</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iliac force (kN)</td>
<td>0 - 4.0</td>
<td>4.1 - 4.8</td>
<td>4.9 - 5.6</td>
<td>&gt;5.6</td>
</tr>
<tr>
<td>Acetabulum force (kN)</td>
<td>0 - 4.0</td>
<td>4.1 - 4.8</td>
<td>4.9 - 5.6</td>
<td>&gt;5.6</td>
</tr>
<tr>
<td>Combined Acetabulum &amp; Illium force (kN)</td>
<td>0 - 5.1</td>
<td>5.2 - 6.1</td>
<td>6.2 - 7.1</td>
<td>&gt;7.1</td>
</tr>
<tr>
<td>Distal femur A-P &amp; L-M force (3ms clip, kN)</td>
<td>0 - 2.8</td>
<td>2.9 - 3.4</td>
<td>3.5 - 3.9</td>
<td>&gt;3.9</td>
</tr>
<tr>
<td>Distal femur A-P &amp; L-M moment (3ms clip, kN)</td>
<td>0-254</td>
<td>255 - 305</td>
<td>306 - 356</td>
<td>&gt;356</td>
</tr>
</tbody>
</table>

To give an overall rating on how well the car performed in the test and how crashworthy it is in a side impact, the rating is calculated as in table 10.6.

Table 10.6. The overall rating in the side impact test.

<table>
<thead>
<tr>
<th>Component</th>
<th>Good</th>
<th>Acceptable</th>
<th>Marginal</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle structure</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Driver:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head Protection</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Head/neck</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Torso</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Pelvis/leg</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Driver Total = d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head Protection</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Head/neck</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Torso</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Pelvis/leg</td>
<td>0</td>
<td>2</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Passenger Total = p</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall rating: (d+p)</td>
<td>0 to 6</td>
<td>8 to 20</td>
<td>22 to 32</td>
<td>34+</td>
</tr>
</tbody>
</table>
### Appendix 3

Table 10.7. The overall length and width of the airbags and airbag type.

<table>
<thead>
<tr>
<th>Vehicle manufacturer</th>
<th>Overall length (flat) mm</th>
<th>Overall width (flat) mm</th>
<th>Airbag type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi A6</td>
<td>560</td>
<td>305</td>
<td>Thorax-Pelvis</td>
</tr>
<tr>
<td>Audi A8</td>
<td>470</td>
<td>400</td>
<td>Thorax</td>
</tr>
<tr>
<td>Chevrolet Cruze</td>
<td>520</td>
<td>330</td>
<td>Thorax-Pelvis</td>
</tr>
<tr>
<td>Fiat Croma</td>
<td>425</td>
<td>380</td>
<td>Thorax</td>
</tr>
<tr>
<td>Fiat Stilo</td>
<td>425</td>
<td>380</td>
<td>Thorax</td>
</tr>
<tr>
<td>Hyundai Genisis</td>
<td>450</td>
<td>410</td>
<td>Thorax</td>
</tr>
<tr>
<td>Mercedes CLS</td>
<td>580</td>
<td>360</td>
<td>Thorax-Pelvis</td>
</tr>
<tr>
<td>Peugeot 308</td>
<td>420</td>
<td>360</td>
<td>Thorax</td>
</tr>
<tr>
<td>Renault Laguna X91</td>
<td>455</td>
<td>365</td>
<td>Thorax</td>
</tr>
<tr>
<td>Seat Exeo</td>
<td>580</td>
<td>310</td>
<td>Thorax-Pelvis</td>
</tr>
<tr>
<td>Volkswagen Golf</td>
<td>550</td>
<td>270</td>
<td>Thorax-Pelvis</td>
</tr>
<tr>
<td>Volkswagen Passat</td>
<td>570</td>
<td>305</td>
<td>Thorax-Pelvis</td>
</tr>
<tr>
<td>Volkswagen Tiguan</td>
<td>580</td>
<td>370</td>
<td>Thorax-Pelvis</td>
</tr>
</tbody>
</table>

Table 10.8. The weight, dimension, name and type of the gas inflators in the vehicles.

<table>
<thead>
<tr>
<th>Inflator</th>
<th>Weight (g)</th>
<th>Length (mm)</th>
<th>Main diameter (mm)</th>
<th>Inflator name</th>
<th>Inflator type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi A6</td>
<td>280</td>
<td>136</td>
<td>25</td>
<td>NASI V2</td>
<td>Pyro</td>
</tr>
<tr>
<td>Audi A8</td>
<td>150</td>
<td>150</td>
<td>20</td>
<td>SPI 2</td>
<td>Pyro</td>
</tr>
<tr>
<td>Fiat Croma</td>
<td>180</td>
<td>140</td>
<td>25</td>
<td>HIS (Thorax)</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Fiat Stilo</td>
<td>180</td>
<td>140</td>
<td>25</td>
<td>HIS (Thorax)</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Hyundai Genesis</td>
<td>186</td>
<td>135</td>
<td>25</td>
<td>AHS 25</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Mercedes CLS</td>
<td>178</td>
<td>165</td>
<td>25</td>
<td>SHI – 12/25 V038</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Peugeot 308</td>
<td>166</td>
<td>120</td>
<td>25</td>
<td>SPI – 2/10</td>
<td>Pyro</td>
</tr>
<tr>
<td>Renault Laguna</td>
<td>338</td>
<td>180</td>
<td>25</td>
<td>ASH 1</td>
<td>Hybrid</td>
</tr>
<tr>
<td>Seat Exeo</td>
<td>272</td>
<td>137</td>
<td>25</td>
<td>NASI2</td>
<td>Pyro</td>
</tr>
<tr>
<td>Volkswagen Golf</td>
<td>161</td>
<td>117</td>
<td>25</td>
<td>SPI – 2/10</td>
<td>Pyro</td>
</tr>
<tr>
<td>Volkswagen Passat</td>
<td>280</td>
<td>136</td>
<td>25</td>
<td>NASI V2</td>
<td>Pyro</td>
</tr>
<tr>
<td>Volkswagen Tiguan</td>
<td>236</td>
<td>132</td>
<td>25</td>
<td>SPI – 2</td>
<td>Pyro</td>
</tr>
</tbody>
</table>
Appendix 4.

Table 10.9. Coated or uncoated and module location in the car models.

<table>
<thead>
<tr>
<th>Vehicle manufacturer</th>
<th>Coated/uncoated</th>
<th>Module location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi A6</td>
<td>N/A</td>
<td>In the rear seat bench seat bolster</td>
</tr>
<tr>
<td>Audi A8</td>
<td>Coated</td>
<td>In the rear seat bench seat bolster</td>
</tr>
<tr>
<td>Chevrolet Cruze</td>
<td>Uncoated</td>
<td>In the rear seat bench seat bolster</td>
</tr>
<tr>
<td>Fiat Croma</td>
<td>N/A</td>
<td>In the rear seat bench seat bolster</td>
</tr>
<tr>
<td>Fiat Stilo</td>
<td>N/A</td>
<td>Seat</td>
</tr>
<tr>
<td>Hyundai Genisis</td>
<td>Uncoated</td>
<td>In the rear seat bench seat bolster</td>
</tr>
<tr>
<td>Mercedes CLS</td>
<td>N/A</td>
<td>Seat</td>
</tr>
<tr>
<td>Peugeot 308</td>
<td>Coated</td>
<td>Seat</td>
</tr>
<tr>
<td>Renault Laguna X91</td>
<td>Coated</td>
<td>N/A</td>
</tr>
<tr>
<td>Seat Exeo</td>
<td>Coated</td>
<td>In the rear seat bench seat bolster</td>
</tr>
<tr>
<td>Volkswagen Golf</td>
<td>N/A</td>
<td>Seat</td>
</tr>
<tr>
<td>Volkswagen Passat</td>
<td>N/A</td>
<td>Seat</td>
</tr>
<tr>
<td>Volkswagen Tiguan</td>
<td>Coated</td>
<td>Door</td>
</tr>
</tbody>
</table>

Table 10.10. Supplier of the airbag and ratings by IIHS and LINCAP

<table>
<thead>
<tr>
<th>Vehicle manufacturer</th>
<th>Supplier</th>
<th>IIHS Side impact rear seat</th>
<th>LINCAP Side impact rear seat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audi A6</td>
<td>Takata-Petri</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>Audi A8</td>
<td>TRW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chevrolet Cruze</td>
<td>Autoliv</td>
<td>Good</td>
<td>5 stars</td>
</tr>
<tr>
<td>Fiat Croma</td>
<td>KSS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiat Stilo</td>
<td>KSS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyundai Genisis</td>
<td>Delphi</td>
<td>Good</td>
<td>5 stars</td>
</tr>
<tr>
<td>Mercedes CLS</td>
<td>TRW</td>
<td>Good</td>
<td>5 stars</td>
</tr>
<tr>
<td>Peugeot 308</td>
<td>TRW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renault Laguna X91</td>
<td>Autoliv</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seat Exeo</td>
<td>Takata-Petri</td>
<td>Good</td>
<td>5 stars</td>
</tr>
<tr>
<td>Volkswagen Golf</td>
<td>TRW</td>
<td>Good</td>
<td>5 stars</td>
</tr>
<tr>
<td>Volkswagen Passat</td>
<td>TRW</td>
<td>Good</td>
<td>4 stars</td>
</tr>
<tr>
<td>Volkswagen Tiguan</td>
<td>TRW</td>
<td>Good</td>
<td>5 stars</td>
</tr>
</tbody>
</table>