CHALMERS
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Concept Development of a Lightweight Driver's Seat Structure & Adjustment System

Combining Optimization & Modern Product Development Methods to achieve a Lightweight Design

Master's thesis in Product Development

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Gothenburg, Sweden 2014

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Cover:
Render of the final seat structure design concept. Further explanation of this concept is found in section 6. *Further development of the chosen concept*

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Summary

The automotive industry is currently going through changes in terms of consumer buying patterns, the best selling cars have gone from large SUV's and luxury sedans to small compact cars that are fuel efficient. In response to this auto manufacturers try to increase the fuel efficiency of their cars. The current trend is to accomplish this by reducing the overall mass of the vehicle, but this cannot compromise the cost and performance of the current solution. The purpose of this thesis has been to develop a lightweight design concept for a generic driver's seat structure and adjustment system, in collaboration with Semcon Sweden AB. Furthermore the developed concept was to answer the question of: *How could the driver's seat mass be reduced, without compromising the safety, cost or ergonomic performance of the current solution?*

The approach to developing a lightweight design was to analyze the current seat design, model this design using CAD-software and analyze it using FEM, to produce a set of target specifications. Based on the specifications new concept designs were generated and optimized using topology optimization software. The generated concept designs were evaluated in the same way as the reference and further refined before a final concept selection was made using selection matrices. The chosen concept was further developed to a detail that could be compared to the reference seat design. As a final step, an evaluation of the final concept was performed using ergonomic analysis, FE-analysis, and cost analysis. The results of the analyses have shown that all target specifications have been fulfilled, and that if compared to the reference seat, the final concept is 27 percent lighter, 1 percent cheaper in terms of unit cost, able to withstand the same impact load cases, and able to fulfill the same basic ergonomic requirements. The main conclusion of this thesis is thus that it is possible to reduce the driver's seat mass without compromising the safety, cost or ergonomic performance of the reference design. More specifically it has been shown that it is possible to achieve this goal by focusing on redevelopment of the seat structure and adjustment system, whilst leaving the remaining seat components untouched.

Keywords: Concept development, automotive, optimization, lightweight, driver's seat

Sammanfattning

Just nu undergår bilindustrin förändringar gällande kundernas köpvanor då de mest säljande biltyperna har övergått från att vara stora SUV:ar, och lyxiga sedaner, till små bränslesnåla bilar. På grund av detta försöker biltillverkare numer minska bränsleförbrukningen på sina bilar. Den nuvarande trenden är att åstadkomma detta genom att reducera fordonets vikt, utan att för den skull äventyra dess tillverkningskostnad eller prestanda. Syftet med detta examensarbetet har varit att utveckla ett lättviktskoncept för en förarstols stomme och justeringssystem, i samarbete med Semcon Sweden AB. Vidare skulle det utvecklade konceptet vara ett svar på frågan: *Hur kan massan på en förarstol minskas utan att äventyra säkerheten, kostnaden eller ergonomin hos den nuvarande lösningen?*

Metoden som användes under utvecklingen av lättviktsstolen var att först analysera den nuvarande stolen, sedan modellera upp denna med hjälp av CAD-program och analysera den nya modellen i FEM, detta för att få fram en kravspecifikation. Baserat på denna kravspecifikation framställdes nya koncept vilka optimerades med hjälp av topologioptimeringsprogram. De nya koncepten utvärderades på samma sätt som referensstolen, vilket ledde till att förfinade koncept kunde fås fram innan ett slutgiltigt koncept valdes med hjälp av elimineringsmatriser. Det slutliga konceptet utvecklades vidare till en nivå där det kunde jämföras med referensstolen. Som ett sista steg utvärderades det slutgiltiga konceptet med hänsyn till ergonomi, strukturella krav (FEM) och tillverkningskostnad. Resultatet från analyserna har visat att samtliga krav i kravspecifikationen har uppfyllts, och jämfört med referensstolen så har vikten reducerats med 27 procent, kostnaden minskat med 1 procent, konstruktionen klarat alla lastfall, samt de grundläggande ergonomiska kraven har blivit uppfyllda. Slutsatsen av detta examensarbete är att det är möjligt att reducera massan hos en förarstol utan att äventyra säkerheten, kostnaden eller ergonomin hos den nuvarande konstruktionen. Mer specifikt så har det visats att det är möjligt att uppnå detta resultat genom att enbart fokusera utvecklingen på stolsramen och dess justeringssystem, och lämna övriga komponenter orörda.

Nyckelord: Konceptutveckling, fordon, optimering, lättvikt, förarstol

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Terminology

CAD	Computer Aided Design, in this thesis the software CATIA V5 is used for concept design
FEM	Finite Element Method, in this thesis the software CATIA V5 is used for structural analysis
Altair Inspire	Topology optimization software
BIW	Body in White, the car body without any loose components such as doors and wheels
Recliner	An adjustment function that enables the seat back to pivot around the axle between the back and base
SRP	Seat Reference Point, the pivoting axle point between the back and the base
Seat Structure	The seat frame without any padding or upholstery
Adjustment system	Collective name of the seat's different adjustment functions, which includes length, height and recliner.
Ergonomic performance	Anthropometry, how well body positions and angles interact with a product, e.g. which knee angle is regarded as comfortable in a seating position
Structural performance / Safety	How much force the seat can withstand without breaking, or bending too much
Sill & Tunnel	The sill is the beam part of the BIW that is running along the outskirts of the vehicle. The tunnel is the center beam part of the BIW. Both of them help reinforce the BIW.
BESO2D	Topology optimization software which only can generate two dimensional models
BOM	Bill of Materials, a list of all components in a product assembly

Table of Contents

1. Background & Problem Identification

In order for the reader to understand the motive for developing a lightweight seat structure concept the current trends of the automotive industry is presented in this introductory chapter. Especially trends relating to environmental impact and consumer behavior, but also the most relevant information of lightweight design in the transportation sector is presented. During this background description the main design problem is identified, which is further clarified in the *Thesis purpose* sub-section. The background chapter also contains a description of a typical current car seat design and a description of the company at which the thesis has been conducted. Finally the chosen development process is presented with a brief description of the methods used. The outline for this chapter is:

1.1 Fuel consumption and trends in the automotive sector
1.2 Possibilities of weight reduction in the automotive industry
1.3 Description of the current car seat design
1.4 Mass allocation of current seats
1.5 Semcon Sweden AB and the thesis
1.6 Thesis purpose
1.7 Unique contribution
1.8 Limitations
1.9 Chosen development process

1.1 Fuel consumption and trends in automobile consumer behavior

Modern cars are faced with constantly increasing demands of lowering emissions and reducing fuel consumption while at the same time improving performance. It is also common to incorporate an increasing amount of functions in an effort to make the owners life easier (Lotus 2010). Regarding emissions the transportation sector is said to account for 23 percent of the world's CO_2-emissions, a figure that is projected to increase by 40 percent by the year 2030 (ITF 2010, p. 5). At the same time fossil fuel reserves are projected to run out shortly after 2050 (Doherty 2012). This has resulted in increased costs for the consumers of automobiles, as both the base price of fuel and the governmental tax in many countries have increased significantly over the last decade (Hatt 2012). Conversely automobile buying patterns has shifted from large SUVs and luxury sedans to smaller more fuel efficient cars that cost less to use. In a survey conducted by NADA guides in USA, the country which is considered to be one of the largest markets of cars, the predominately determining factor in consumers buying their next car will be fuel consumption, even compared to such factors as quality and safety (PR Newswire 2013). Interestingly enough a large part of the respondents were willing to downsize or give up comfort functions in order to achieve lower fuel consumption. The challenge for modern car producers will be how to increase fuel efficiency while at the same time advancing the cars performance relative to competitors, all while keeping the cost of the vehicle down. The performance of the car is associated with several criteria, such as acceleration, handling, and comfort. The mass of the car plays a large role here as reducing it will have a positive impact on both performance and fuel efficiency. The major limitation to mass reduction is cost, as lightweight materials are generally more expensive than traditional engineering materials such as steel. Thus innovative design ideas that could utilize traditional materials in more effective ways would also be a potential source of mass reduction at maintained cost levels. This leads to the question:

How can vehicle mass be reduced, without sacrificing cost, safety and ergonomics?

1.2 Possibilities of weight reduction in the automotive industry

In 2010 Lotus engineering released a major study on the capabilities of weight reduction in modern cars. Based on a detailed reengineering of a 2009 Toyota Venza, they found that by combining the best solutions on the market together with a system-level engineering methodology it was possible to achieve significant weight reduction and lower the cost of the vehicle (Lotus 2010). This was achieved without sacrificing vehicle functions, performance or safety. In summary a total of 21 percent weight reduction was achieved in a low development scenario involving 2017's production models, and a total of 38 percent in a future scenario that would start development by the year 2020 (Lotus 2010, p. 7). Although this study acknowledges some absence of detailed analysis in cost, mass and impact performances, it reveals a large potential area of improvement within the automotive industry. Another recent study on this subject is a working paper by the International Council of Clean Transportation (ICCT) where a detailed weight reduction forecast on light-duty vehicles within EU conducted by the FEV Company was included. The paper focuses on the change of manufacturing costs due to the implementation of weight reduction and how much emission cuts costs relative to the reduction of weight (Meszler et al. 2013). In conclusion FEV estimated that 18.3 percent of the total weight could be reduced by year 2020. This study was based on the 2010-era cars Toyota Yaris, Ford Focus, Toyota Camry, Ford Transit Connect and Ford Transit. An outtake from ICCT's paper on just the car seat reductions can be seen in table 1 below.

Table 1: An outtake showing potential weight reduction (Meszler et al. 2013, p. 5)

Part	Base mass [kg]	Mass reduction [kg]	Mass reduction [%]
Rear 60% seat	26.48	13.55	51.2
Rear 40% seat	16.41	1.49	9.1
Front driver's seat	26.91	4.72	17.5
Front passenger seat	22.75	3.64	16.0
Seats total	**92.55**	**23.39**	**25.3**

In order to explain the results of both the Lotus study and the FEV findings, the system level approach must be understood. Weight reduction of just one component might not necessarily improve fuel economy or performance significantly, but could increase the component cost more than it contributes to performance or fuel efficiency. However if a system level approach is considered, the reduced weight of one component, e.g. the body, could lower the constraints on another component, e.g. the drivetrain. Not only will this free up resources that could be used for weight reduction but it will also produce a cascading effect. An example of a cascading effect would be that the reduction of Body-In-White (BIW) mass enables a 1.6 liter engine to be used instead of a 2.0 liter engine, which in turn would require a smaller drivetrain. This smaller engine and drivetrain would put less strain on the chassis and suspension system which subsequently could also be downsized, the result of all this downsizing is reduced mass and structural requirements. This cascading effect opens up opportunities for car manufacturers to improve fuel efficiency and performance whilst still keeping costs down. In the 2009 Toyota Venza the seat sub-system make up 39 percent of the total interior mass which is why the seats were targeted as having the greatest potential for weight reduction of the interior (Lotus 2012, p. 77).

1.2.1 Current trends of weight reduction in car seats

Current trends in weight reduction of seats include system integration and co-modeling processes, as well as the use of lightweight frame materials such as magnesium and hybrid combinations. However, a magnesium frame using conventional frame tools would increase the unit costs by as much as 50 percent according to Faurecia, which is one of the largest car seat manufacturers (Lotus 2010, p. 81). Faurecia does however have a strategy for decreasing these costs which is making use of die casting tools in the production process along with an integration of composite materials in the frame. Another lightweight material is ultra-strong polyamide plastics with woven fabrics creating new possible ways to construct lightweight seats (BASF 2014). This material is exceptionally stiff and strong, and can in some cases even replace metal as a construction material. Another technology developed by BASF a is binder technology for powder injection molding which uses metallurgy combined with a traditional plastic process that enables metal to be formed into shapes that conventionally only have been possible for plastic parts. For foams, environmentally friendly materials which are recyclable mark a clear trend within car seats. One of these is Elastoflex® W produced by the BASF chemical company which claims to also have reduced the weight by 15 percent. Composites are a potential construction material for seats as well, making the seat back entirely in composite could evidently reduce the thickness of the seat back by 15 percent and decrease mass by 20 percent (Faurecia 2014a). Since the choice of material often set the boundary for engineering designs, these new materials open up exciting possibilities for future designs. Although they provide a promising future as construction materials, most of them imply increasing production costs which contradicts the automotive companies' often tight budgets. A faint paradox is that to reduce weight more integration of hybrid materials and complex structures are often needed, but this also implies higher costs (Faurecia 2014b). Because of this many of them are not yet feasible for market introduction. The great challenge ahead will be to reduce material and manufacturing costs, as well as creating innovative designs that enables lighter vehicle components to be produced and be used in competitive solutions.

Regarding the design of the seat, the Lotus study acknowledges some potentially weight reducing areas of improvement. The back frame shape is not considered to be ergonomically optimal at the moment since the current shape requires compensational foam and suspensions to work (Lotus 2010). Conventional seat backs structures create pinch points at the front edges of the frame and needs extra padding to satisfy the customers' requirements on comfort. Lotus suggests a more ergonomic and thinner design, much like the one used in Mercedes SLK, which would reduce the amount of padding needed and thus save weight.

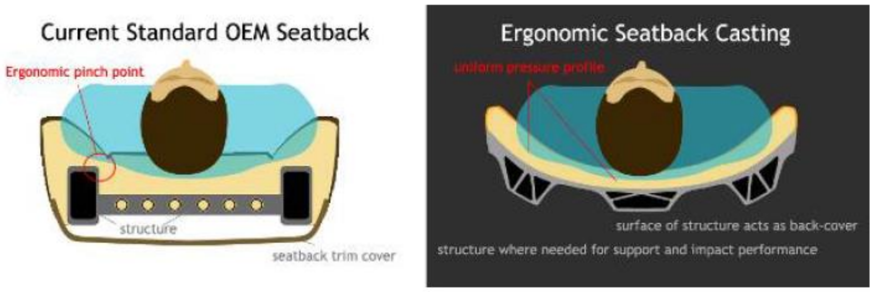


Figure 1: Standard seatback vs. new thinner seatback (Lotus 2010, p. 80)

Another design idea that proved useful in saving weight was the integration of seat mounts into the sill and tunnel areas of the vehicle body. Traditionally front seats are mounted on steel risers and tracks, which are then bolted to the floor. The floor is reinforced to accommodate the seat loads during transport and in the event of a crash. Replacing these floor mounted seat attachments and floor reinforcements could reduce the seat sub-system mass, as the sill and tunnel are already reinforced eliminating the need for extra structural reinforcement (Lotus 2010).

1.3 Car Seat Components and Adjustments

When designing a new seat system it is important to understand the current system, and a good way of understanding this is to describe the different components in the system and what functions they perform. Because this thesis focuses on the driver's seat the rear seats are not included in this system analysis. The subsystem 'Front Seats' consists of two seats, the driver's seat and the passenger seat. The driver's seat is often the heaviest as it encompasses additional comfort features such as power assisted adjustments and lumbar support. The subsystem shall provide all customers, for which the cars are designed, with the ability to adjust the seat manually or electrically to ensure that an ergonomically correct driving position is possible. It shall together with the seat belt, and side airbags protect the occupants in the event of an accident. In this section a breakdown of this sub-system is explained.

Figure 2: Exploded view of a typical modern car seat, BMW 3 Series 328i (A2mac1 2014)

The seat component sub-system consists of two major segments, the seat base and the seat back. The interface between the front seats and the BIW is a sliding rail and track segment which is bolted to the floor and the seat base frame. The seat base is built up of the lower frame, pad and base cover. The purpose of the base is to support the driver's weight in the z-axis and to provide the main structure of the seat as the base frame connects to the BIW via a track and rail segment, as well as connecting to the back frame of the seat

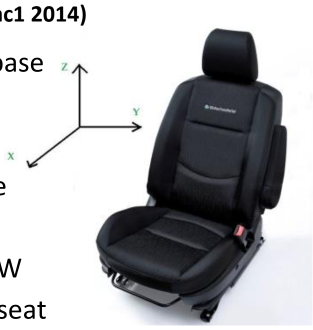


Figure 3: Cartesian coordinate system of a seat

which regarded as a critical component in terms of performance and mass. Another function of the seat base, which was discovered after discussions with an automobile expert, is to prevent the driver to slip under the seat belt during a frontal crash, a phenomenon also called submarining. Therefore the seat base is always angled between 10° – 20° in order to absorb the kinetic energy that the driver's mass will produce during a frontal crash.

The seat back consists of the rear frame, rear cover, pad and headrest which together mainly supports the driver in x-axis. It is also common in modern car seats for the seat back to incorporate an adjustable lumbar support as well some form of whiplash protection in the headrest. The reclining mechanism is usually located within this component and functions as a link between the base and back structure. This mechanism also allows a change in back angle which in this thesis will be referred to as the recliner function. On both the seat back and seat base there are side cushions sticking out from the pads which supports the driver in y-axis. The connection between the seat base and BIW usually consists of four support legs and two rails, the latter being bolted to the BIW. The support legs are moveable which allows the seat to be adjusted in height via a lever that lifts the base frame upwards. The rails can slide within each other enabling a length adjustment of the entire seat. Together with the recliner function they make up the main adjustments of a car seat. An important aspect of the seat structure is that it should be able to transmit occupant and seat belt loads to the vehicle body in case of a collision. This implies a structural restraint in terms of mass reduction as the seat must be strong enough to meet all performance requirements set by current seat designs.

1.4 Mass allocation

When trying to reduce weight it is interesting to look at how the weight of the seat sub-system is distributed across the different components. As seen in the pie-charts of a selection of cars in different segments, the mass of the frame is the largest contributor to the seat sub-system total mass. It can also be seen that the power adjustment equipment make up a large fraction of the mass in seats that have this feature.

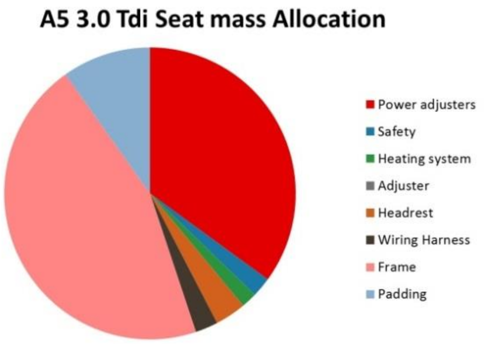


Figure 4: Weight allocation of an Audi A5 3.0 Tdi (A2mac1 2014)

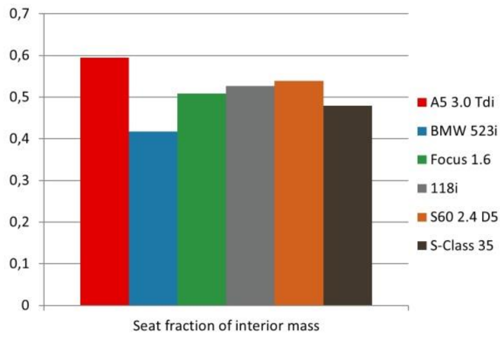


Figure 5: Seat fraction of interior mass (A2mac1 2014)

The reason for choosing the seat in particular is that the seats constitute as much as 50-60 percent of a car's interior mass (A2mac1 2014). Consequently it is believed that there is room for potential weight reduction of the seats and that reducing weight here will have a large effect on the overall interior weight, this might also produce a cascading effect on the entire vehicle's mass as described earlier. Together with the adjustment system the seat structure is a promising candidate for mass reducing redevelopment purposes, the remaining components such as the padding, heating system, and side airbags account for a much smaller fraction of the total seat mass.

1.5 Semcon Sweden AB and the thesis

In recent years weight reduction has become increasingly important in automobile design. In order to differentiate themselves in the marketplace it is important for car producers to come up with innovative solutions that could lower weight and thus improve fuel efficiency and performance, but at the same time not add significantly to production costs. This is where Semcon enters the picture, as a company that delivers expertise and conceptual ideas to major auto developers it is in Semcon's interest to help develop innovative ideas and strengthen their knowledge in lightweight design. Furthermore interior car design is an area that lies at the core of Semcon's business plan, thus research in lightweight interior design is most interesting for this company. One way of advancing in the field of lightweight interior design is to collaborate with research institutions such as Chalmers University of Technology which leads to the thesis project that is at hand. This thesis is a first step towards a lightweight seat design proposal that Semcon hopes to deliver in the future. The Lightweight Car Seat is a thesis carried out by two students at MSc level.

1.6 Thesis purpose

When developing a new solution for the seat design the team should not focus solely on reduction of mass but also on how to maintain the current level of safety and ergonomic performance. There is simply no purpose of having a lightweight design if it cannot fulfill the basic functional criteria that is expected of a modern car seat. Similarly a lightweight design would not yield any benefits if no car manufacturer can afford to implement it into their current or near future line-up, which implies that a cost constraint is put on the developed concept. This thesis aims to incorporate a mixed optimization and traditional product development approach to design a concept that solves the following problem:

How can the driver's seat mass be reduced, without compromising the safety, cost or ergonomic performance of the current solution?

The goal is to find this solution by exploring lightweight interior design and to carry out a computer aided design of a seat structure that fulfills the following criteria:

- Reduce the mass of the driver's seat as much as possible (Goal)

Without violating the following constraints:

- Maximum unit cost should not exceed the current solution cost
- Maintained performance, i.e. safety and comfort, compared to the current solution

1.7 Unique Contribution

Recent studies indicate that the use of topology optimization, which is further explained in the theory section 2.6, early in the development phase results in significant reductions of mass (Zhu et al. 2011; Polavarapu 2008). However these studies tend to focus on the optimization method and calculations itself rather than the use of topology optimization as an aid in generating design concepts. One study investigates the use of topology optimization in the early design phase of the car body but not in the application of car seat design (Hasselblad 2011). This thesis unique contribution is to apply topology optimization as an inspirational tool, alongside traditional design methods, throughout the development process.

1.8 Delimitations

This thesis is conducted by two students, which means that the work has to be focused on the most essential elements of the seat design. In order to prevent the scope from becoming too wide, and thus reduce the efficiency of the development process, a number of delimitations are necessary in agreement with the supervisors at both Semcon and Chalmers. The delimitations are listed below.

- The thesis only includes a conceptual study and a concept selection. The end product is a finished CAD model, mass analysis and cost analysis of that concept.
- The thesis does not include a detailed design. The concept includes the main parts that are needed, but detailed parts like screws are left out.
- The thesis only focuses on the driver's seat. Although some ideas might be compatible with the passenger's seat, the reference seat is still the driver's seat.
- The main elements of interest in the development work are the seat adjustment system and the seat structure. These are focused on throughout the thesis.
- The thesis does not include any prototype constructions or testing. Tests are only performed by using CATIA V5, both ergonomically and structurally (FEM).
- The thesis does not evaluate any optimization tools, but rather just apply them throughout the project.

1.9 Chosen Development Process

In order to achieve the goal of this thesis, to develop a concept that has less mass than the reference design without lowering safety, cost, or ergonomic performance, an iterative strategy that borrows elements from Ulrich & Eppinger (2012) was chosen. The entire project is divided into five main phases: Planning, Concept generation, Concept selection, Further development, and Final evaluation which will be described in more detail below.

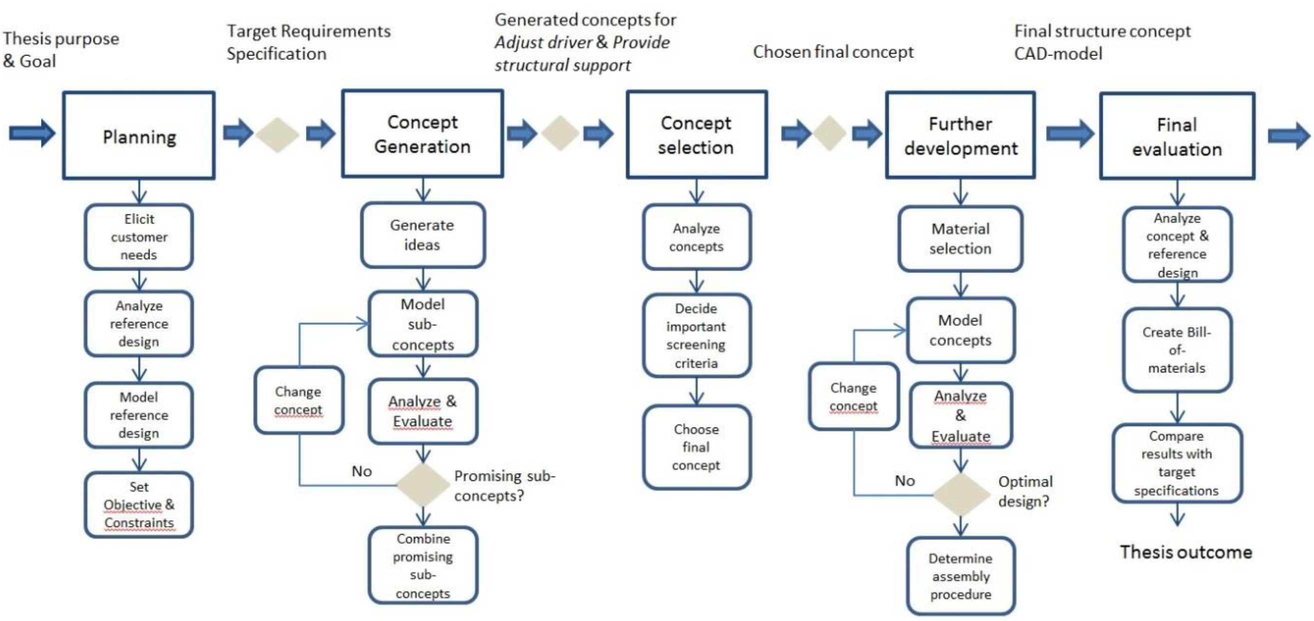


Figure 6: Concept development process map

1.9.1 Planning of the development process (Chapter 3)

The purpose of this phase is to analyze a typical current design of a car seat in order to create a reference design for the later phases of development. Another objective is to understand the customer needs and translate these into measurable targets, i.e. a set of target specifications, for the development process. Analysis is done by dismantling a physical seat as well as modeling this seat in CATIA V5 which yields measurements, mass and performance of the different components. The load cases for the most important impact scenarios are researched here as well. Customer needs are found using personal interviews with drivers and engineers at Semcon, and translated using methodology from Ulrich & Eppinger (2012). The deliverables of the preparation phase is a reference design and a target requirements specification that constitutes the basis for all subsequent development work.

1.9.2 Concept generation (Chapter 4)

The focus in this phase is on exploring alternative solutions that might fulfill the goal of mass reduction, safety, ergonomics, and cost. First the functional requirements of the seat structure are understood in more detail through the use of functional-means modeling. This is followed by idea generation for the two main functional criteria *Adjust driver* and *Provide structural support*. The long list of sub-solution ideas is initially screened down to a number of feasible concepts that are developed in more detail. The ideas are digitally realized using CATIA v5 and analyzed using Altair Inspire. The use of Inspire, which is a topology optimization software, produces new concepts which means that this is an iterative process. During this process the sub-solution concepts are developed in more detail and evaluated based on their potential to reduce seat mass, FE-analysis is thus used already at this early stage. With the aid of morphological matrices corresponding to the functional-means models the sub-solution concepts are combined into 4 main concepts for the *Adjust driver* criteria, and 11 concepts for the *Provide structural support* criteria.

1.9.3 Concept selection (Chapter 5)

Utilizing the requirements specification as a starting point, one concept for each of the two main functional criteria is selected, and then combined into one seat structure design concept. In order for the selection process to be as valid as possible, each concept is analyzed in terms of mass, cost, and ergonomic performance. After determining weights, i.e. importance, of the different screening criteria two concept scoring matrices are used to choose a final concept for each of the two main functional criteria.

1.9.4 Further development of the chosen concept (Chapter 6)

Having determined the design solutions and overall layout of the final concept, material and manufacturing processes are chosen. This is done with the aid of materials selection software CES and an optimization approach. The final geometry is then optimized based on the selected material and manufacturing process, resulting in a final concept CAD-design.

1.9.5 Final evaluation against target specifications (Chapter 7)

To verify that the thesis purpose has been fulfilled an evaluation of the final concept design against the target specifications is conducted. The final analysis consists of an ergonomic evaluation with virtual test dummies in CATIA, FE-analysis of the structural performance when subjected to the identified impact load cases, and a cost analysis of the final concept bill-of-materials. The results from this analysis is compared to the reference seat design results and then evaluated using the target specifications set up in the preparation phase. This closes the “development loop” and the delivery of a lightweight seat structure concept is completed.

2. Theory

In this chapter different theories and methods that were used throughout the thesis are explained and presented. This is to keep the reader up to date with how the product development theories and tools currently are, and help understand the rest of the thesis better. Further descriptions of how these methods were used are stated in each correspondent chapter.

2.1 Competitive Benchmarking

To assure that a product development team will be successful, performing a competitive benchmarking is vital (Ulrich & Eppinger 2012). The reason for this is to gain important insight as to what level of performance commercially available products are at, and get an overview perspective of other product designs before a product development project can begin. One way of doing this is to set up a benchmarking chart that lists all the metrics that have been acquired through the customer needs collection, and then set the values of the different competitors' relative products for each metric. Although this process seems straight forward, gathering all the data required can be time consuming and sometimes includes purchasing other products and dismantling them. This is because data obtained from competitors own literature might be incorrect and information should always come from a neutral and independent source. Another method that can be used for benchmarking is to grade each metric performance subjectively, which can be obtained by measuring customer satisfaction and perceptions regarding the product. This can be a preferred method if gathering numeric values is difficult.

2.2 Reverse Engineering

When trying to understand a product without previous knowledge or having very little understanding about it, implementing the reverse engineering method can be useful. It involves dismantling an existing product that has been identified in the benchmarking process for a new design. This can either be used to copy a design or to improve it (Evertsson 2013). The first step is to investigate the product space and main functions in order to determine the product domain which should relate to customer needs. The second step is to reconstruct the initial product in detail in order to create a Bill of Materials (BOM). This is done by tearing down the product and investigating part interfaces and assimilability. After this phase a functional analysis can be performed in order to study the energy and force flows, and discover possible sub-functions that could be cross integrated using, for instance, a morphological matrix. A new product specification can now be created which will lead design modelling and analysis into a redesign phase which often corresponds to a normal product development strategy. This final phase can either be a parametric redesign where the new design is just an improved version of the old model, an adaptive redesign where the main model is still the same but its sub-functions may have been altered, or an original redesign where knowledge from the initial model have led to an entirely new concept.

2.3 Target Specification

A target specification is the first out of normally two specifications during a product development process, the last one being the final specification which is determined after the concept screening and testing. Before a target specification can be made, a translation of the customer needs and requirements into metrics and units are necessary in order for them to be measurable (Ulrich & Eppinger 2012). This is possible by first making a list of the different needs that the product has to fulfill, including the importance of each need. The needs should be formulated in a way that they do not relate to existing solutions and be expressed as wishes. The next step is to define units for each need that is possible to measure, and to identify if some metrics can fulfill multiple needs and vice versa. To be able to decide which values and grades that is to be included in the set of specifications, a collection of competitive benchmarking information is vital for any project. This reassures that the finished product will be at a competitive level and profitable. The value for each metric should be set to an ideal and a marginal value, where the marginal value is the minimum requirement and the ideal is the best case scenario.

2.4 Brainstorming

In able to generate new and creative ideas, concept generations often begin with an initial search in form of brainstorming conducted within a project group or a company. It is important for the participants to remain open minded and follow a clear protocol in order not to suppress any radical or unorthodox ideas. The following version is one of these protocols (Ulrich & Eppinger 2012, p. 127).

1. Suspend judgment. Subjective judgment is constantly used in everyday life to make quick and necessary decisions in order to succeed. This however inhibits the ability to come up with creative ideas and solutions. Therefore any criticisms are not allowed in a brainstorming session and all ideas are of equal importance.
2. Generate a lot of ideas. It is believed that increasing the quantity of ideas lowers the expectations of other ideas and helps stimulate new even more creative solutions to be generated.
3. Welcome ideas that may seem infeasible. Infeasible or in some cases rather silly ideas helps to stretch the solution boundaries and contributes to the ‘outside the box’-thinking.
4. Use graphical and physical media. An idea can be difficult to comprehend in just words and trough verbal communication. Therefore it is important to use sketches or other quick physical models to help translate ideas between the participants.

2.5 Function means modelling

Function means modelling is a way to divide a product’s function requirements (FR) and design solutions (DS), and see which requirements corresponds to which sub-solution (Johannesson, Persson & Pettersson 2013). This is often done in a tree structure where a FR only can have one DS, but a DS can fulfill multiple FR’s. The method is used in the early stages of product development to illustrate an overview of a product’s functions and to possibly identify unnecessary DS’s that might not fulfill a function. It can also be used to better see if DS’s can be combined or satisfy multiple FR’s.

2.6 Design Optimization

Optimization methods can be used to seek the optimal solution in the design space. Even if many solutions can satisfy all the constraints and requirements, optimization tools can guide the product development to the best result. The simplest form of optimization is using trial and error to come up with the best solution (Hoffenson 2013). This method can be time and work consuming but is sometimes the only feasible way to proceed, i.e. when the problem is too complex to formulate mathematically. In other cases when the problem can be formulated, a target function $f(x)$ is set to either be maximized or minimized depending on the problem. Design requirements can be set as constraints, e.g. $g(x,t)<0$ and $h(x,t)=0$, creating the boundaries in which the optimal solution would be located. These constraints can either be inequalities or equalities. According to Hoffenson (2013), the design optimization process can be divided into five steps. The first step is to define the system and design space, which largely determines the end result and is often the hardest part of an optimization procedure. The second step is to formulate the problem by deciding on what the objective is and which constraints there are in the system. Deciding on which design variables to be working with is also important along with definition of parameters, which can be assumed fixed elements, and constants which are by definition fixed. The formulation usually looks like this:

$$\min f(x)$$
$$g(x,t) \leq 0$$
$$h(x,t) = 0$$
$$x_{min} \leq x \leq x_{max}$$

The third step is to create an analytical model and simulate using FEA and optimization software tools in order to test and validate the output data. Since optimization is not often a trivial process a variety of methods can be used when sampling the different variables in the experiment models. Step number four is exploring the problem space in order to see which constraints that are active and determine the function behavior. The last step is to find the optimal solution, often by using different mathematical or numerical methods. The concept of global optimum and local optimum should also be explained. A global optimum is the best possible result in the entire available design domain; a local optimum is the best possible result in a limited section of the entire design domain. An optimization problem could have several local optima but only one global optimum; it is this global optimum that needs to be found if a truly optimal solution is to be reached.

2.6.1 Topology Optimization

One special application of the FE-method is topology optimization where an initial design space is subjected to a structural optimization procedure where at least one objective is minimized, e.g. mass, without violating design requirements formulated as constraints. This technique has the ability to change dimensions and geometry of the initial design in an automated process by creating geometry vacancies or changing the outer boundary of a structure. It is generally used in the initial stage of a development process since it is a powerful tool when the objective is to find new conceptual designs. One software program that incorporates this method is Altair Inspire which has the ability to apply topology optimization to an existing CAD-model. A useful side effect of this is that it can show the designer the location of internal stresses and directions of forces, thus enabling an optimal design in both the conceptual and the detail design phases of development.

2.7 Concept Combination Table (Morphological Matrix)

A concept combination matrix, or a morphological table, can generate ideas for a complete solution by combining many different sub-solutions for each sub-problem. To perform this method a table is set up where the different sub-functions creates the column titles, and below them the different solutions (fragments) can be set up (Ulrich & Eppinger 2012). This divides the different functions and solutions into categories which enables for different combinations of them to be made. By combining and comparing these types of solutions can potentially trigger new innovating thinking and clarify the problem in a new way. However, the amount of different possible combinations can be enormous if there are too many sub-functions or solutions. Therefore it is only suitable to be used when the number of columns (sub-functions) is no more than three or four. One way of reducing the amount of combinations is to deem a fragment or a sub-solution infeasible, which can be done by using a concept evaluation tool.

2.8 Weight decision matrix

A weight decision matrix is used to decide weights that might be included in a concept scoring matrix, without any directly subjective judgment (Johannesson, Persson & Pettersson 2013). It's performed by listing up all the criteria that is thought to be of relative importance, and then rank them with each other. If a criterion is less important than another it receives a value of 0, equally as important a value of 0.5, and if it's more important a value of 1. This will result in an *n x n*-matrix and the total ranking sum of a criterion will be the final weight score, which can be interpolated into a weight scale.

2.9 Concept Screening and Scoring Matrix

A concept screening matrix, or a Pugh matrix, is often the first selection tool used in order to narrow down different concepts (Ulrich & Eppinger 2012, p. 150). It uses a reference solution, often the current solution, to compare the new ideas with. If the new concept is better than the reference it receives a '+' for that category, a '0' if it's about the same or a '-'if worse. These rates are then added up to a net score and then ranked to finalize the evaluation. After this a decision which concepts to continue with and/or which ones to combine is made. The rates are decided with the project members' intuition and previous knowledge and are not always easy to judge. That is why this tool only should be used as a guideline and not as a definitive selection tool. A combination with other concept screening tools is therefore often recommended, which for instance can be a concept scoring matrix. The concept scoring matrix works similar to the screening matrix, but it uses criteria weights as well. Having a weighted matrix enables for a more detailed concept selection and a better end result.

2.10 Cost Analysis

There are many different ways of assessing production costs of different parts and materials. One way is to start with the BOM and try to get an estimation of cost for each part (Ulrich & Eppinger 2012). Normally a company or a manufacturer already has knowledge and experience of how much a typical standard part costs by comparing similar parts already produced or purchased. If the number of parts produced is high, for instance more than 100 000 unit per month, the production cost becomes low and usually stagnates around a known value, which also implies material prices. Another way of collect correct estimates is to soliciting price quotes from vendors or suppliers whom often can give some useful indicators of price, even though it's not entirely correct. After gathering advice from these experts and niched manufacturers, total cost estimation for a product that uses standard part can then be achieved. However, a new product often requires new types of parts and in some sense custom parts are needed to be implemented. This is not as easy as estimating standard part costs but instead focuses on production tools and the complexity of a part. New tools are often needed which increases the fixed expenses, which in turn requires an investment from the company. Other costs as assembly costs and overhead costs could also be estimated, but are even harder to predict. Needless to say total cost estimations are time consuming and will almost always differ from reality. For a product specification early on in a development project only a rough cost assessment is required because of the uncertainties of the product outcome. A more detailed estimate is more feasible during the production ramp-up phase.

2.11 Computer Software

Along the course of this thesis, a number of different software programs have been used to make the product development process efficient and effective. As a Computer Aided Design tool (CAD), CATIA V5 have been used to make 3D-models of different concepts and has also been the main tool to obtaining the correct mass for each concept. For simulating forces and mechanically testing the concepts, the Finite Element Method program (FEM) in CATIA V5 was used throughout the thesis. The most unique software that was used was Altair Inspire which is an optimization tool. It uses FEM as well which is imbedded in the program. It creates a model with altered geometry in a way that lets a development team see where to use mass when the goal is to reduce weight. To decide which material is optimal CES EduPack 2013 has been used. This program uses Granta's material database and it enables material indices and cost analysis to be set up against each other. The material index that was used in this thesis is stated below and is the index of choice when trying to create a beam with high bending stiffness and low weight (Ashby 2011). This can also be referred to the goal function in an optimization problem as in chapter 2.6.

$$minimize: \quad \frac{\rho}{E^{1/2}}$$

3. Preparing the development process

For the purpose of developing a new seat structure concept design, an extensive development process has been undertaken. Prior to the actual development work, which officially started with breaking down the functionality of the driver seat and the generation of concepts as described in the *Concept generation* section, a planning phase was undertaken. The planning phase served as a preparation for the actual development work, with important areas of pre-study being covered. First there was a need to find out what the actual users of driver seats would expect a new concept to achieve, without this input there would be no way of knowing if the final concept design could be implemented in the automotive market. Thus knowing that the concept solution should be light was simply not enough to ensure a successful product. After finding out what the customers expected and wanted of a future solution, the current solution had to be analyzed in order to provide a valuable point of reference. This was done by reverse engineering an actual driver seat from a leading car manufacturer and creating a digital representation of its seat structure in CATIA. This model will be referred to as the *reference design* throughout the rest of this report. Being a part of analyzing the reference design was also the load case analysis. The load cases for the most critical impact scenarios had to be found in order to be able to evaluate the structural performance and safety of the final concept design as well as the reference design. Finally all of the information gathered in this preparation stage had to be converted into measurable targets for the subsequent development effort; this was done by establishing engineering metrics, benchmarking, and setting target specifications. The outline of this section is as following:

- *Customer needs*
- *Analysis of reference seat*, which details the Reverse engineering, CAD-modelling, & Load case analysis
- *Initial product specifications*, which details the Engineering metrics, Benchmarking, & Target specifications

3.1 Customer needs

In order for the subsequent development effort to be successful it was important to determine what the actual customers of car seats wanted the concept design to achieve. It was already known that the company wanted a lightweight seat design but in order to accomplish that, a new concept essentially built from scratch, had to be developed. For that purpose the goal of low mass was not enough, first the necessary functions had to be studied as these would be the main drivers for the new concept design solutions. Understanding which functionality the customers expected of a car seat, and what they thought was missing in the current solutions, was an important first step in eliciting the functional criteria that would guide the rest of the development effort. The method chosen for finding these user needs was interviews performed with different types of car drivers, and automotive engineers. Complementary to these interviews, visits to three different retailers of personal cars were also conducted. Cars of different segments were tested and investigated and interviews were performed with salesmen in the different retailer locations. In this section the elicited customer needs, found by the mentioned methods, are summarized.

The customer in this case was a mix of different stakeholders primarily consisting of car drivers and the companies that produce and sell automobiles. For the driver, the comfort and safety of the seat was of the highest importance. Since drivers come in many different shapes and sizes, the comfort not only depends on the shape of the seat, but to a large extent also its adjustability. For the driver it is therefore important to be able to adjust the seat in length, height and in the angle of the seat back. Many drivers also need a supportive function in the lower back, while taller drivers appreciate extra leg support at the front of the seat. For car owners, there are some additional considerations regarding the seat. The cost of the seat should be included in the price of the car as few customers choose to pay extra for higher quality seats. The fuel consumption of the car should be kept to a minimum, and so should the environmental impact. Both these demands directly translate to a lower mass of the vehicle and thus a minimum weight of the seat was desired, as long as this does not violate the previously mentioned demands on comfort and price. For the producers of automobiles, it is vital to keep costs down since the profit margin in the current car industry is very low. This equates to keeping the costs of all components down while satisfying as many customer demands as possible. In the case of seats it is important to be able to incorporate all functions that the future car owner would want, as well as to make the seat aesthetically pleasing since this improves the overall image of the car specifically and the brand in general. As already mentioned this information was gathered from a mix of potential stakeholders for car seats, utilizing personal interviews. All answers were written down, organized and compared in order to get a quantitative result from the qualitative data collection approach. Having identified potential stakeholders, and gathered qualitative as well as quantitative data on their demands and desires regarding the driver seats of cars, ten customer needs where derived:

1) The seat should be comfortable when driving for an extended period of time
2) The seat should be comfortable when driving for a short period of time
3) The seat (car) should not be too expensive
4) The seat (car) should be as light as possible in order to reduce fuel consumption and pollution
5) The seat should protect the driver in case of collision
6) The seat should be adjustable in length
7) The seat should be adjustable in height
8) The angle of the seat back should be adjustable
9) The controls for seat adjustment should be easy to find and reach
10) The seat should be aesthetically pleasing

Evaluating the elicited needs it was apparent that comfort and adjustability functions were connected and that they were also important in the eyes of the main user. Adjustment functions would thus be one of the main drivers for developing new design solutions, they were named *Adjust driver*. The other needs found would mainly act as constraints in the subsequent concept selection processes. The most important of these was safety performance. Since the focus of this thesis was to develop a new frame structure for the seat, user need number ten involving the aesthetics of the seat would not be used in the development process.

3.2 Analysis of Reference Seat

In order to provide a starting point for the development process the elicited customer needs had to be converted into measurable targets. In order to do this more information had to be gathered, specifically regarding the seat structure, functions and impact load cases. The load cases would not only be a vital measurement of performance, but would also be used as input to the optimization process. This was to ensure that the optimization procedure would not result in designs that could not meet the customers' expectations on safety. The analysis was based on a car seat of modern design that was reverse engineered to create an understanding of the structure and functionality. The structure was then modeled in CATIA and analyzed using Altair Inspire which would serve as a reference design for the subsequent evaluation of concept designs during the development effort. Prior to analyzing the structure, the dimensioning load cases and forces had to be discovered, which was done using an existing seat requirements specification combined with dynamic calculations of energy in motion. Assumptions and calculations were later confirmed by a lead seat designer in an interview. In this section all the steps of the seat analysis are explained in detail.

3.2.1 Reverse engineering a current seat

In order to create a reference model of a current car seat, a physical teardown of a driver seat from a leading car manufacturer was performed. This gave a detailed insight of the different components, shapes and materials of the entire seat.

Figure 7: The reference seat halfway through the reverse engineering process

The first discovery made was that the seat back structure was divided into two segments, one lower supporting structure and an upper bar bent to shape. The reason for having separated the back into two parts was believed to be an active head restraint. This is a function that creates a support for the driver's head during rear impact by automatically releasing a spring loaded mechanism that folds the backrest forward. The function was believed to be the main source of complexity in the reference seat and a driver of both mass and cost. The connecting parts between the seat back and the base, which also served as the reclining function, were sturdy and consisted of thick steel bars. The reason for this was believed to be that the seat experiences the highest loads near the recliner during impact, which was later confirmed in the load case analysis. The lumbar support function consisted of two steel wires and fabric, it was presumed as already light and simplified. The main structures of both the seat back and seat base were constructed using stamped sheet metal, which were 1.5 millimeters thick. The bent tube supporting the upper back was also interesting as the circular cross section might be used for the concept design as well. The sturdiness and length of the tracks that attach to the BIW were also noticed, another component which was believed to suffer large forces upon impact. All parts of the seat were measured and modeled in CATIA and then weighed; this information was used in the subsequent benchmarking table. Regarding the functionality of the seat, most of the information gathered in the customer needs process was confirmed. *The seat back* angle could be adjusted through the use of a rotational joint connecting the back structure to the base structure. The point at which the center of this rotational joint was located is called SRP (Seat Reference Point), as it would turn out during the load case analysis this was also the point used for measuring the resulting moment acting on the seat upon rearward impact. A high strength design resulting from the loads suffered at the center of the recliner mount drives both mass and cost.

The seat base structure featured a height adjustment mechanism that works by rotating an asymmetrical bar connected to the track segment. A result of this is that the joints between the track segment and the base structure, receives an added level of complexity which includes the fact that several metal bars have to be added. This drives both mass and cost. *The attachment structure* had two main functions, transfer forces from the seat structure to the floor of the car and enable longitudinal adjustment of the seat relative the steering wheel and pedals. The first function was achieved through fastening elements connected to the floor and a locking mechanism in the rails. Longitudinal adjustment was achieved by the use of rails that slide in tracks, this means that the full length of the track and rail segment, at maximum length adjustment, is more than twice the length of the seat. Having these four long reinforced metal components in the design, drives both mass and cost of the seat, as well as the mass of the car body due to necessary added reinforcements in the floor. Both the seat base and the seat back contained a *spring loaded suspension* grate used to absorb driver movements. Constructed mainly of metal parts these components were judged as cost effective although not necessarily optimal in terms of mass reduction.

The main conclusion of this reverse engineering process was that if the adjustment functionality could be removed or accomplished in alternative ways, there would be a significant potential for reducing mass and perhaps unit cost as well.

3.2.2 CAD-model of reference seat

A CAD-model was built based on interpretations and measurements of the actual seat used for the reverse engineering process; this was to generate a reference model that would be used for the subsequent design and evaluation process. The model was weighed in CATIA and thus provided a fair estimation of mass when compared to the concept designs later on, as these were also modeled and weighed in CATIA.

Figure 8: Reference seat design modeled in CATIA

3.2.3 Forces acting upon the seat

In order to use finite element based software such as Altair Inspire, the user have to specify input forces and constraints on the design to be optimized. It was therefore important to understand the dominant load cases acting upon the car seat structure during regular use, as well as in a crash situation. Based on physical principles of energy in motion as described in appendix 1 (Load case analysis), and information compiled from actual car seat requirement specifications, an analysis of the load cases present in the car seat was carried out. Estimated forces and load cases were afterwards confirmed during interviews with an expert in car seat design. For clarity a distinction has been made between load cases inherent in regular use, called static load cases, and load cases that are present in different types of collisions, called dynamic load cases.

Static load cases:
The loads depicted here are meant to represent forces that could be exposed to the seat by the user during regular use i.e. in all other scenarios other than collisions.

a) The complete seat shall withstand a *minimum moment load of 1600 Nm forward around the H-point*, representing the resulting moment of a force applied to the back of the seat, e.g. a passenger pressing against the seat back.

b) The complete seat shall withstand a *minimum moment load of 2050 Nm rearward around the H-point*, representing the moment caused by a driver throwing his weight at the backrest while sitting down.

c) The seat shall withstand an *extreme load of 1600 N anywhere on its structure*, in order to withstand general mishandling of the product.

Dynamic load cases:
These were loads that the seat structure must withstand in order to protect the driver in a crash situation, which was an essential user need as stated earlier in this report. Using the physical law of conservation of energy and applying this theory to the case of slowing down a car from an initial velocity to a standstill in a specified distance, the force exerted on the seat could be approximated. Data on velocity and stopping distance has been gathered from the previously mentioned requirement specifications which contain actual crash test scenarios. It was revealed that a safety margin of 1.5 was accounted for in these specifications which eliminated the need for additional safety margins in the calculations for this thesis. For company secrecy purposes the requirement specification could not be published within this thesis report. After analyzing the different scenarios and consulting with lead car seat designers, the realization that the seat back was the main component affected in a crash situation, was made. More specifically the recliner joint was a critical dimensioning design element since this was the seat component affected by the largest load in any situation. Based on this, only the seat back and the load cases acting upon it are detailed in this section. The remaining load cases for the base structure and attachment structure can be found in appendix 1 (Load case analysis).

Rearward impact with another car, initial velocity 54 km/h.

This is the load case that exerts the largest force on the seat, and the seat back in particular. The mass of the driver has to be supported by the seat back as it decelerates from an initial velocity of 54 km/h to 0 km/h in a distance of 0.3 m which is the same stopping distance as the car. In this scenario there can be no elongation of stopping distance, as opposed to the frontal impact scenario where the stretch of the belt enables the driver to achieve a longer stopping distance, effectively reducing the force of impact. Adding to this force is the inertia caused by the mass of the seat back itself. It was believed that this load case primarily determined the necessary structural requirement of the seat back and recliner structure.

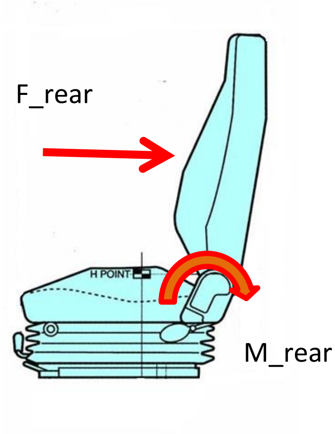


Figure 9: Load Case during rear impact

d) The seat back and recliner structure should remain its structural integrity while subjected to a resulting *rearward moment of 2100 Nm around SRP*. This corresponds to a rearward impact of 54 km/h with another car.

Frontal impact with unrestrained cargo, initial velocity 50 km/h

In this scenario the seat back must be able to stop an object projecting from the backseat without failing. This creates a forward resulting moment on the seat back as the mass of the object must be supported as

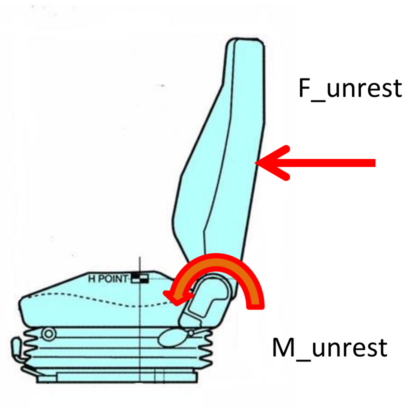


Figure 10: Load Case during frontal impact

it decelerates from 50 km/h to 0 km/h in a distance shorter than the car's stopping distance. Due to the higher point of impact when compared to the previous load case, this load case actually results in the largest moment around the recliner mechanism. Therefore this would be the actual load case determining the necessary structural requirements of the seat frame structure.

e) The seat back and recliner structure should remain its structural integrity while subjected to a resulting *forward moment of 2500 Nm around SRP*. This corresponds to a frontal impact of 50 km/h against a rigid wall where an unrestrained box of 18 kg would hit the upper seat back.

General attachment

f) The rail & track segment attachment points should withstand a *minimum force of 4 kN* in any direction. This represents the structural integrity needed to withstand the force absorbed by the belt and inertia of the seat structure, during a front collision with another car.

The main conclusion of this load case analysis is that the seat back will have to be designed to resist both forward and rearward dynamic bending while the seat base structure will be designed mainly to handle submarining force and static pressure. During the load case analysis it was realized that there were user needs apparent in the seat design that had not been previously elicited. These were mainly functional criteria assumed to always be found in a seat design such as the base structure supporting the driver from below and the back structure from the rear. Similarly the attachment structure is responsible for transferring loads from the seat to the car body. Thus a second set of functions that would drive new concept design solutions had been found, they were named *Provide structural support*. Together with the functional criteria *Adjust driver* the main functional criteria had now been found.

3.3 Initial Product Specifications

In accordance with Ulrich & Eppinger's (2012) theory of establishing product specifications, the following steps, involving metrics, benchmarking and analysis, have been used in the planning phase of this thesis:

1. Utilizing the customer needs as a starting point, a list of engineering metrics has been established.
2. Information about leading designs have been gathered and compared using the list of engineering metrics.
3. The benchmarking in step two has been used as a basis for setting measurable targets for the development effort.

3.3.1 Establish engineering metrics

Customer needs are subjective and leave too much margin for interpretation; therefore there was a need for a translation of customer needs into a set of specifications that spell out in measurable detail *what* the future product had to do. This was done by establishing a set of engineering metrics that would connect the customer needs to targets for the subsequent development effort. Based on the assumption that meeting these specifications would lead to a satisfaction of the associated customer needs, the metrics were linked to specific customer needs where possible.

Table 2: Identified customer needs and their relevant importance

No.	Need	Importance
	Customer needs	
1	The seat is comfortable when driving for an extended period of time	5
2	The seat is comfortable when driving for a short period of time	3
3	The seat is affordable for a majority of car manufacturers	4
4	The seat is as light as possible in order to reduce fuel consumption and pollution	4
5	The seat protects the driver in case of a collision	5
6	The seat supports a variety of driver heights	4
7	The seat supports a variety of driver widths	3
8	The seat supports the driver's back in different angles	2
9	The seat is easy to operate	3

The metrics were derived from analyzing the list of customer needs and the necessary functions that were discovered in the reference seat analysis. Generally thinking in the way of how an engineer would express that need and how to measure it in an objective way. It was decided to only include metrics that could be practically measured by the team during the development process; otherwise it was judged that impractical metrics would simply be overlooked. For instance since it was not in the scope of this thesis to perform any extensive testing, the crash test requirements found when scanning through several auto seat requirements had to be translated into load cases that could be used as input and constraints in the optimization, and FE- software instead.

Table 3: Engineering metrics translated from the customer needs

Metric No.	Need Nos.	Metric	Importance	Units
		Adjustment system		
1	6,7	Length adjustment interval of H-point (X-direction)	5	mm
2	7,6	Height adjustment interval of H-point (Z-direction)	5	mm
3	8	Back angle adjustment interval (around Y-axis)	4	degrees
4	1,2	Ankle angle interval	4	degrees
5	1,2	Knee angle interval	4	degrees
6	1,2	Elbow angle interval	4	degrees
7	1,2	Clear field of view for driver within size range	5	Subjective
8	1,2	Clear sight of instrument cluster for driver within size range	5	Subjective
9	9	Time to adjust seat	2	s
		Base structure		
10	5	Max. allowed deflection from driver weight (Z-direction)	4	mm
11	5	Max. allowed deflection from submarining (X-direction)	5	mm
12	5	Max. allowed stress during impact	5	Mpa
13	1,2	Width	3	mm
14	1,2	Length	3	mm
		Back structure		
15	5	Max. allowed deflection during impact (Pos. X-direction)	5	mm
16	5	Max. allowed stress during impact	5	Mpa
17	5	Max. allowed deflection from driver weight (Neg. X-direction)	4	mm
		Has side support	3	Binary
18	5	Has whiplash protection	4	Binary
19	1,2	Width	3	mm
20	1,2	Height	3	mm
		Attachment structure		
21	5	Max. allowed deflection from driver weight (Z-direction)	4	mm
22	5	Max allowed stress during impact (any direction)	5	Mpa
		General		
23	3	Unit manufacturing cost	5	SEK
24	3,4	Added manufacturing cost / Reduced mass	4	SEK/kg
25	4	Potential for reducing overall car weight	4	Subjective
26	4	Total mass / Reference mass	5	%

Most of the metrics followed logically from the user needs, but metric no. 25 might need further explanation. This was a derivative from the background study and the philosophy of a cascading mass reduction effect as explained in the Lotus report (Lotus 2010). This is a subjective evaluation of a concepts potential to cause mass reduction in other sub-systems other than the seat. According to lead seat designers the safety metrics, relating to need no. 5, will be dimensioning for the seat frame structure which is why these have been highlighted as important. Although theory states that a metric should only be linked to one specific customer need there were some cases where one metric was inevitably associated with multiple needs (Ulrich & Eppinger 2012). This was true in the case of metric no. 25: *potential for reducing overall car weight*. This metric had a direct association to customer need no. 4, the seat is lightweight, but also affected the cost of the car in a positive way and thereby need no. 3 as well. The complete list of engineering metrics can be seen in table 3.

3.3.2 Competitive benchmarking

Before determining what values of the engineering metrics to aim for in the subsequent development process, reference values had to be gathered. The reference seat already analyzed could supply these values but in order to develop confidence that the resulting concept design would be feasible in the automotive market, information about competitors' products was needed as well.

Since the engineering metrics would be used to evaluate the future concept design, it was natural to use these as a basis for evaluating solutions that were already in the marketplace. The main source of information about the other products was a2mac1.com. This is a company that buys new cars and completely tears them down while documenting the entire process. Data such as component mass, dimensions and placement can easily be found on their website along with detailed images that helped this analysis. However two vital sources of information that could not be found in this way was the structural performance of a component and the component cost. Since these were integral for evaluating the success of a subsequent concept design they had to be explored in some way. The lack of performance data was replaced with the assumption that all available solutions at the very least had the same structural performance requirements as the reference seat. The reference seat is older than any of the other seats analyzed, which motivated this assumption. For the cost, a cost model had to be developed. This was based on the actual cost of components in a reference seat, with penalty functions adding cost for more material used, and added complexity such as more parts, difficult shapes or other manufacturing techniques. This would then adjust the cost of the other designs accordingly. The car J seat frame for instance is made up of few components which consist mostly of stamped sheet metal, a majority of its components are not painted, and it uses less material than the other designs. As a result it is approximately 35 percent cheaper than the reference design. At this stage the cost analysis was only based on the structure of the seat as this would be the main component of interest for this thesis. When the benchmarking chart had been constructed several conclusions could be drawn and the most important ones were:

- Across the solutions there was a small difference in frame mass; one reason for this could be that the overall design was similar as well.
- The undercarriage containing the tracks for length adjustment varied from 2.2 kg to 5.9 kg hinting that there is room for a potential weight reduction in this section of the seat.
- The lightest solutions all made use of tubular construction elements in the frame; the tubular cross section could be an important feature in terms of mass reduction.

- Although the base frame did not vary considerably in mass across the solutions, the total mass revealed large differences depending on the number of adjustability functions incorporated in the seat. If it would be possible to reduce the number of functions with maintained comfort, this could possibly result in mass savings.
- The dimensions of the seat frames and components were similar across vehicle segments, which could be due to similar size of the people they were designed for.
- The cost varied mainly with the complexity of the seat structure, and again with the number of adjustability functions incorporated in the seat.

A fraction of the Benchmarking table can be seen in figure 11 while the full table can be found in appendix 2.

Metric	Importance	Units	Reference	Car B	Car E	Car F	Car G	Car J
Adjustment system								
Length adjustment interval of H-point (X-direction)	5	mm	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)
Height adjustment interval of H-point (Z-direction)	5	mm	305(+30,-30)	345(+30,-30)	320(+30,-30)	300(+30,-30)	300(+30,-30)	300(+0,-0)
Back angle adjustment interval (around Y-axis)	4	degrees	angle -25,(+15,-30)	ıngle -25,(+15,-30	angle -25,(+15,-40)	angle -25,(+15,-45)	angle -25,(+15,-45)	angle -25,(+15,-50)
Time to adjust seat	2	s	3	7	7	5	7	6
Base structure								
Max. allowed deflection from driver weight (Z-direction)	4	mm	1	1	1	1	1	1
Max. allowed deflection from submarining (X-direction)	5	mm	4	4	4	4	4	4
Max. allowed stress during impact	5	Mpa	700	700	700	700	700	700
Width	3	mm	495	500	490	480	490	525
Back structure								
Max. allowed deflection during impact (Pos. X-direction)	5	mm	11.2	11.2	11.2	11.2	11.2	11.2
Max. allowed stress during impact	5	Mpa	700	700	700	700	700	700
Max. allowed deflection from driver weight (Neg. X-direction)	4	mm	1.2	1.2	1.2	1.2	1.2	1.2
Has side support	3	Binary	Yes	Yes	Yes	Only on back	Yes	Only on back
Has whiplash protection	4	Binary	Yes	Yes	Yes	Yes	Yes	Yes
Width	3	mm	515	530	485	520	515	535
Attachment structure								
Max. allowed deflection from driver weight (Z-direction)	4	mm	0.5	0.5	0.5	0.5	0.5	0.5
Max allowed stress during impact (any direction)	5	Mpa	700	700	700	700	700	700
General								
Unit manufacturing cost (Frame + Padding)	5	SEK	860	958	834	692	617	593
Potential for reducing overall car weight	4	Subjective	1	1	1	1	1	1
Frame mass	4	kg	7,85	11,267	7,882	7,983	7,469	7,676
Adjusters mass	4	kg	7,8	5,882	5,372	3,905	4,01	2,248
Seat mass	5	kg	25,376	23,422	18,472	18,13	18,011	14,57
Total mass / Reference mass	**5**	**%**	**100**	**92,3**	**72,8**	**71,4**	**71**	**57,4**

Figure 11: An outtake from the benchmarking table (for complete version see appendix 2)

3.3.3 Target specifications

The target specifications were intended to both act as a guide throughout the development effort and to enable an evaluation of the final concept design against the customer needs and purpose of this thesis. These specifications would thus act as an agreement of objectives between the team and the main stakeholders as a way to measure the success of the end result. The target values were based on the benchmarking analysis as well as the reference seat analysis, and the focus was on mass reduction. This meant setting the mass reduction targets quite aggressively, which would serve as a goal function for the optimization procedure. The other specifications such as comfort, adjustability and cost, which would be used as constraints in the optimization procedure, were set close to their current level by aiming for the mean value of the designs analyzed. The reason for choosing two different targets for cost was to make sure a reasonable basic price would be maintained, the *unit manufacturing cost* target, and to establish a relationship between amount of mass reduced and the resulting tolerated cost increase, the *cost/reduced mass* target. The critical targets were the specifications associated with need number five, safety. The other specifications are a mix of measurable dimensions and subjective evaluations that ensures a satisfaction of customer needs. The aim had now been set for the subsequent development process. The target specifications are compiled in a spreadsheet and can be seen in table 4.

Table 4: Complete target specification which the thesis is based on

Target Specifications

Spec. No.	Need Nos.	Statement	Imp.	Units	Marginal Value	Ideal Value
		Adjustment system				
1	6,7	Adjust length of H-point in X-direction. Min. interval = 210 mm.	5	mm	210	220
2	7,6	Adjust height of H-point in Z-direction. Min interval = 50 mm.	4	mm	50	60
3	8	Adjust back angle around Y-axis. Min interval = 14 degrees.	3	degrees	14	>14
4	1,2	Maintain ankle angle in comfortable position. Min. interval = 90-110	4	degrees	90-100	N/a
5	1,2	Maintain knee angle in comfortable position. Min. interval = 110-130	4	degrees	110-130	N/a
6	1,2	Maintain elbow angle in comfortable position. Min. interval = 80-165	4	degrees	80-165	N/a
7	1,2	Enable clear field of view for driver. Size range = 5-95 &	5	Subjective	5-95 Percentile	1-99 Percentile
8	1,2	Enable clear sight of instrument cluster for driver. Size range = 5-95 %	5	Subjective	5-95 Percentile	1-99 Percentile
9	9	Driver is able to adjust seat easily. Max. time to adjust seat = 10 s	2	s	10	6
		Base structure				
10	5	Support driver when subjected to a static load of 1600 N in Z-direction. Max. allowed deflection = 1 mm.	5	mm	1	<1
11	5	Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max allowed stress = Yield limit of material.	5	Mpa	Yield limit of material	N/a
12	5	Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed stress = Yield limit of material.	5	Mpa	Yield limit of material	N/a
13	5	Support driver when subjected to a submarining load of 4000 N in X-direction. Max allowed deflection = 5 mm.	5	mm	5	2
14	1,2	Width of seat base	3	mm	500	N/a
15	1,2	Length of seat base	3	mm	600	N/a
		Back structure				
16	5	Support driver when subjected to a static load of 1600 N in X-direction. Max. allowed deflection = 2 mm.	5	mm	2	<2
17	5	Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max. allowed stress = Yield limit of material.	5	Mpa	Yield limit of material	N/a
18	5	Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max. allowed deflection = 14 mm.	5	mm	14	N/a
19	5	Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed stress = Yield limit of material.	5	Mpa	Yield limit of material	N/a
20	5	Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed deflection = 14 mm.	5	mm	14	N/a
21	1,2	Support driver during hard cornering	3	Binary	Yes	N/a
22	5	Protects driver from whiplash during rear impact.	4	Binary	Yes	N/a
23	1,2	Width of back structure	3	mm	485	N/a
24	1,2	Height of back structure	3	mm	900	N/a
		Attachment structure				
25	5	Support driver & seat when subjected to an individual load of 4000 N in Z- and X-direction. Max. allowed stress = Yield limit of material	5	Mpa	Yield limit of material	N/a
26	5	Support driver & seat when subjected to an individual load of 4000 N in Z-direction. Max. allowed deflection = 0.5 mm	5	mm	0.5	<0.5
		General				
27	3	Max. Unit manufacturing cost	5	SEK	2485	2300
28	3,4	Added manufacturing cost / Reduced mass	4	SEK/kg	50	0
29	4	Potential for reducing overall car weight	4	Subjective	2	5
30	4	Lower mass than the reference design. Total mass / Reference mass	5	%	20	25

4. Concept generation

The previous section contains the details regarding the target specifications for the seat structure concept. The target specifications is a list of functional criteria, combined with a set of constraining criteria, that together details *what* the final concept design has to achieve in order to be a viable solution to the problem identified earlier: How can the seat system mass be reduced, without sacrificing the safety, cost, and ergonomic performance of the current solution? In order to develop a solution to this problem, a concept synthesis, or generation, phase has been carried out. The aim of this phase was to generate an acceptable number of design solution concepts for the different functional criteria (FR) that could be identified from the target specifications, thus detailing *how* the concept design would solve the identified problem. It is important to clarify what is meant by a design solution concept, and what it should include. In this case it would include a technical solution to the functional criteria, and a geometric layout of this solution. This is represented by models of varying level of detail depending on in which phase the development process is in, ranging from hand drawn sketches in the concept generation phase to more detailed CAD-models with FE-simulations in the final phase. In accordance with product development theory the functional criteria were not taken directly from the target specifications, instead they were reformulated in a more abstract form to allow for a larger solutions space to be explored (Johannesson, Persson, & Pettersson 2013). The strategy of first conducting a functional-means model analysis to break down the main seat structure function into several sub-functions, followed by a generation of solutions to these sub-functions was borrowed from the theory as well. The reason for choosing this strategy was that the seat structure is complex and subjected to several different requirements and constraints from different disciplines such as mechanics, ergonomics, and material science. Focusing the development effort on individual sub-functions separately at first and then combining the sub-solutions into a complete concept was a way of coping with the complexity of the seat structure. As a way of ensuring that the design solutions with the highest potential for mass reduction would be found and further developed, an optimization procedure was implemented in the concept generation phase. By making use of topology optimization, approximate CAD-models, and rough FE-analysis, the mass savings potential of the initial sub-solution concepts could be compared to each other. Following this synthesis-analysis step, the most promising concept ideas could be combined using morphological matrices which were created based on the functional-means model produced earlier. The output of the concept generation phase was a list of promising concept design solutions for the two main functional requirements identified in the function-means analysis, *Adjust driver* and *Provide support*. The outlined process of this section can be seen below:

1. Based on the target specifications, the functional requirements have been reformulated into a more abstract form.
2. A function means-model analysis has been carried out on the seat structure.
3. The solution space for the identified sub-functions has been explored using brainstorming.
4. An initial screening of the generated ideas, based on feasibility, has been carried out.
5. The remaining ideas have been combined into initial sub-solution concepts
6. An early optimization procedure has been carried out on the sub-solution concepts
7. The optimized sub-solution concepts have been combined using morphological matrices.

4.1 Reformulation of functional criteria

For the purpose of widening the solution space, and to avoid preconceptions regarding the seat structure design, the most important functional criteria had to be extracted and reformulated into a more abstract solution-independent description. This is also described in the theory (Johannesson, Persson, & Pettersson 2013).

Table 5: Reformulation of target specifications for the base structure into functional requirements and constraints

In target spec.	After extraction & widening	
Base structure	**Constraint**	**Functional requirement**
Support driver when subjected to a static load of 1600 N in Z-direction. Max. allowed deflection = 1 mm.	Rigid when subjected to a load of 1600 N in Z-direction. Max. allowed deflection = 1 mm.	
Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max allowed stress = Yield limit of material.	No yield when subjected to a load of 2100 Nm around recliner axis. Max. allowed stress = Yield limit of material	FR1 = Support driver from below
Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed stress = Yield limit of material.	No yield when subjected to a load of 2500 Nm around (-)recliner axis. Max. allowed stress = Yield limit of material	
Support driver when subjected to a submarining load of 4000 N in X-direction. Max allowed deflection = 5 mm.	Rigid when subjected to a load of 4000 N in X-direction. Max. allowed deflection = 5 mm.	FR2 = Protect driver from submarining

Table 5 contains the reformulation of target specifications for the base structure into more abstract functional requirements, FR1 and FR2. These functional requirements were the drivers for generating solutions throughout the rest of the concept generation phase. When a number of solutions had been found, the corresponding constraints, which are also formulated in table 5, could be used to screen the ideas and concepts to find the most promising ones.

Table 6: Reformulation of specifications for the adjustment system

Adjustment mechanisms		
Adjust length of H-point in X-direction. Min. interval = 210 mm.	Min. length adjustment interval = 210 mm	FR7 = Adjust length of H-point
Adjust height of H-point in Z-direction. Min interval = 60 mm.	Min. height adjustment interval = 50 mm	FR8 = Adjust height of H-point
Adjust back angle around Y-axis. Min interval = 14 degrees.	Min. back angle adjustment interval = 14 degrees.	FR9 = Adjust angle of back

The functional requirements that were created from the target specifications were also used as a basis for the functional-means model created afterwards. For the full list of functional requirements and constraints, see appendix 3 (Reformulation of criteria).

4.2 Functional-means model analysis

After analyzing the functional criteria it was realized that a distinction could be made between functional requirements relating to the function of supporting the driver and the requirements that related to the adjustment system. It was decided to create two main functions based on this distinction: Adjust driver, and Provide structural support. The functional criteria described in the previous section were divided and matched to these two main functions, with FR1-FR6 labeled as *provide support* requirements and FR7-FR9 labeled as *adjustment* requirements. Due to the large number of functional requirements and the different nature of the identified main functions, i.e. Adjust driver & Provide structural support, the choice was made to create separate F-M models for these functions. By searching for solutions to the functional constraints that together make up each separate F-M model, it would enable a large design problem to be divided into several smaller ones. It was also desirable to separate the more mechanical design aspects inherent in the design solutions for *provide structural support*, from the ergonomic design aspects inherent in the design solutions for *adjust driver*, though both F-M models were drivers of mass and cost. To begin with both main functions was put into the appropriate context by creating an F-M model of the driver seat system, this would give the team a system level approach to solving the main design problem as well.

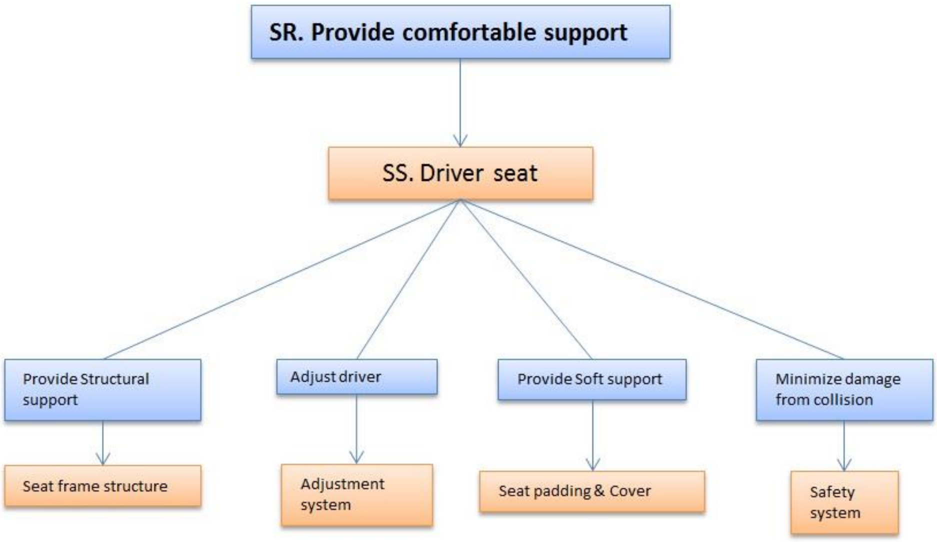


Figure 12: F-M model of the driver seat system

Although the adjustment system and the frame structure have been combined in the same component in the reference solution, this does not have to be the case. It was believed that separating these two functions would simplify the development work in the following phases. The focus of this thesis has been to find new concept design solutions to the functions *Provide structural support* and *Adjust driver*, which excluded finding new solutions to the seat padding and safety system. For the final complete concept it was assumed that the reference solutions will be used for the functions that were not covered by the development process. It should be mentioned here that the safety system in the model includes the side airbag and belt system but not the whiplash protection or measures taken to avoid submarining during impact. This was because it was difficult to separate those two functions from the seat support structure. Having put the main functions into a context they could be focused on and broken down further. Starting with the adjustment system an F-M model was created based on the abstracted functional criteria formulated in the previous section, which can be seen in figure 13 below. In each of the created F-M models the functional criteria (FR), design solutions (DS) and main function are included. The limiting constraints corresponding to the FR's are found in appendix 3 (Reformulation of criteria).

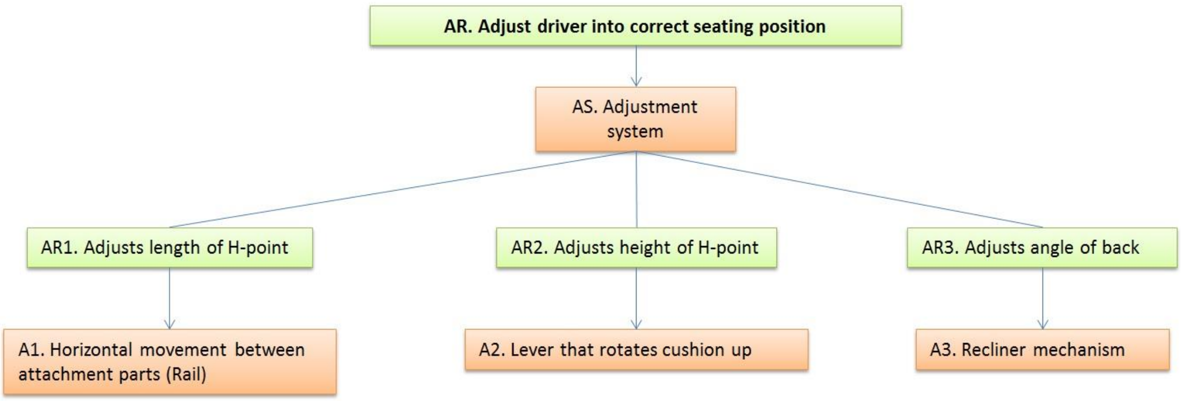


Figure 13: F-M model of the driver seat adjustment system

In figure 13 the design solutions of the reference seat have been included (A1-A3). These correspond to functional sub-requirements (AR1-AR3) that together make up the adjustment system. The actual development process has been aimed to replace these design solutions with mass reduction in mind. Having analyzed the reference seat prior to this F-M analysis, knowledge had been gathered regarding the fact that the separate solutions for the adjustment functions were responsible for a large fraction of the seat mass and cost. At some point during the functional analysis process it was also realized that if one or more of these solutions could be combined into one this would reduce both mass and cost of the seat. An even better result could be achieved if one or more of these adjustment design solutions had been eliminated completely. An important conclusion of the F-M analysis was thus: To reduce both mass and cost of the seat, the number of design solutions for the *Adjust driver* functional requirement, and complexity thereof, should be kept to a minimum. Following the F-M analysis of the adjustment system, a similar analysis was made of the structural support frame, which can be seen in figure 14.

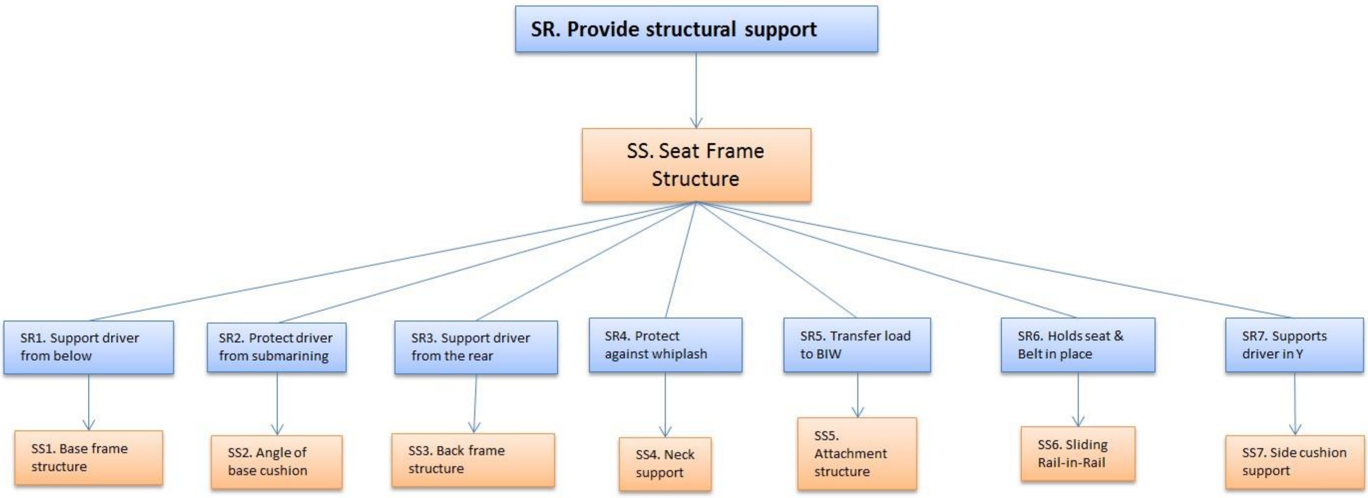


Figure 14: F-M model of the driver seat frame structure

In figure 14 the design solutions of the reference seat have been included (SS1-SS7). These correspond to functional sub-requirements (SR1-SR7) that together make up the seat frame structure. The purpose of the concept generation phase was to come up with new solutions that solved these sub-requirements, while reducing mass at a maintained cost level. Most of these design solutions are subject to both mechanical and ergonomic constraints although the mechanical constraints dominate. The constraints can be found in appendix 3 (Reformulation of criteria). Apart from aiding the development team during the idea generation and initial screening, the F-M models were used as a basis for the morphological matrices created at the end of the concept generation phase.

4.3 Exploration of the solution space

The purpose of this step was to generate ideas that could directly solve, or give inspiration to developing solutions to the elicited functional requirements. Upon having generated a large number of ideas the successive elimination and combination of them would yield a number of concept design solutions. It was believed that generating a large quantity of ideas would ensure a large part of the available solution space to be covered. The chosen method for finding solutions was Brainstorming. It was conducted much in accordance with the theory for brainstorming sessions with no critique allowed and a goal of generating a high quantity of ideas each session. In order to receive input from several different disciplines, three brainstorming sessions involving different Semcon employees were conducted. The participants were mostly engineers although of varying age and field of expertise, ranging from mechanical engineers to industrial designers, and experts in ergonomic design. In one of the sessions an expert in seat design participated as well. At the start of each session the design problem and the most important functional requirements were introduced, after this the participants would elicit ideas to the general seat design freely. Having gone through general ideas, the team in each session would then focus on the individual functional constraints belonging to the Adjust driver and Provide structural support main functions. Although no specific systematic idea generation such as benchmarking were conducted in this phase, the team screened through the internet in search of solutions to similar design problems in other applications prior to each brainstorming session. These applications included aircraft, motorcycles, biological systems and gym equipment to mention a few. Pictures of interesting solutions were printed and used as inspiration during the brainstorming sessions. This was a good way to trigger the imagination of the participants after the initial ideas had been expressed. As a result of these sessions a list of 98 ideas could be compiled. Some ideas were complete concepts while others were fractions of concepts that had to be combined with other ideas to create a concept. Since 98 ideas are too many to be described in detail some examples of ideas are presented here, along with a number of conclusions and general impressions that summarize the ideas.

- *Quadriceps seat*
  This idea mainly built on the concept that it is common for short drivers to adjust the seat to a forward position in terms of length and a high position in terms of height, while tall drivers generally adjust the seat to the most rearward and lowest position. This almost linear correlation of length and height adjustment led to the idea of combining the two functions in an angled length/height adjustment. Since a similar design was found to be used in gym equipment machines for training legs the idea was named the Quadriceps.

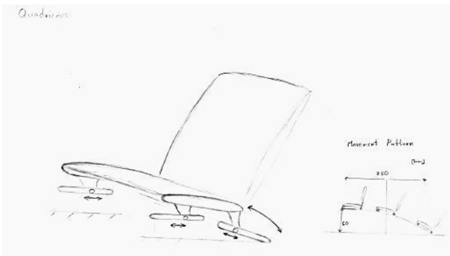


Figure 15: Quadriceps seat

- *Heightened recliner*
  During the brainstorming sessions a large emphasis was put on eliciting ideas that would enable a smaller recliner mechanism to be used, one of these was the idea of moving

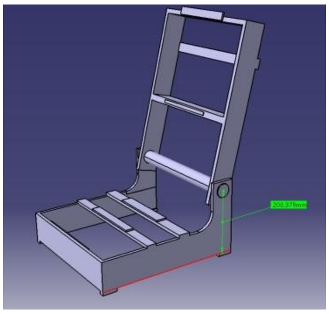


Figure 16: Heightened recliner

the recliner to a mounting position 200 mm higher up than in the reference design. This would generate a smaller moment load to act on the recliner mechanism.

- *Support strut*
  Another idea aimed at downsizing the recliner mechanism and generally increase the stiffness of the seat support structure was the concept of having struts mounted between the base frame and back frame, they would be mounted on hinges so as not to hinder the recliner function.

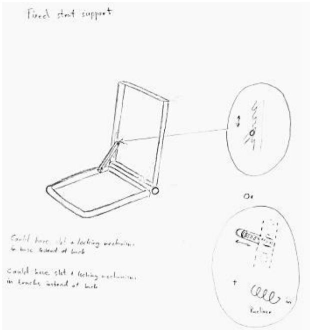


Figure 17: Support strut

- *Inflatable cushions*
  Building on the theme that having a fixed frame structure would increase stiffness drastically and thus be able to reduce overall mass, the idea of having inflatable inserts into the back frame to adjust the angle of the drivers back was introduced. Many other adjustable inserts ideas were introduced as well.
- *Wires*
  Similar to the support strut concept, several ideas involving wires between the base frame and back frame were introduced. The main benefit of having wires was believed to be that they would not be in the way or in sight until an actual impact would occur.
- *Ergonomic backrest*
  An issue that was revealed during the first benchmarking (section 1.2.1) was that the seat back frame was not ergonomically optimal as the structure itself created pinch points near the drivers back. To compensate for this current seats utilize added foam thickness near these points which drives up mass of the entire seat. If a thin arched top profile would be used for the seat back frame it would enable a thinner layer of foam to be used.

Figure 18: Ergonomic backrest

- *Attachment structures*
  There were several ideas introduced that aimed to reduce the mass of the attachment structure, mounting the seat into the sill and the tunnel of the car body was one of these. Another idea was to have a single rail in the center underneath the seat. But other ideas such as raising the floor of the car underneath the seat and mounting the seat with wheels that rotated within tracks were found.

The ideas mentioned above were only some examples of the long list of ideas found in the explorative phase of this thesis, the complete list of ideas can be found in appendix 4 (Brainstorming ideas). To summarize this section is a number of conclusions found after reviewing the idea generation process: One of the main themes during the idea generation was to find ideas that would replace the current recliner, height adjustment, and length adjustment mechanisms. This was natural as it had been previously identified that the adjustment mechanisms were responsible for a large fraction of the seat mass (a2mac1 2014). Another theme was to find efficient structural support ideas such as having a fixed frame in order to improve stiffness and mass of the support structure. Although not specifically linked to the functional sub-criteria found in the F-M models, many ideas involved finding new materials and cross sectional shapes as well as inspiration for the geometrical layout of the seat structure.

4.4 Initial screening and optimization of sub-solution concepts

Having generated as many as 98 ideas it would be incomprehensible to combine them using morphological matrices right away, the number of possible combinations would be overwhelming. For this reason an initial screening strategy was introduced:

1. All ideas were ranked subjectively on a scale of one to five based on feasibility.
2. The ideas that scored higher than three were extracted and sorted based on the functional requirement they corresponded to.
3. Before any further screening was made, these promising ideas were refined using further brainstorming and sketching.
4. The refined ideas were used as a basis for design domains that were used as input to a topology optimization procedure.
5. The results from the topology optimization were modeled using CATIA.
6. The CATIA concept models were analyzed using FEM and the load cases described in the *reference seat analysis* section.
7. An evaluation was made to determine the mass savings potential of each concept.

In order to provide a fair comparison, seeing as the concepts were at such an early stage, only simple CAD-models and FE-analysis were used. Furthermore since the team wanted to include the reference design in the comparison a simplified reference model was made. If the fully detailed reference design had been used at this stage the FE-results would have been incomparable. Steps one through three in the screening strategy was made using the analytical thinking and experience of the development team. Steps four through seven however made up an optimization loop that ran for several iterations before the final result could be gathered. Using the topology optimization results as inspiration the CAD-models were designed to be as light and stiff as possible within the available design domain for the different concepts. Utilizing FE-analysis the mass was then further reduced by normalizing the structural performance e.g. the stiffness and yield strength to be as close to the reference design as possible. In optimization terms, the maximum deflection (stiffness) and maximum von Mises stress (yield strength) were used as constraints while the geometry within the design domain boundary was used as a parameter that was adjusted to decrease the value of the goal function (mass) as much as possible. This resulted in a fair comparison of which basic concepts that had most mass savings potential at this early stage in the development process. As a bonus feature this synthesis-analysis loop also resulted in near optimal concepts for the overall geometry of the seat frame support structure. These concepts were not screened in the same way as the functional concepts for adjustment and structural support. They were assumed close to optimal and were subsequently applied to all structural support concepts in the concept selection phase. This was also used as a constraint in the concept selection process: If an adjustment or structural support solution could not be combined with the pre-determined geometrical concept shape, that concept would not be chosen for further development. The geometry concepts were later used as input during the detail design phase (*Further development of the chosen concept*).

4.4.1 Ranking and sorting of ideas

The ideas were sorted based on what the team believed was feasible. In this case feasible meant in part what could be realized during the subsequent development work, and in part what would actually yield a promising result. As 98 ideas were too many to be evaluated in any more detail than this during a master thesis it was assumed that it was an adequate level of screening at that point in the development process. There were several ideas that involved the overall shape of the seat structure, but since topology optimization would be used as a part of eliciting new concepts it was realized that the most optimal shapes would be discovered during that process, hence all ideas involving seat shape and layout were discarded. All ideas involving changing material were saved for a material selection stage in the subsequent development process under the assumption that regardless of which design solution concepts for the adjust driver and provide structural support functions that would be chosen the material could be selected independently afterwards. Using similar reasoning all ideas involving the shape of different cross sections were put on hold to be used in the detail design phase (Further development of the chosen concept). After ranking and sorting all ideas they were compiled in a spreadsheet format which can be seen in table 7 below.

Table 7: The most feasible and promising ideas sorted into corresponding functional sub-criteria

AR1	**Adjust length of H-point**
5	Quadriceps seat
5	Reference rail adjuster
AR2	**Adjust height of H-point**
5	Quadriceps seat
4	Adjustable insert within fixed frame (movable pads, wire plates, excenters)
4	Mechanical lever
AR3	**Adjust angle of back**
4	Adjustable insert within fixed frame (movable pads, wire plates, excenters)
3	Adjust complete seat instead of just the back (angle)
4	Backrest mounted direct on floor, no recline bar in seatframe
SR1	**Support driver from below**
4	Topology optimize base frame
4	Magnesium base frame
SR3	**Support driver from the rear**
5	Fixed joined base & back
4	Recliner mount 200 mm higher up than reference
4	Fixed armrest creating framework between base & back
5	Topology optimize back frame
5	Thin frame saves vehicle weight (+ Ergonomic shape)
SR5	**Transfer load to BIW**
5	Bolted to sill and tunnel
4	Single rail
4	Topology optimize rail
SR4	**Protect driver from whiplash**
4	Seat back with integrated head rest

The remaining ideas for Adjust driver, denoted as AR in figure 13, would now have given rise to 2x3x3 = 18 concepts if they had been entered in a morphological matrix. Similarly the ideas for Provide structural support, denoted as SR in figure 14, would have resulted in 2x5x3x1 = 30 concepts. In table 7 there are only four out of seven support criteria included, and this is because no new solutions for the other criteria were found. It was assumed that the reference solutions were going to be used for the remaining three criteria: SR2, SR6, and SR7. All in all the result would yield 58 concepts that afterwards needed to be modeled in CATIA and analyzed with FEM, something which would have been too time consuming. Thus even after sorting out a large number of ideas the remaining number of ideas still would have resulted in too large morphological matrices for the scope of this thesis.

4.4.2 Refinement and description of promising concept ideas

Instead of creating initial concepts right away, a stage of refinement and evaluation of concept strengths and weaknesses was conducted too further narrow down the available ideas and thus lessen the workload in the more time consuming synthesis-analysis procedure. A prerequisite for such an optimization procedure to be of use at an early stage in a small project like a master's thesis is that it can be iterated several times without delaying the overall development process. Basically the idea of compensating for the recliner mechanism by having adjustable inserts was abandoned at this point. Even though the team tried to solve it in several ways the net result never seemed to prove any advantage over the reference recliner mechanism. The idea of mounting the backrest directly to the floor was abandoned at this stage due to similar reasons, and the fixed armrest support idea was transformed into the strut support concept which introduced a movable support strut that connected the base and back frame to create added support. Below is a short description of the refined concept design sub-solutions that would later be combined into concepts for the *Adjust driver* and *Provide structural support* main functional criteria.

- *Quadriceps seat (AR1 & AR2)*
  This concept resembled the adjustment function of a quadriceps extender gym machine. Overall an interesting concept as it replaced two or possibly even all three adjustment functions with one. This concept worked by sliding the entire seat along a straight inclined or curved track. The potential for weight reduction with this concept was large, as the mass of the seat correlated with the amount of separate adjustment functions included. General benefits for this concept included the fact that similar solutions existed in other applications, that it probably had a low cost as it would be incomplex. The main drawback if this concept was the lack of support for individual height and length adjustment which might be perceived as hindering by certain drivers.

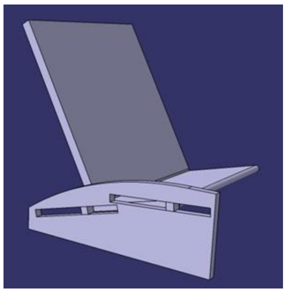


Figure 19: Early CAD-model of quadriceps seat

- *Adjust complete seat (AR1, AR2 & AR3)*
  Further building on the idea of combined functions was the concept of adjusting the complete seat including the back frame angle by sliding the seat on a curved track. This was similar to the Quadriceps concept, but with the added mass savings potential of removing the recliner mechanism as well. It also had added an added drawback in the form of even further reduced individual adjustability by not being able to adjust the seat back angle independently from the length and height adjustment functions.

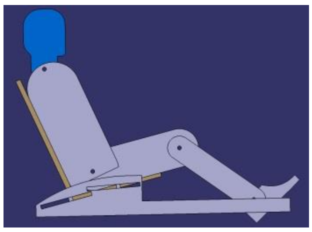


Figure 20: Adjust complete seat, incl. manikin

- *Adjustable inserts (AR1 & AR2)*
  These concepts aimed to make the pads adjustable independent of the seat structure movement. This would enable a rigid and lightweight one-piece frame to be used. There are current solutions that utilize this

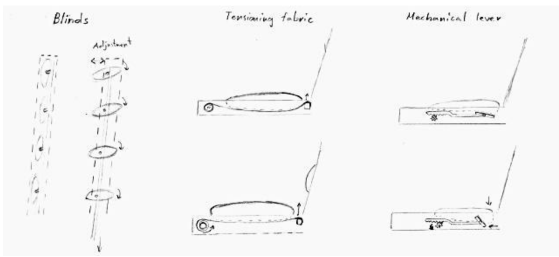


Figure 21: Sketches of adjustable inserts

technique in the height adjustment function, such as the mechanical lever used to raise the rear end of the seat cushion in the Nissan Micra (a2mac1.com). No current mechanical solutions are in use for adjusting the back pad although there are high end cars that use air pressure to adjust the comfort of the back pads. This might be due to tougher structural constraints on the back. The trade-off for implementing similar solutions would have been between the weight and cost of the recliner versus weight and cost for adjustable back inserts, or the weight and cost of the current height adjustment versus the weight and cost of an independently adjustable cushion.

- *Fixed frame (SR1 & SR3)*
  The structural benefits of removing the joint between the base and the back structure, and replacing it with a fixed frame were obvious but it would have required either a quadriceps-type of adjustment system or adjustable inserts. Since the adjustable inserts were abandoned at this point, the quadriceps adjustment system was the only option if a fixed seat frame was to be used. For this reason whenever the fixed frame is mentioned in the rest of the report it is assumed that the quadriceps adjustment is used as well.

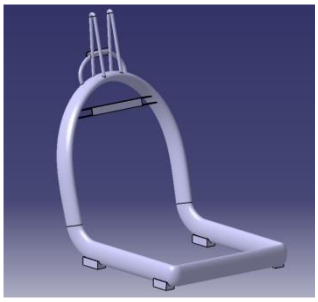


Figure 22: Early CAD-model of fixed frame

- *Support strut (SR3)*
  This concept introduced a strut between the back structure and the base structure (alternatively between the back and the tracks). This created a truss-like structure where the support strut relieves the reclining mechanism of moment force. The locking mechanism of the recliner is thus no longer needed, however the recliner still has to withstand the supporting moment created between the strut attachment point and the reclining point which is smaller than the moment created without the strut. One of the attachment points is a slot which allows the strut to move as the backrest angle is adjusted. The adjustment required a locking mechanism which could be a spring-loaded sprint that locks into holes in the back frame. The potential for mass reduction lay in the increased structural integrity created by connecting the base and back frame, as well as the ability to downsize the reclining mechanism due to less loads.

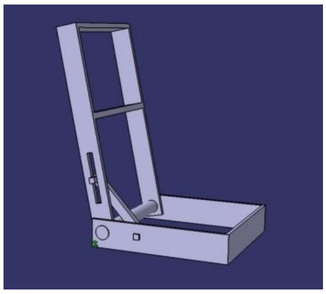


Figure 23: Early CAD-model of support strut

- *Heightened recliner (SR3)*
  This concept involved raising the recliner mount by 200 mm which would result in a shorter lever distance to the point where impact forces where affecting the seat back. It would have to be investigated if moving the recliner mount would yield any negative ergonomic side-effects at a later stage. Although the fact that several seat designs, analyzed in the benchmarking study performed earlier in the thesis, used a relatively high recliner mount at least validated this concept to a certain degree. Moving up the recliner mount seemed to be a useful concept due to the smaller moment force generated on the recliner mechanism with this layout. Another benefit of moving up the recliner that was realized was the fact that less material

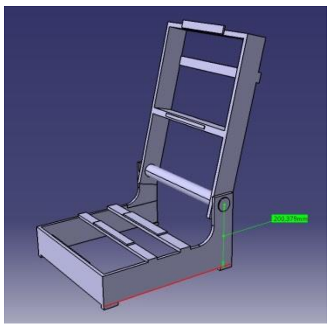


Figure 24: Heightened recliner

could be used on the seat back which could be sensitive to deflection caused by the front and rear impact load cases.

- *Sill & Tunnel (SR5)*
  This was a concept that had been in production by both Audi and Saab in the eighties. It involved changing the mounting position of the tracks which are currently bolted on a reinforced section of the floor, to being side mounted on the inner tunnel and outer sill which are also reinforced for other reasons. This would have eliminated the need for additional reinforcement of the floor which in turn would result in a lighter vehicle body. It would also free up space underneath the driver seat for the feet of rear passengers. Lastly it would also eliminate the need for seat risers thus reducing mass even further. The main drawback of this concept was that it would require some modifications to be performed on the car interior body.

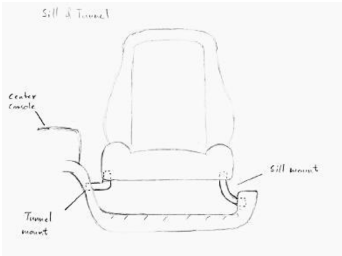


Figure 25: Sketch of Sill & Tunnel

Although the concept sub-solutions presented here all had shown promise of being further developed, all evaluations that had been made was purely subjective and based on experience as well as engineering intuition. In order to reveal the true mass savings potential of the concepts, and to generate even more promising concepts, an optimization procedure was undertaken.

4.5 Optimization process

The detailed result of this section is found in appendix 5 (Optimization loop). A description of the approach is presented here along with a summary of the result. From the remaining concept ideas four design domains were first sketched and then created in CATIA.

- The fixed structure without recliner (requires quadriceps adjustment)
- The support strut concept
- The heightened recliner concept
- The reference design.

These concept ideas all belonged to the *Provide structural support* functional criteria. The reason for not including the concept ideas for adjustment functions was that the fixed frame concept already covered the idea of not having a recliner mechanism which was the only really feasible design solution for back angle adjustment, apart from the reference recliner. For the adjust length and adjust height functions the solutions was to be incorporated in the attachment structure component which were evaluated separately from the base and back frame structure.

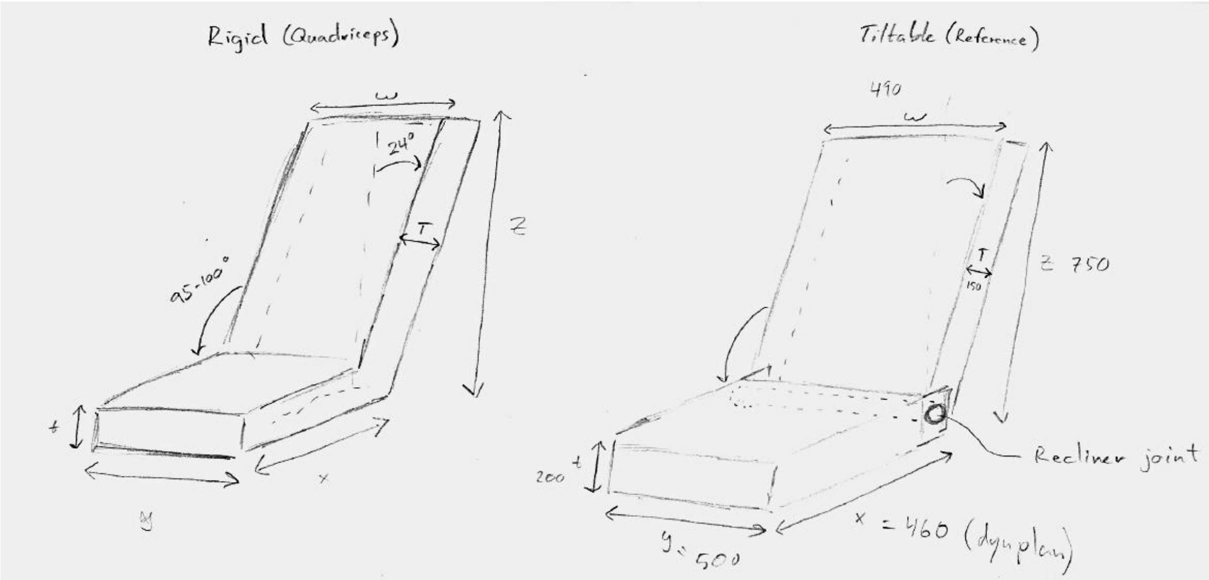


Figure 26: Sketch of two of the design domains that were created from the generated concept ideas, a fixed seat domain without recliner (Quadriceps) to the left and the reference domain with recliner to the right.

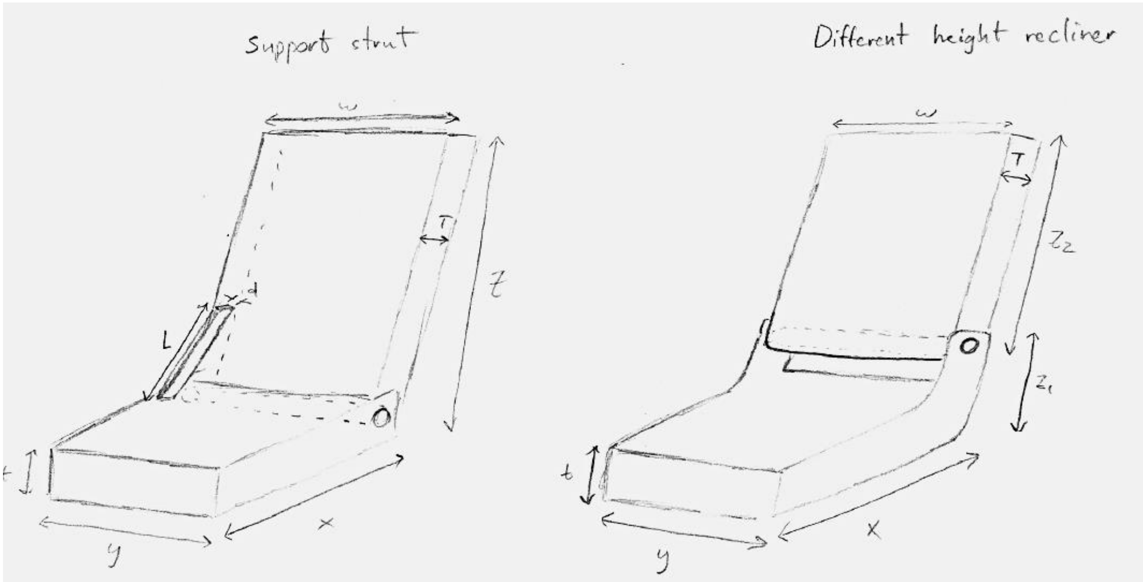


Figure 27: The support strut concept to the left, incorporating a rigid strut for extra support during collision. The heightened recliner concept to the right, a higher position of the recliner was believed to reduce the loads during impact.

After modeling the initial design domains, a topology optimization software called Altair Inspire was used to create optimized geometry and to better understand which parts of the design that would be vulnerable to impact loads, and which were less vulnerable thus more susceptible to mass reduction. The software visualized this by removing material where the stress was sufficiently low, or where the material did not aid in stiffening the structure. In order to be able to carry out this procedure the software also needed the load cases for the different impact scenarios as well as the static scenarios, which were extracted from the *analysis of reference seat* section. The software was able to perform the optimization procedure after adding several different load cases and scenarios, something which could not be done in CATIA's FE-module. It was also possible to assign different material properties to different parts of the model. After having performed the optimization procedure on the different input design domains and observed the result the following conclusions could be made:

- In all scenarios the software avoided removing material from the outer edges of the design domain, concentrating the mass as far from the centerline as possible seemed to increase the stiffness of the design.
- The software consistently removed more material at the upper part of the back structure. The stresses seemed to be highest near the recliner mounts and lowest near the neck support structure.
- The base structure profile did in most cases end up to resemble a bridge-like shape, thus removing material in the lower middle part of the base frame profile was possible.
- The rigid frame without recliner (requires quadriceps) could according to Inspire be made 60 percent lighter than the reference seat design, this however included the mass of the recliner mechanism.
- The support strut effectively reduced the loads applied at the recliner by having a shorter distance between the strut and the impact load application position. From this result the assumption was made that the structure mass could be reduced somewhat but that most mass reduction would come from downsizing the recliner mechanism.
- Similar to the support strut result, the heightened recliner concept also reduced the loads on the recliner mechanism during impact, by shortening the lever arm distance and effectively reducing moment force.

Figure 28: Initial design domain for the fixed seat structure concept.

Figure 29: Topology optimized design of the fixed seat structure concept. Suggesting 60 percent mass reduction compared to reference design.

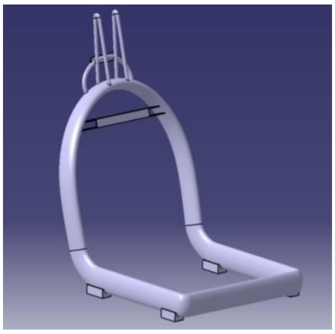


Figure 30: Topology optimized design modeled in CATIA.

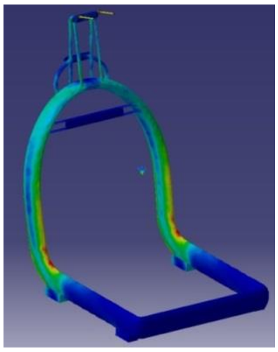


Figure 31: FE- analysis of the optimized fixed structure model.

For each concept the resulting geometry from Inspire was used to create a simple CAD-model in CATIA. This model had to be made in a single part due to limitations of analyzing assembly models in the FE-module in CATIA. All the interfaces of the models was the same as the final design but the overall geometry less complex in order to facilitate fast iterations at this point in the development process. The initial concept design was then analyzed using CATIA's FE-module with the load cases described in the *analysis of reference seat* analysis section of this thesis. The optimization aspect of this phase came into action when the concept model results were compared to the reference model results. If the stiffness of the concepts was higher than for the reference, the mass of the concept would be reduced until equal deflection results had been reached in the FE-analysis. The main parameter that was changed in the design-analysis loop was the structure wall thickness. However at this early stage it was not possible to optimize all of the models, the support strut and heightened recliner concept both showed potential of increasing stiffness of the design but in order to reduce mass the models had to be drastically changed. To avoid spending too much time at this point the potential for increased stiffness was included in the mass savings potential result. This was done under the assumption that an increased stiffness would equal savings in mass for the final design. A summary of the results from the procedure can be seen in table 8.

Table 8: Results from the first synthesis-analysis procedure

Load case	Reference structure	Optimized Structure	Quadriceps structure	Support strut structure	Heightened recliner structure
Rear Impact (Max. stress; Mpa)	473	429	420	310	331,1
Unrestrained cargo (Max. stress; Mpa)	572	564	542	375	389
Submarining (Max. stress; Mpa)	280	260	270	280	280
Unrestr. Cargo Stiffness (Max. Deflection; mm)	11,3	11,2	10,1	8,1	7,91
Mass (kg)	7,32	6,35	4,6	6	5,8
Potential mass reduction compared to reference (%)	N/a	12	37,2	24	27

Potential mass reduction estimated by combining increased stiffness with the already achieved mass reduction

As predicted by the topology optimization software, the fixed structure (required Quadriceps) showed the highest potential for mass reduction. The removal of a recliner joint enabled a simple uniform design which saved mass just by having a more optimal geometry. Adding further to this the fixed frame handled the impact loads better than the reference which would yield even more mass reduction. The heightened recliner structure also showed good mass reduction potential due to major reductions in stress and deflection under heavy loads. The support strut structure showed similar results as the heightened recliner concept although somewhat lower due to the added mass of the support struts. Interestingly enough the design created based on the topology optimization of the reference design domain showed a mass savings potential of 12 percent. This was achieved simply by changing the geometry to reflect the results from Inspire and not changing anything else. This proved that optimization was a useful tool for creating a lightweight design concept and the decision was made to use it throughout the rest of the development process.

4.6 Generation of concepts for Adjust driver & Provide structural support

At this stage in the development process the concepts that had been created were design solutions to sub-functional criteria in the function-means model of the driver seat structure. The aim of the thesis was to develop a complete seat structure concept which meant that the sub-solution concepts had to be combined into complete concepts. This was made in several steps to reduce the complexity throughout the project. First the sub-solution concepts were combined into design solution concepts for the two main functional criteria in focus, Adjust driver and Provide structural support. The development work then continued with these two areas until a final concept selection could be made, after which the concepts for adjustment and support could be combined into a final seat structure concept. For the first combination of sub-solutions, two morphological matrices were produced, one for the adjustment system and one for the support structure. Each morphological matrix corresponded to the function-means model of the same functional criteria.

Table 9: Combination matrix for the concept solutions belonging to the adjustment system

Morphological Matrix for Adjustment System

AR No.	Adjustability Req.	Adjustability Solutions (AS)	
1	Adjust length of H-point	**AS1a. Horizontal movement betw. attachment parts**	
2	Adjust height of H-point	**AS2a. Vertical movement betw. attachment parts**	**AS2b. Lever that rotates cushion up**
3	Adjust angle of back	**AS3a. Reference recliner**	**AS3b. Adjust complete seat (Fixed seatback)**

For each adjustment sub-criteria, such as Adjust length of H-point, all of the remaining concept solutions for that criterion were listed. Polygons were then drawn vertically to create the synthesized adjustment system concept. Since many ideas had already been screened out due to infeasibility or compatibility, the resulting morphological matrix for adjustment concepts was relatively small with 1x2x2 = 4 possible concept combinations. The adjustment concept combinations can be seen in table 10.

Table 10: The resulting concept solutions for *Adjust driver*

Concept No.	Resulting Concepts		
AC1	Horizontal movement betw. attachment parts	Vertical movement betw. attachment parts	Reference recliner
AC2	Horizontal movement betw. attachment parts	Vertical movement betw. attachment parts	Adjust complete seat (Fixed seatback)
AC3	Horizontal movement betw. attachment parts	Lever that rotates cushion up	Reference recliner
AC4	Horizontal movement betw. attachment parts	Lever that rotates cushion up	Adjust complete seat (Fixed seatback)

The four combinations all share the same type of length adjustment principle. This is the same as in the current seat structure as well, moving two rails within each other. Simply put there were no other feasible ideas for adjusting length discovered during the concept generation process, all other ideas such as inflatable adjustment pillows and the like ended up adding mass in the end. The height adjustment was different between the concepts though, the traditional mechanical lever was one option, with the combined length-height adjuster (Quadriceps) being another. By changing the inclination of the length adjuster rail, a change in height was achieved as well. Seeing as height and length adjustment seemed to be correlated, initial ergonomic analysis validated this principle and this concept became an early favorite with the team. Finally the method for changing the back angle had two variants as well, keeping the recliner mechanism found in the reference design, or removing it completely and instead tilting the entire seat structure.

Table 11: Combination matrix for the concept dub-solutions belonging to the support structure

Morphological Matrix for Support Structure

SR No.	Structural Req.	Support solutions (SS)			
1	Supports driver in Z	SS1a. Base Cushion Support			
2	Transfer Loads to BIW	SS2a. Bolted to Floor	SS2b. Bolted to Tunnel & Floor		
3	Minimizes submarining	SS3a. Positive Angle of Base Cushion			
4	Supports driver in X	SS4a. Optimized Reference Back frame	SS4b. Fixed Base & back	SS4c. Support Strut Betw. Base & Back	SS4d. Moving up Recliner Mount
5	Holds Seat & Belt in place	SS5a. Sliding Rail-in-Rail	SS5b. Wheel & Track (Tunnel)		
6	Protect against whiplash	SS6a. Removable Neck support	SS6b. Neck support integrated in Back frame		
7	Supports driver in Y	SS7a. Side Cushion support			

For each adjustment sub-criteria, such as *Support driver from the rear*, all of the remaining concept solutions for that criterion were listed. Polygons were then drawn vertically to create the synthesized support structure concept. Although many ideas had already been screened out due to infeasibility or compatibility, the resulting morphological matrix for support sub-concepts was more complex than the one for Adjust driver. There were 1x2x1x4x2x1x1 = 16 possible concept combinations. However not all of these combinations were compatible with each other, for instance the heightened recliner mount could not be combined with the fixed base and back. There were five of these incompatible combinations which meant that only 11 concepts could be generated for the support structure. Before combining the concepts it was also decided that a fixed neck support would be used which is why the removable neck support was eliminated at this stage. The created structural concept combinations can be seen in table 12.

Table 12: The resulting concept solutions for *Provide structural support*

Concept No.	Resulting concepts		
SS1	Bolted to Floor	Optimized Reference Back	Sliding Rail-in-Rail
SS2	Bolted to Tunnel & Floor	Optimized Reference Back	Sliding Rail-in-Rail
SS3	Bolted to Floor	Fixed Base & back	Sliding Rail-in-Rail
SS4	Bolted to Floor	Support Strut Betw. Base & Back	Sliding Rail-in-Rail
SS5	Bolted to Floor	Moving up Recliner Mount	Sliding Rail-in-Rail
SS6	Bolted to Tunnel & Floor	Fixed Base & back	Sliding Rail-in-Rail
SS7	Bolted to Tunnel & Floor	Fixed Base & back	Wheel & Track (Tunnel)
SS8	Bolted to Tunnel & Floor	Support Strut Betw. Base & Back	Sliding Rail-in-Rail
SS9	Bolted to Tunnel & Floor	Support Strut Betw. Base & Back	Wheel & Track (Tunnel)
SS10	Bolted to Tunnel & Floor	Moving up Recliner Mount	Sliding Rail-in-Rail
SS11	Bolted to Tunnel & Floor	Moving up Recliner Mount	Wheel & Track (Tunnel)

All 11 concepts had an attachment structure consisting of either two rails bolted to the floor, or one rail bolted to the floor and one to the tunnel structure. Neither attachment mechanism seemed to depend on the other sub-solutions why this could be evaluated independently later on. For the back support (*support driver from the rear)* the choice was more elaborate with four different options. The fixed base & back structure (required Quadriceps) which had shown the largest potential for mass reduction in the optimization loop previously performed. The heightened recliner concept had shown potential for mass reduction, although not at the same level as in the fixed concept. The support strut design, that effectively reduced impact loads on the recliner mechanism. And finally the reference back structure with optimized geometry, although the assumption was made that all the other concepts could be used with optimized geometry as well. The fact that one of the sub-solution columns included *Sliding Rail-in-Rail* and *Wheel & track* was because it was believed at the time that the attachment structure connection point was part of the design scope as well. If this had been the case a concept which involved wheels on the seat to rotate within rails attached to the car body had shown promise of reducing mass. After realizing that it would only work with a sill & tunnel type attachment structure as well as not really being part of the thesis scope, it was decided that the reference type connection, i.e. the rail-in-rail, would be used in all support structure concepts.

Figure 32: Illustrations of concepts for the adjustment system (AC1 top left, to AC4 bottom right)

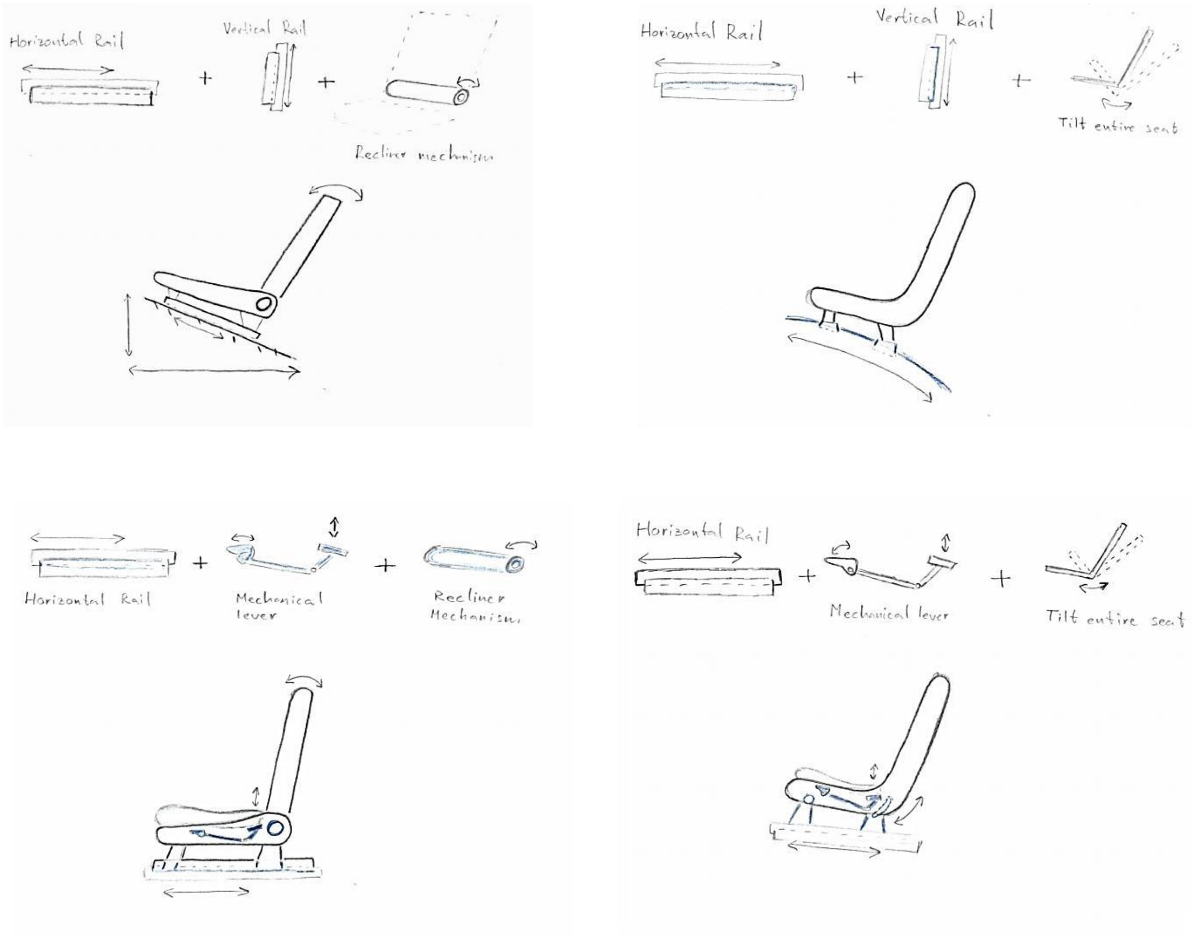
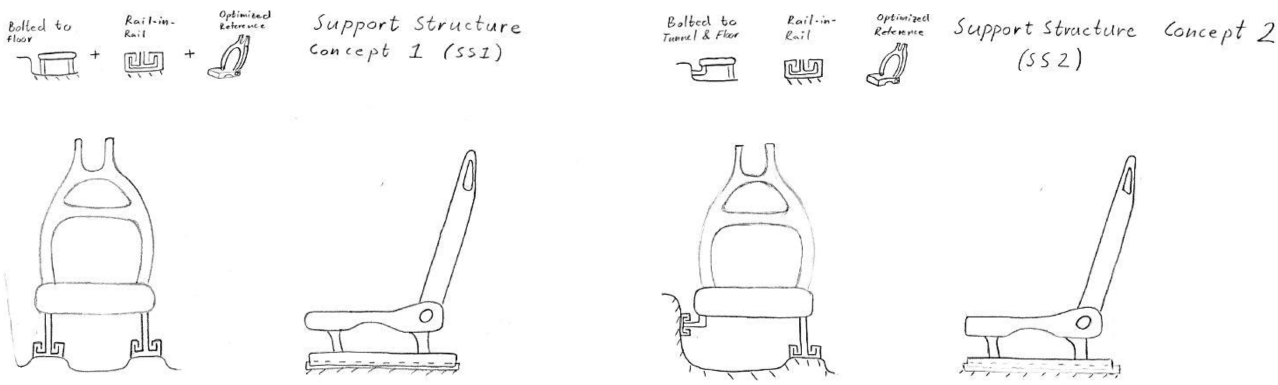
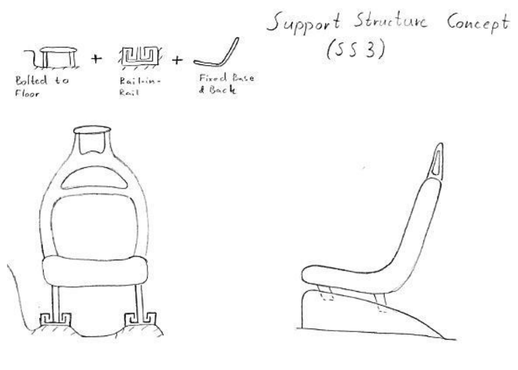
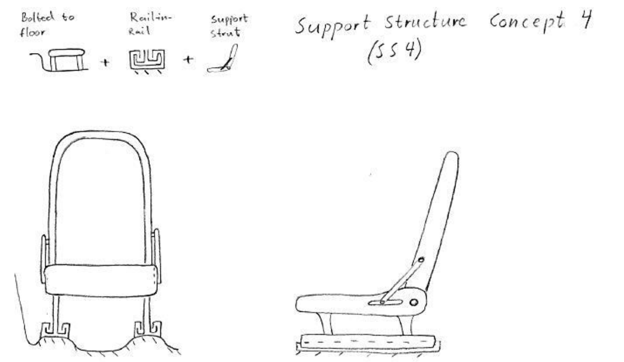
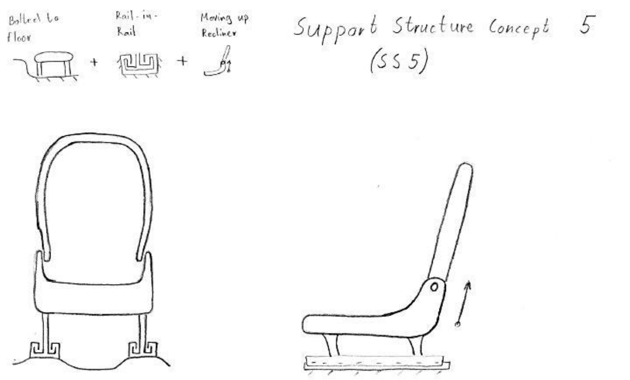


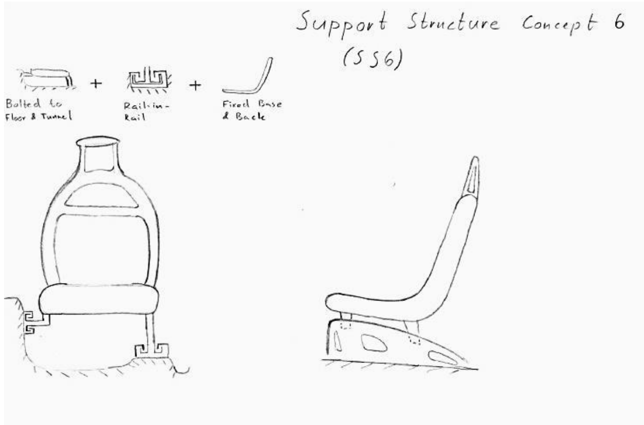
Figure 33: Illustrations of concepts for the support structure (SS1-SS11)

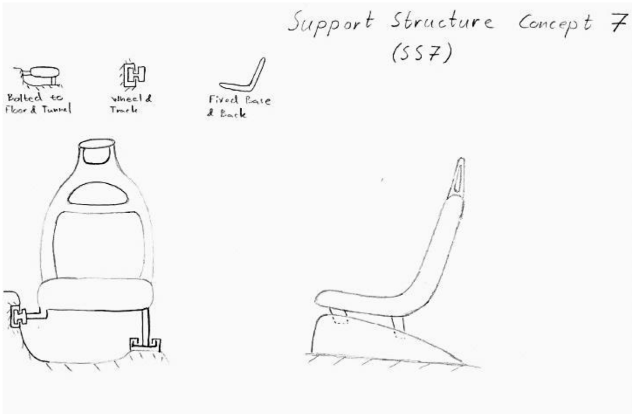


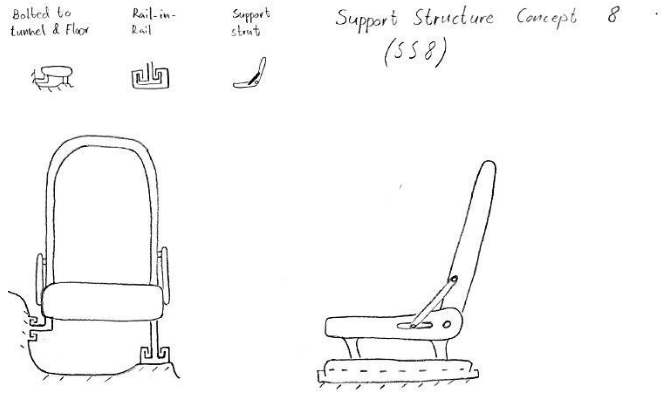

Support Structure Concept 3
(SS 3)
Bolted to Floor
Rail-in-Rail
Fixed Base & Back

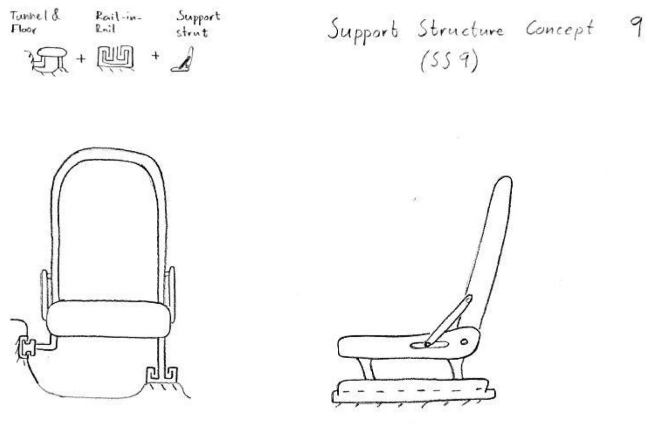

Support Structure Concept 4
(SS 4)
Bolted to floor
Rail-in-Rail
Support strut

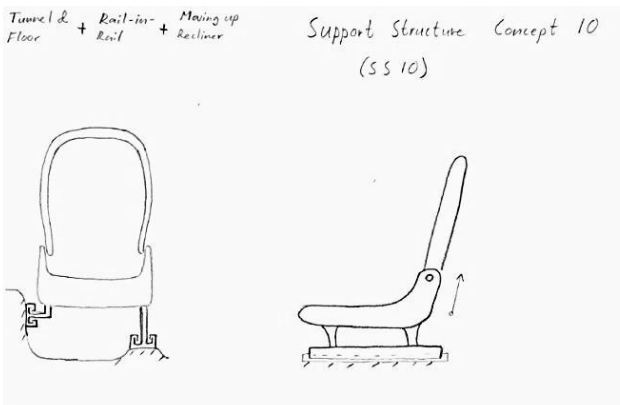

Support Structure Concept 5
(SS 5)
Bolted to Floor
Rail-in-Rail
Moving up Recliner

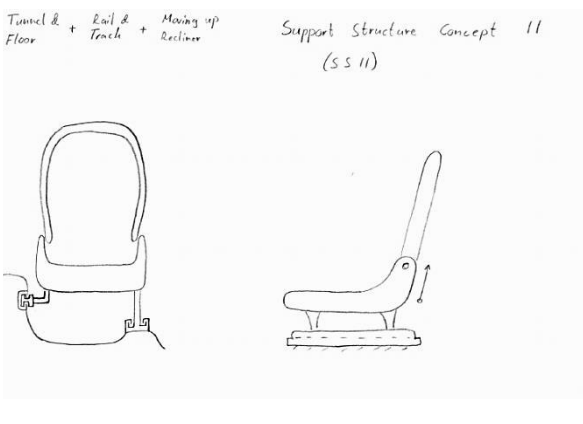

Support Structure Concept 6
(SS6)
Bolted to Floor & Tunnel
Rail-in-Rail
Fixed Base & Back


Support Structure Concept 7
(SS7)
Bolted to Floor & Tunnel
Wheel & Track
Fixed Base & Back


Support Structure Concept 8
(SS8)
Bolted to tunnel & Floor
Rail-in-Rail
Support strut


Support Structure Concept 9
(SS 9)
Tunnel & Floor
Rail-in-Rail
Support strut


Support Structure Concept 10
(SS 10)
Tunnel & Floor
Rail-in-Rail
Moving up Recliner


Support Structure Concept 11
(SS 11)
Tunnel & Floor
Rail & Track
Moving up Recliner

5. Concept Selection

After the morphological matrices had generated three new adjustment concepts and 11 new structural concepts, it was now time to dig deeper and investigate further in able to make a more detailed comparison before a final selection could be made. This chapter explains the procedure leading up to the final concept selection and the method for the selecting final concept. For the final selection it was necessary to have a weighted selection matrix, which meant that weights were needed to be acquired. Therefore a weight decision matrix was performed; more on how that was made is explained in the following chapter. After this matrix was made the need for an ergonomic evaluation, mass analysis and cost analysis was necessary in order to set the right weights for each criterion, and to have enough data going in to the final selection. This chapter outline will be as follows.

1. Choosing weighted screening criteria
2. Ergonomic analysis
3. Mass analysis
4. Cost analysis
5. Weighted selection matrix screening
6. Description of chosen adjustment solution and structural support

5.1 Choosing weighted screening criteria

Leading up to a final concept selection it was necessary to choose which criteria that would decide the outcome of the concept selection matrix. To achieve a better result these criteria were also to be weighted from 1 – 10 which corresponded to their relevant importance for this product application. The weighting procedure was performed using a weight decision matrix which ranks the different criteria against each other (Johannesson, Persson & Pettersson 2013). The reason for using this matrix was to avoid subjective weight ranking which could be misleading. One of the matrices used for this thesis can be observed in table 13 below. The criteria and criteria ranking were decided by the team together with an experienced automobile expert at Semcon.

Table 13: The final weight decision matrix for a production rate of 100 000 units per year

Weigth Decision Matrix 2 (100 000 units/yr.)												
All basic requirements are already fulfilled	Lightweight	Investment Cost	Reduce Unit Cost	Manufactury complexity	Bonus Features	Changes to interior architecture	Adoption complexity to car	Quality	Easy to operate	Ind. Sum	Ind. Sum/Tot. Sum	Final weight
Lightweight	-	1	0,5	0,5	1	1	1	0	0	5	0,139	7
Investment Cost	0	-	0	1	1	1	1	0	1	5	0,139	7
Reduce Unit Cost	0,5	1	-	1	1	1	1	1	1	7,5	0,208	10
Manufactury complexity	0,5	0	0	-	0	1	1	0	0	2,5	0,069	3
Bonus Features	0	0	0	1	-	1	1	0	0	3	0,083	4
Changes to interior architecture	0	0	0	0	0	-	0	0	0	0	0,000	0
Adoption complexity to car	0	0	0	0	0	1	-	0	0	1	0,028	1
Quality	1	1	0	1	1	1	1	-	0	6	0,167	8
Easy to operate	1	0	0	1	1	1	1	1	-	6	0,167	8
									Tot. Sum	36	1	

There were also two other weight decision matrices made, one for 20 000 units per year and one with 500 000 units per year. The outcome from these matrices varied only a little, but one significant observation that could be made was that the unit cost became more important for lower production series than for the larger ones. Despite this it was decided to assume a mean production rate of 100 000 units per year for the remainder of this thesis since covering three different production rate scenarios would have been out of the scope for this thesis. For all of the criteria it was assumed that they already fulfilled the basic requirements. However, to test the concepts ergonomically an additional criterion was later added to the final selection matrix called 'basic ergonomic requirements'. This criterion was considered as very important and therefore received a weight factor of 10.The other most important criteria were 'reducing the unit cost' along with 'quality' and 'easy to operate'. 'Lightweight' and 'investment cost' were also regarded as important factors for further selection. All three weight decision matrices can be found in appendix 9. Before the final matrix could be performed, a basic mass and cost analysis would have to be made in order to make the final selection more viable. These analyses were then the base for deciding the lightweight, investment cost and unit cost criteria. The remaining criteria were decided through subjective judgment.

5.2 Ergonomic analysis of solution concepts

In this section the early ergonomic evaluation, that occurred prior to the final concept selection, is explained. As stated before it is divided into 'adjust driver' concepts and 'provide structural support' concepts.

5.2.1 Adjustment system concepts

In some of the adjustment concepts chosen to be investigated further the ergonomic validity of them was uncertain or unclear. These concepts were the ones named *Quadriceps* where the seat has a combined length and height adjustment, and the concept with a combined length, height and recline adjustment (fixed seat structure). To be able to test these concepts two simple CATIA models of a 5 percent and a 95 percent sized human body were created which were based on the ergonomic constraints that were gathered in the pre-study of this thesis. By measuring distances between certain body parts and angles of the limbs, the adjustment motion required could be obtained for the concepts with combined height and length adjustment. These early manikins can be seen in appendix 6. For the concept that used a fixed seat structure it could no longer have a single linear rail motion but required either two separate rails with different angels or one spline shaped rail in order to also have a change in tilt angle of the seat to compensate for the lack of reline function. With this concept it was harder to achieve an ergonomically feasible solution than for the one with only a combined height and length adjustment, but the tests showed that this type of seat adjustment was plausible. However after having spoken to an ergonomic expert at Semcon the fixed seat concept would probably have great difficulty to be accepted by the customer and would therefore be discarded. After some discussions the decision was made to not continue with this concept for the driver's seat, but instead keep it in mind for the recommendations later in this thesis because of its large weight saving potentials. Even thought it could probably not work as a driver's seat it still had interesting features as a passenger seat. This concept would therefore be a part of the further mass and cost analyses later in this chapter in order to investigate its true potentials, but then as a passenger seat configuration only.

5.2.2 Structural support concepts

The concept of a heightened recliner mount also brought suspicions regarding if it could work without providing any discomfort for the driver. During the benchmarking in the planning phase of this thesis it was found that some seat frame models already had a heighted recliner to some extent. The question now was how much recliner mount could be raised, and how thick the cushion pad had to be in order to provide a satisfying driving experience. It was therefore assumed that this concept would have a heightened recliner, but just as high as the ergonomic requirements would let it. The final height would then be decided in a later stage of development if this sub-solution were to be selected. During the concept generation phase it was assumed that a fixed neck support would be the optimal choice for a lightweight concept. This would mean lesser parts and a simpler design. This decision was based on the fact that several current seat designs have this configuration which meant that it would already fulfill the required ergonomic constraints.

5.3 Concept mass analyses

In order to evaluate the different mass reduction potentials of the different concepts two different analyses were needed, one for each final selection matrix. As in chapter 5.1 the mass analyses were divided into adjustment concepts and structural concepts. The final calculated mass for each concept were based on the reference seat and included all parts, not just the structural frame. The reference mass of the frame parts were taken from CAD-models made earlier in this thesis, and for the rest of the parts, the mass values were gathered from a2mac1.com. For each concept this mass was the starting point, and they only varied depended on which parts that was necessary for that current concept. In appendix 12 the full mass analysis tables can be found.

5.3.1 Mass analysis of adjustment concepts

In this analysis there were only three different parts that varied in mass; these parts were the height adjuster, recline adjuster and support legs. From the morphological matrix there were only four different adjustment configurations of the seat, and they were named after which solution they have for each function, e.g. 'Length –Height – Recliner'. These were 'Rail-Rail-Recliner', 'Rail-Rail-No Recliner', 'Rail-Lever-Recliner' and 'Rail-Lever-No Recliner'. Here the 'Rail-Lever-Recliner' was the same as the reference adjustment solution configuration but with optimized support legs. The mass of each concept was calculated depending on which adjustment parts they had. For example, in a concept that did not have a recline function, that part's mass was removed from the total concept mass. In this way the lightest adjustment solutions could be found.

5.3.2 Mass analysis of structural concepts

The amount of structural design solutions was more than for the adjustment concepts, but the same method was performed here. The difference was however that this analysis focused on the optimized frame structure parts which were divided into 'attachment-to-floor' solutions and 'type of recliner' function. All design solutions except the reference concept included optimized back and base frames which were significant weight reducing factors in this analysis. But when comparing all the new ideas with each other it was no longer a factor since they were all already optimized. Then it was mainly the structure support parts that made a difference in weight. Since the height adjustment function was included in the adjustment mass analysis, all height adjustment masses were here set to be the same as for the reference solution (lever) except for the fixed seat structure, which did not require this function. The reason for this was to separate functions from structural components and keep the two analyses independent from each other. Since the 'wheel & track' solution for the tunnel fixation was removed previously in this thesis, it can be seen in appendix 7 that all structural concepts are named 'rail-in-rail' since this was the lone remaining solution. Another part that was removed from the list of all the design solutions was the headrest frame, this because of the earlier decision to stick with a fixed head rest since it already exists in other modern vehicle seats and it reduces mass.

The reference part masses were gathered from a2mac1.com which gives an accurate view of the weight allocation of a seat. The masses of the optimized designs were gathered from the CAD-models and for this comparison the same steel material was used for all concepts. An outtake of the structural concept mass analysis is illustrated in table 14 below, and in table 15 the end result from the structural mass analysis is presented.

Table 14: An outtake from the structural concept mass analysis

Reference (Fits w. CAD)	[kg]	Support Structure: Floor+Optimized Ref.Back+Rail-in-rail		Support Structure: Tunnel+Optimized Ref.Back+Rail-in-rail	
		SS1		SS2	
Head Rest	0,747	Head Rest	0,747	Head Rest	0,747
Cover	0,198	Cover	0,198	Cover	0,198
Padding	0,221	Padding	0,221	Padding	0,221
Frame	0,328	Frame	0	Frame	0
Back	5,877	Back	4,742	Back	4,742
Cover	0,813	Cover	0,813	Cover	0,813
Pad	1,11	Pad	1,11	Pad	1,11
Frame	3,8	Frame	2,7	Frame	2,7
Suspension	0,046	Suspension	0,046	Suspension	0,046
Head Rest Support Bracket	0,035	Head Rest Support Bracket	0	Head Rest Support Bracket	0
Bearing Plate	0,073	Bearing Plate	0,073	Bearing Plate	0,073
Cushion	5,756	Cushion	5,456	Cushion	5,456
Cover	0,446	Cover	0,446	Cover	0,446
Pad	0,863	Pad	0,863	Pad	0,863
Frame	3,5	Frame	3,2	Frame	3,2
Suspension	0,341	Suspension	0,341	Suspension	0,341
Garnish	0,606	Garnish	0,606	Garnish	0,606
Side Airbag	0,666	Side Airbag	0,666	Side Airbag	0,666
Adjusters	6,941	Adjusters	6,941	Adjusters	6,561
Lever	0,13	Lever	0,13	Lever	0,13
Rails	2	Rails	2	Rails	2
Inner foot	0,5	Inner foot	0,5	Inner foot	0,12
Outer foot	0,6	Outer foot	0,6	Outer foot	0,6
Coupling Bar	0,212	Coupling Bar	0,212	Coupling Bar	0,212
Recline system	2,278	Recline system	2,278	Recline system	2,278
Height	0,688	Height	0,688	Height	0,688
Lumbar	0,533	Lumbar	0,533	Lumbar	0,533
Support System	0,077	Support System	0,077	Support System	0,077
Heating System	0,193	Heating System	0,193	Heating System	0,193
Total mass	**20,257**	**Total mass**	**18,822**	**Total mass**	**18,442**
		Improvement over Reference [%]	**7,1**	**Improvement over Reference [%]**	**9**

Table 15: The end result from the structural mass analysis

Design Solution:	Total mass [kg]	Improvement of Reference [%]
Reference	20,257	0
Floor, Optimized Ref. Back, Rail-in-rail	18,822	7,1
Tunnel, Optimized Ref. Back, Rail-in-rail	18,442	9
Floor, Fixed, Rail-in-rail	14,228	29,8
Floor, Supp. Strut, Rail-in-rail	16,916	16,5
Floor, Move Recliner, Rail-in-rail	17,636	12,9
Tunnel, Fixed, Rail-in-rail	13,848	31,6
Tunnel, Supp. Strut, Rail-in-Rail	16,536	18,4
Tunnel, Move Recliner, Rail-in-Rail	17,256	14,8

As expected the concepts with the fixed seat structure received the highest weight reduction of the recliner function solutions, followed by 'Support Strut' and 'Heightened Recliner'. The reason for this was that the fixed seat structure did not require a height and recliner function which reduced the weight considerably. A fixed frame also enabled a more optimal frame geometry to be used which also reduces weight. The support strut would in the FE-analyses show that it did take up large forces because the stresses are concentrated to where the seat base and back connects. This enabled a lighter seat structure to be made and therefore be slightly lighter than to heighten the recliner mount. This analysis also showed that a tunnel attachment was superior to the traditional floor attachment, this because of the smaller mass needed for the support legs.

5.4 Concept cost analysis

To make a reliable cost analysis for the different concepts a more detailed BOM was necessary in order to both be able to estimate the cost of each part, but also to differentiate the different design solutions better. Since the production method was not yet decided a mean value of three different production methods was used later in the ranked scoring matrix. For this thesis only three production methods were assumed to be relevant when constructing a seat, which were sheet metal plates, extruded parts and casting. These production methods would mostly differ in the investment cost analysis since the tooling costs are specifically bound to the production method. The cost analysis was limited to the frame parts only since these were targeted earlier in the thesis to be focused on. The material used was normalized to be low alloy steel at the price 4.2 SEK/kg for all parts, and the reason for this was to be able to compare the different production methods fairly and not the material choice. This choice would be a later issue in this thesis. The method used when estimating the part costs was the CES EduPack software which uses the Granta material cost database. In this software the cheapest possible method was used, which were stamping for sheet metal, impact extrusion for the extrusion parts, and high pressure die for the casting. The design differed depending on these methods and an example of this is illustrated below for the optimized reference seat concept.

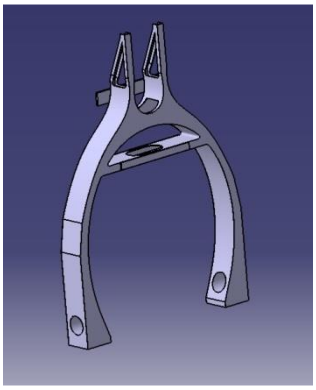


Figure 34: Optimized reference back with sheet metal

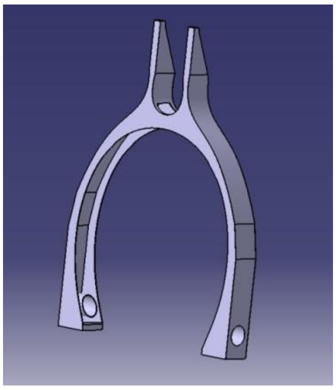


Figure 35: Optimized reference back with casted material

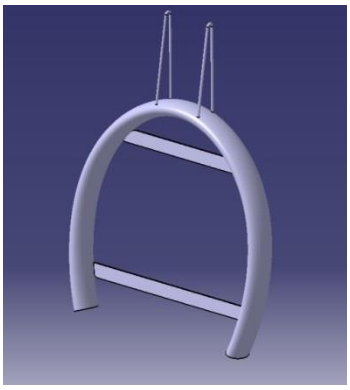


Figure 36: Optimized reference back with extruded parts

In order to normalize these numbers a modern car seat BOM with professionally estimated costs was acquired, but for corporate secrecy reasons the type of seat will remain unnamed. In this way a sufficiently accurate comparison could be achieved which would lay the basis of the criteria ‘Unit Cost’ and ‘Investment Cost’. This reference cost seat was also manually adjusted which fitted well with the scope of this thesis. The cost analysis was divided into different estimation categories which then could be added together depending on which features the specific concept had. The mean value of each category then included the three different production method cost estimations which then could be added to the final comparison. The categories are listed below.

- Reference
- Optimized Reference
- Support Strut
- Heightened Recliner

- Fixed Seat Structure (needs quadriceps)
- Mounts
- Adjusters

The result of both the adjustment concepts and structural concepts are summarized in tables 16 and 17 below. As illustrated the adjustment concept with the lowest cost was the one motion controlled seat with a fixed frame, and the highest to be the reference seat configuration. For the structural concepts were also here the seats with fixed frames the cheapest, followed by the heighted recliner concepts. The difference between a floor mount and a tunnel mount did not differ significantly in cost and could therefore be assumed to be equally expensive. The concept that received the highest cost estimation was the support strut which almost doubled the frame cost from the reference solution. Another interesting observation is that most of the concept showed already in this stage a reduction in cost from the reference seat.

Table 16: The result from adjustment concept cost analysis

Adjustment concepts	Reference seat adjusters	Horizontal rail + Vertical rail + Recliner	Horizontal rail + Vertical rail + Adjust complete seat	Horizontal rail + Lever + Adjust complete seat
Total Cost [SEK]	**261,3**	**185,4**	**93,4**	**201,3**

Table 17: The result from structural concept cost analysis

Structural concepts	Floor + Opt. Ref. Back + Rail-in-rail	Tunnel + Optimized Ref. Back + Rail-in-rail	Floor + Fixed + Rail-in-rail	Floor + Supp. Strut + Rail-in-rail	Floor + Move Recliner + Rail-in-rail	Tunnel + Fixed + Rail-in-rail	Tunnel + Support Strut + Rail-in-Rail	Tunnel + Move Recliner + Rail-in-Rail
Mean tool cost [M. SEK]	**9,3**	**9,3**	**12**	**9,8**	**9,3**	**12**	**9,8**	**9,3**
Mean unit cost [SEK]	**187**	**188**	**123,5**	**321**	**168,7**	**124,5**	**322**	**169,7**

The full cost analyses part by part are located in appendix 8.

5.5 Weighted selection matrix screening

As stated before the final concept selection would be two-parted, one to decide which adjusters to use and one to decide the structural composition. Having the weights already acquired from the weight decision matrix all that was needed to be done at this stage was the actual rating of the concepts for each criteria. For the criteria unit cost, investment cost and lightweight, the ranking was decided via interpretation of the cost and mass analyses which were previously made. This was done by interpolating the values and round them to the nearest integer, making it into a five grade scale which stretched between -2 and +2. For the other criteria the ranking was done subjectively by the team together with a concept engineer at Semcon who has many years of automobile experience and is an expert in interior design.

The reference configuration/solution in both matrices was set to zero in all of the criteria, and the rest were then ranked between -2 and +2. This ranking matrix, also called a Pugh matrix, generated one out of two results. But to get a more detailed comparison the weights were multiplied with each ranking of each concept, resulting in a second result. Together these would form a basis of the final adjustment concept and structural concept selection.

5.5.1 Adjustment concept selection matrix

The result from the adjustment concept selection matrix showed that the concept of having no recliner (fixed seat frame) and a combined length and height function received the highest score in both the non-weighted and weighted result. The second best solution was the one with combined height and length function but with a recline function. The main reason for this result was the reduced cost possibilities and reduced manufacture complexity by not having a height function as a separate function. This type of combined functionality would also enable a lighter seat structure. But as stated in chapter 5.1 the concepts that had a no recliners and fixed seat structures were seemed unfit to use as a driver's seat, which was the scope of this thesis. Therefore these concepts could not be chosen, and hence the final adjustment concept was chosen to be the one with a combined height and length adjustment with a recliner (AC1). The final adjustment concept selection matrix is illustrated in table 18 below.

Table 18: Final selection matrix for the adjustment concepts

Final Selection Matrix Adjustment Concepts				
	Reference (AC3)	Combined horizontal & vertical rail + Recliner (AC1)	Combined horizontal & vertical rail + No recliner (AC2)	Horizontal Rail + Height lever + No recliner (AC4)
Lightweight	**0**	1	2	2
Investment Cost	**0**	1	2	0
Reduce Unit Cost	**0**	1	2	1
Manufactory Complexity	**0**	2	2	0
Bonus Features	**0**	-1	-2	0
Changes to interior architecture	**0**	0	0	0
Adoption to different models	**0**	0	0	0
Quality	**0**	0	0	0
Basic ergonomical requirements	**0**	1	-1	-1
Easy to operate	**0**	1	2	0
Total (+/-)	**0**	**6**	**7**	**2**
Total with weights	**0**	**44**	**52**	**14**

5.5.2 Structural concept selection matrix

To decide the final structural concept, this selection matrix followed the same procedure and the same weights as the adjustment selection matrix. Since the final adjustment concept was the combined height and length concept, so called 'rail-in-rail', this was then an already chosen feature of the final concept. Since the ranking of the criteria 'Lightweight', 'Investment Cost' and 'Reduce Unit Cost' were based on the previous mass and cost analyses, the other rankings had to take other factors into consideration. Some of these factors were e.g., number of parts for 'Manufactory Complexity' and 'Quality', ability to customize seating position for 'Basic ergonomic requirements' and number of adjustments needed to change seat position for 'Easy to operate', etc. In the structural selection matrix, the results showed that also here the concepts with fixed seat structures (SS3 & SS6) received the highest scores and that the concepts with a tunnel attachment became slightly better than the floor attachment ones. But since the fixed seat frame designs were invalid solutions the third best concept became the winner, which was the concept with tunnel attachment and heightened recliner (SS10). The final structural concept selection matrix is illustrated in table 19 below.

Table 19: Final selection matrix for the structural concepts

Final Selection Matrix Structual Concepts													
		Lightweight	Investment Cost	Reduce Unit Cost	Manufactury Complexity	Bonus Features	Changes to interior architecture	Adoption to different models	Basic ergonomic requirements	Quality	Easy to operate	Total (+/-)	Total with weights
SS0	**Reference (Fits w. CAD)**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
SS1	Floor+Optimized Ref.Back+Rail-in-rail	0	0	0	0	0	0	0	0	0	1	**1**	**8**
SS2	Tunnel+Optimized Ref.Back+Rail-in-rail	0	0	0	0	1	-1	-1	0	0	1	**0**	**11**
SS3	Floor+Fixed+Rail-in-rail	2	1	1	1	-2	0	0	-2	1	1	**3**	**22**
SS4	Floor+Supp.Strut+Rail-in-rail	1	-1	-2	-1	-1	0	0	0	-1	1	**-4**	**-27**
SS5	Floor+Heightened Recliner+Rail-in-rail	1	0	0	0	-1	0	0	0	0	1	**1**	**11**
SS6	Tunnel+Fixed+Rail-in-rail	2	1	1	1	-1	-1	-1	-2	1	1	**2**	**25**
SS8	Tunnel+Support Strut+Rail-in-Rail	1	-1	-2	-1	0	-1	-1	0	-1	1	**-5**	**-24**
SS10	Tunnel+Heightened Recliner+Rail-in-Rail	1	0	0	0	0	-1	-1	0	0	1	**0**	**14**

5.6 Description of chosen solutions for adjustment and structural support

Having completed selection matrices for adjustment solutions and structural support solutions, a final concept could be selected for further development. For functional requirement 1 (adjust driver), the adjustment concept AC1 was selected for further development. The design combination of length and height adjustment with an angled rail placement eliminates the current height adjuster mechanism, and this solution would result in a 5 percent reduction of mass as well as a cost reduction of 11 percent. In figure 37 below shows a rough sketch of the adjustment concept AC1. For Functional requirement 2 (support driver during all load cases), the support solution SS10 was selected for further development. This concept combines the traditional mounting position in the floor with a mounting position in the tunnel structure. Not only does this reduce the mass of the seat, but it also provides more leg room for the rear seat passenger. The main structure is similar to the reference except for the fact that the vertical position of the recliner is heightened by approximately 150 mm which reduces the loads applied to the recliner mechanism implying that it can be downsized by 30 percent. The result of this specific design solution was approximately a 14.8 percent reduction in total seat mass compared to the reference seat. The cost for this concept would be similar to the reference, only a 3 percent increase according to the previous cost analysis.

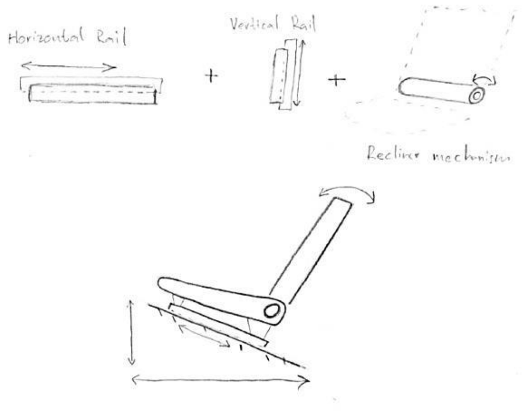


Figure 37: AC1, combined length-height adjuster with recliner

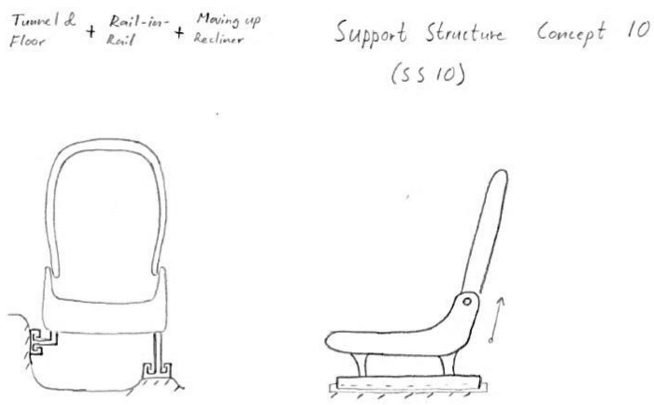


Figure 38: SS10, heightened recliner mounted in tunnel and floor

For the remaining functional requirements the reference design solutions were to remain unchanged. The net result of the chosen concept was a 21 percent reduction in total seat mass, and a reduced unit cost by 8 percent, compared to the reference seat figures compiled in the benchmarking performed earlier in this thesis. It should be noted here that the adjustment solutions that eliminated the need for a recliner mechanism, and incorporated a rigid joined base and back frame structure, were rated highest in all of the comparisons conducted. However, as stated in chapter 5.1.1, these solutions were judged as not being able to fulfill the basic requirements for a car driver seat.

"Nobody would be able to sell a car without the existing reclining mechanism solution"

- Ergonomics Expert

Since the focus of this thesis was on developing a lightweight concept for a driver seat, these solutions could not be selected after gathering this knowledge. The passenger seat is usually not subjected to the same adjustment requirements as the driver seat, with most lacking a height adjustment mechanism, thus it should be possible to use a different design for the driver and passenger seats. In that case the concepts without recliner (AC2, SS6) would be most promising design choices. This would however not be covered further in this thesis.

6. Further development of the chosen concept

Up to this point the development work had resulted in new design solutions for the Adjust driver-, and Structural support functions of the driver seat structure. Initial sketches and CAD-models had been made to represent the realization of these design solutions on a separate part level. As well as preliminary FE-simulations and cost estimations to aid in the concept selection process. However the goal stated in the initial planning of this thesis was to deliver a fully functional CAD-model of a lightweight concept for the driver seat structure, the success of this was to be determined by analysis and a comparison with the reference solution. In order to carry out this final evaluation there was a need for a concept in which all the chosen separate design solutions were combined to present a complete seat structure. In order to accomplish this complete seat structure, further development of the chosen concept had to be conducted. This section of the report covers the approach that was used to develop the final concept and also the details of this concept. This is outlined in the following subchapters:

6.1 Material selection & optimization
6.2 Design considerations
6.3 Optimizing the final design
6.4 Visualization & assembly procedure

The development work was divided into three main structural segments of the driver seat, these segments were: the base structure, the back structure, and the seat-to-floor attachment structure. The segments in a way resembled the function-means model developed earlier. The connection being that the base structure had to be modified to house the heightened recliner design solution, the back structure could be downsized due to the lower loads felt at the recliner, and the seat-to-floor attachment structure would house the innovative design solution that combines both length and height adjustment into one function. In the following subchapters the three structural segments is covered individually following a description of the general approach.

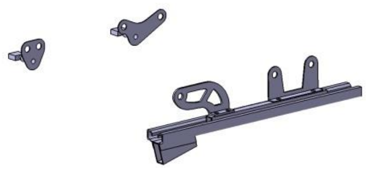


Figure 39: Seat-to-floor attachment structure

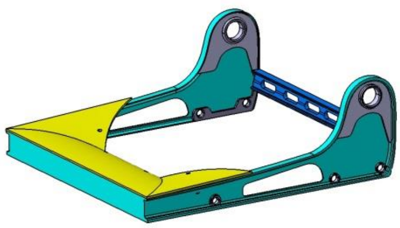


Figure 40: Base frame structure

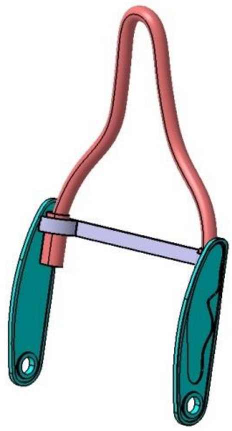


Figure 41: Back frame structure

6.1. Material selection and Optimization

To start off, a material selection for the final concept had to be made. This was necessary as other materials than the current low alloy steel could add further to the mass reduction that would already be achieved with the new design solutions. The choice of material would also affect another highly important parameter included in the final evaluation, the cost of the seat structure. The material selection process was largely a trade-off between low mass and low cost, as low density materials such as composites were generally more expensive than higher density materials such as steel. The material database software developed by Granta called CES EduPack was used as a basis for the material selection process. The same software was used in the estimation of production costs for the parts in the structure later on. There is theory on the subject of material selection written by M Ashby (2011), where the material selection process is essentially set up as an optimization problem. This approach fit well with this thesis which is why it was used to conduct the initial material screening. Utilizing material indices that correspond to constraints such as stiffness and cost, the CES software enables all the materials to be plotted against these material indices and the goal function of minimized mass. The result of this plot is a Pareto frontier of dominating solutions, source Pareto. All materials that lie on this curve are optimal solutions, and a better choice than the ones that lie within the curve. This does not take the importance of mass versus cost into consideration, which is why all of these optimal materials were selected for further study.

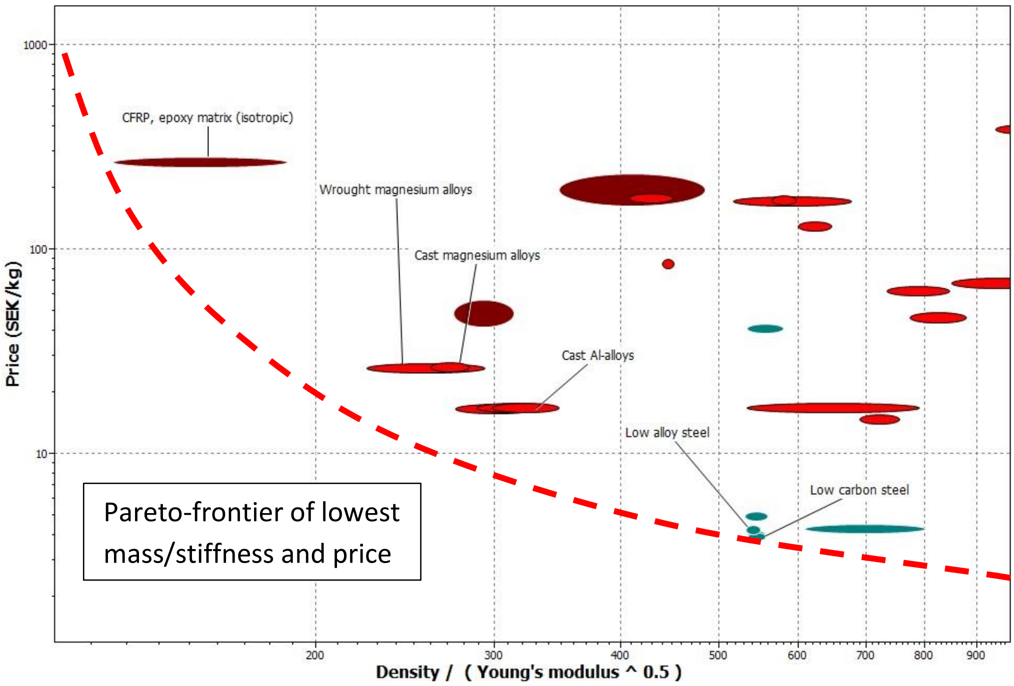


Figure 42: Material selection diagram with the two relevant material indices

From the Pareto-curve in CES the following materials were selected for further study:

- Low-alloy steel
- Low-carbon steel
- Wrought Magnesium
- Cast Magnesium
- Cast Aluminum
- Epoxy SMC CF
- CFRP

These materials were further analyzed using CATIA's engineering optimizer, which was set up to minimize the mass of the concept back frame structure by changing the wall thickness parameter of the CAD-model. The constraints that were used were the structural limits on deflection and stress, 14 mm and the yield strength of the material being analyzed.

Material evaluation							
Parameters	*Reference (Steel)*	Low alloy steel	Low Carbon steel	Wrought magnesium	Cast Alu	CFRP	Epoxy SMC CF
Minimum wall thickness (mm)	*1,5*	1,02	1,7	3,55	2,91	1,6	2,13
Max. Deflection (11,2 mm) or 14 mm	*11,2*	8	6,3	13,95	9,7	12	9,9
Max. V.M. Stress (0,95*Sigma) Mpa	*572*	600	300	138	170	240	239
Material cost (SEK)	*4*	4,2	4	26	16,3	265	163
Minimum mass (kg)	*3,8*	**2,7**	**4,24**	**1,78**	**2,37**	**0,8**	**1,03**
Unit material cost (SEK)	*15,2*	11,34	16,96	46,28	38,631	212	167,89
Added cost per kg saved mass (SEK / kg)		0	Non saved	37,98	82,7	105,61	93,74

Table 20: Summary of the result from the material optimization procedure. Limiting stress or stiffness is in red numbers, unfavorable materials in red squares. For full material evaluation results, see appendix 10.

From the materials considered in this analysis, it was clear that the choice was between low alloy steel and magnesium. All composites were too expensive for this application and aluminum did not reduce the mass as much as magnesium. Steel was cheap but also contributed to a heavier design than magnesium, which at the other hand had the potential to save mass in the area of 1 kg of the back structure but to an increased cost of 35 SEK per unit in material cost. However if a stamped sheet production process was considered, a manufacturer called STOLFIG is able to produce magnesium sheet using considerably less stamping pressure than would be needed for low alloy steel. Conversely the processing cost for magnesium stamped sheet parts was cheaper than low alloy steel parts. An assumption was thus that the produced unit cost would be 29 SEK for low alloy steel and 59 SEK for magnesium. This was while saving approximately 1 kg of mass. According to employees at Semcon, that have a long experience within the automotive industry, car producers in general are willing to pay an additional 50 SEK per kilogram reduced mass. The difference of 20 SEK was well below the elicited limit of 50 SEK/reduced kg that auto manufacturers were assumed willing to pay. Thus magnesium alloy was considered for the final concept design of the back and the base structure. Regarding the manufacturing process this would be assumed at a component level as different parts of the final concept design could have different requirements. According to STOLFIG (2014) it is possible to use stamping, extrusion, and casting processes with magnesium alloys which means that all of these could be used on the final design. It should also be mentioned that if cast parts are needed, then magnesium alloy components are cheaper to produce than the corresponding components in steel, this is due to magnesium having a lower melting temperature meaning less energy needed in the process.

6.2. Design considerations

In order to design a complete driver seat structure all of the previously chosen sub-solutions had to be combined in such a way that the complete structure fulfilled all of the stated requirements on structural support, ergonomics, and cost. When preparing the final design there were some issues appearing that hadn't been realized when developing the individual design solution concepts. To produce a fully functional final concept design these issues had to be addressed, this section covers the most important design considerations that were prominent in further development of the chosen driver seat structure concept.

6.2.1. Dimensions

As the purpose of this final design was to produce a CAD-model that could be evaluated and verified in a comparison with the reference design, the main dimensions of the structure had to be similar. Otherwise a smaller structure would have yielded unfair results with excessively low mass. The chosen dimensions were taken from measuring the physical seat used in the reverse engineering process.

6.2.2. Moving the recliner mount

The concept chosen for the structural support function of the seat structure involved moving the recliner mount upwards by 150 mm from its current position at 55 mm, measured in the Z-direction from the lowest point of the base structure. This would result in lower loads applied to the recliner due to a shorter lever distance to the load application points of the impact forces. However something that wasn't realized earlier was that the placement of the side airbag on the seat back above the recliner did not allow moving the recliner upwards by more than 100 mm. Since this thesis did not cover the functionality of the side airbag and there was little known as to what would happen if this was moved upwards, it was decided to leave it at its current position and restrict the movement of the recliner mount to 100 mm.

6.2.3. Height of the tunnel

The chosen concept for structural support also involved a change to the seat-to-floor attachment structure, the inside rail was to be rotated 90 degrees and mounted in the center tunnel structure of the car. This would enable mass reduction in the form of smaller connecting legs as the tunnel mount would be higher and closer to the seat base than the rail mounted in the floor, it would also provide extra leg room for the rear passenger. During the further development phase a cockpit layout from the reference car was analyzed, but the center tunnel in this car wasn't high enough to accommodate the mounting position of the inside rail. If the rail would have been mounted lower, the design solutions for the adjustment functions of adjust driver length, and height would not have fulfilled the ergonomic requirements. After consolidation with automotive engineers at Semcon it was realized that the tunnel height was largely dependent on the drivetrain layout of the car, an FR (front engine-rear wheel drive) car would have a much higher tunnel than the studied FF-car (Front engine-front wheel drive). It was decided that a mean tunnel height of 220 mm would be used, which allowed the original placement of the inside rail to be applied.

6.2.4. Neck support

The final concept design would be implementing a non-adjustable neck support, this to reduce both mass and cost. By comparison the reference design utilized an adjustable neck support to accommodate different driver lengths. Since measurements were taken from the reference seat, the back structure height proved to be too short to supply neck support for the medium and tall drivers when analyzed in the ergonomic mockup. The non-adjustable neck support solution had to be higher than the reference in order to accommodate different driver lengths, this added somewhat to the mass of the back frame structure, and an optimal design would probably utilize a smaller section thickness of the back frame at the top where the neck support is.

6.2.5. Supporting driver weight

When designing the base structure, a previously non-dimensioning constraint became problematic. That the structure could not deflect more than 1 mm when subjected to a static load of 1600 N, this corresponds to supporting a heavy driver statically. In other words the seat structure should not feel soft when supporting the driver, it should remain rigid. As the chosen magnesium material had a lower Young's modulus than low alloy steel used in the reference design, this deflection became problematic. In order to avoid increasing the volume of the seat structure to the point where mass would be drastically affected, a seat pan design was implemented. This was observed on several other designs during the benchmarking, and works by distributing the applied force over a larger area. With this design the static deflection target could be reached without affecting the mass drastically. As a bonus this seat pan design was a very effective submarining-protection as well.

6.2.6. Ergonomic constraints

In order to validate the chosen concept, more detailed investigations of the seat assembly together with manikins and the BIW were necessary. The manikins used during the concept selection phase were simple models based on several ergonomic measurements sources, and the seat itself was also a very basic model of a seat structure. The result from these tests showed a lot of promise, both regarding the seat with and without a recline function. But to decide exactly how much the seat would have to be adjusted to fit the population between 5 percent and 95 percent, more accurate manikins from CATIA V5 were used. The constraints would again be the different angle intervals stated in the requirement specification and also that the line of sight would enable the driver to both have a clear view of the cluster panel, and have a clear view of the road ahead. The optimal line of sight angle would be the same as the angle of the steering wheel, which was set in this thesis to be 22°, but still above the highest point of the steering wheel. Another design consideration was the placements of the support legs, which decided the length of the rails. If the support legs were closer together it would mean that the rails could be made shorter, thus reducing weight and increasing leg space for rear passengers.

6.3. Optimizing the final design

Having selected a different material, magnesium alloy, and made other changes to the concept as mentioned in the *design considerations* section, the final design had to be optimized for these changes. The final design procedure was similar to the procedure used when developing the initial design solution concepts:

1. Design geometry from topology optimization was used as input
2. Initial CAD-design of the main structural segments (Base, Back, Attachment structure)
3. Analysis of the design with FE-software, Ergonomic mockup
4. Evaluation of the analysis results
5. Optimal design? (Very close to Stiffness, Stress, Ergonomic constraints?)
6. No? Then redesign in CAD

The input to this design was the design solution concepts previously chosen, and the geometry from the topology optimization software (Inspire). An initial redesign was done to accommodate the change in material, increasing the general volume of the back and base components. But also to incorporate the heightened recliner mount in both the base structure and the back structure, and the different placement of the attachment structure. This initial redesign was then analyzed in CATIA's FE-module and in a cockpit mockup with different test dummies to determine structural and ergonomic performance. After comparison with constraints on stiffness (allowable deflection 14mm) and stress (yield strength of Mg) as well as ergonomic constraints, the design was either approved of or sent back for redesign in the CAD-software. The goal here was to come up with a design that performed as close to the constraints as possible in order to reduce mass as much as possible. There was however a secondary goal here, to produce a cost effective design. In order be cost effective an emphasis on low complexity and as few parts as possible was utilized throughout the final design process. Integrated in this process was the manufacturing method for the different components, since this was still at the concept stage the manufacturing methods were assumed most likely rather than heavily analyzed. A more in depth explanation of the different structural components of the final design follows below.

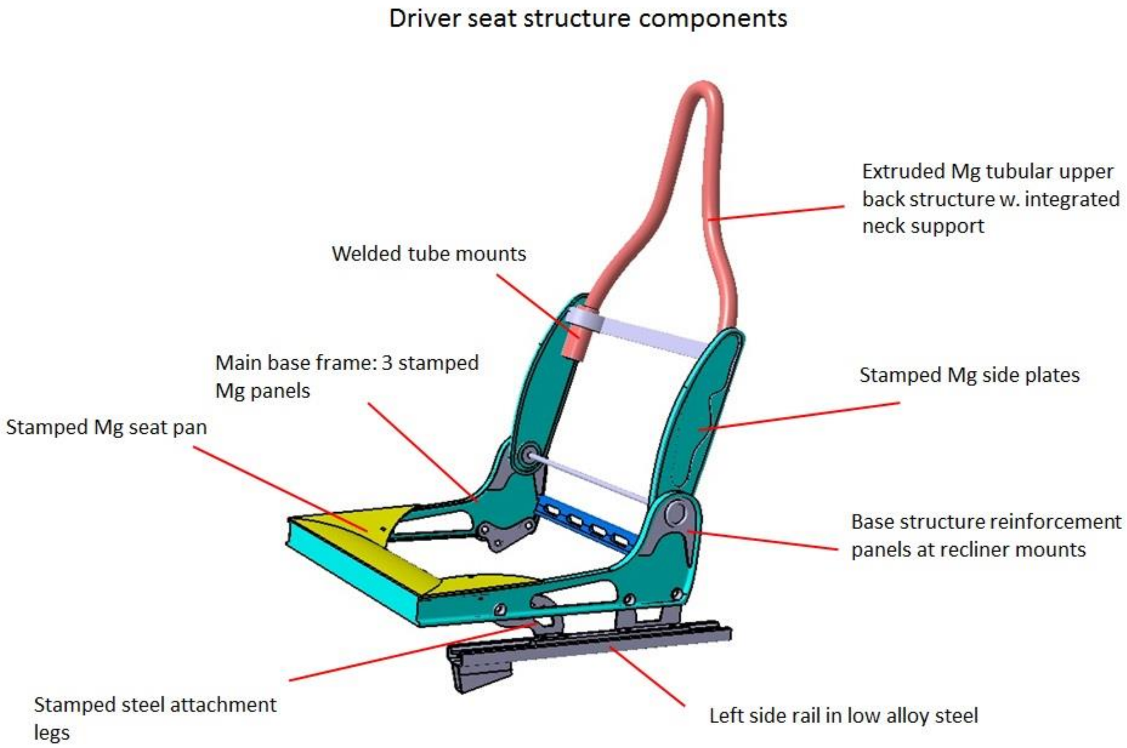


Figure 43: Breakdown of the components in the final assembly design

6.3.1. Base

For the final design, the original base design had to be redesigned to accommodate the heightened recliner mounts and the change in material. The recliner mounts were raised 100 mm from their previous position which did not compromise the position of the side airbag, yet still resulted in a reduction of impact loads at the recliner. It was assumed that the side and front panels would be made of stamped magnesium as these could be made rather thin (2mm) which would enable unnecessary added volume where it wasn't needed. Both the recliner mounts and the mounting positions to the attachment structure proved to be critical components in terms of yield strength as FE-analysis showed that the largest amount of stresses was located at these positions. To cope with this, the recliner mounts and attachment mounts would be in thicker magnesium and made separately from the main base frame in a casting process. After welding the reinforcements to the side panels, a rear magnesium I-shaped beam is welded to the main structure, which purpose is to support the seat suspension in the rear. To accommodate static support, and submarining protection, a seat pan in magnesium was designed which divided the load evenly over a large surface. The seat pan is welded to the main base frame structure and an extruded support bar. The main challenge in designing the base frame was to decide where to locate the reinforcements and mounting positions for the attachment structure, this was accomplished through several design-analysis iterations.

6.3.2. Back

When re-designing the back frame, the base geometry received from the topology optimization procedure conducted in the concept generation phase of this thesis, was used. Although when considering the location of the side airbag it was realized that the final design would probably have to use side panels at the lower end of the back frame, similar to the reference frame design. These would be made of stamped magnesium. In the concept selection phase a preliminary analysis of different designs and manufacturing methods was made which revealed that a tubular design of the back frame would be both cost effective and light. For this reason an extruded magnesium tube design was selected for the upper section of the seat back frame. This upper tube would be made long enough to incorporate a rigid neck support as well, thus eliminating the adjustable neck support that can be found in the reference seat design. Eliminating the adjustable neck support saves both mass and cost. In order to attach the tubular upper section to the lower side plates, two extruded mounting brackets have to be welded to the side plates. The mounting brackets provide added material thickness at the critical "folding point" of the back frame, necessary to achieve the desired stiffness when subjected to bending impact forces. The final concept back frame is thus quite similar to the reference back frame although the geometry of the tubular part is different. The concept design also has shorter side plates due to the new recliner mounting position.

6.3.3 Seat-to-floor attachment structure

Along with having a combined function for height and length adjustment, the final concept of how to fasten the seat to the BIW was by having it bolted to the floor on the left side (driver's seat) and bolted onto the tunnel segment on the right side. FEM analysis had shown that a smaller leg mass was needed with this configuration even though it required a minimal tunnel height of 220 mm. This change in tunnel size would in comparison to some car models mean an increase in total weight. The argument to stick with the tunnel attachment was then that it could enable the space underneath to store other vehicle components such as car batteries for an electrical powered vehicle. Using that argument, the tunnel size would actually not matter that much for the total weight since it was assumed that the space below could be used efficiently. One design requirement of the BIW for this concept is the angled rear body support that is needed to fit the tilted rail. As seen in figure 31 the left rail is directly mounted onto the BIW rear body support and the cross reinforcement beam. In able to be fastened to the cross reinforcement beam two bended sheet metal plates which are welded together act as a front support for the left rail. No rail development was included in this thesis and therefore the rails used for the final concept were assumed to be the same as the reference solution. To connect the seat base frame to the rails, four individually optimized leg supports were designed using BESO2D to some extent and FEM-analysis as validation for all models. The right support legs each consists of a 1.5 mm thick sheet metal plates especially designed for making the tunnel rail as short as possible, this was in able to reduce weight. Each of the right leg supports had two holes to be used for bolting it too the base frame and one hole to connect a cylinder to the tunnel rail. The cylinders are welded to the right support leg plates and acts as links between the seat and the BIW. The left leg supports were also topology optimized using BESO2D which gave them their shape in two dimensions. Their thicknesses were decided through iterative FEM-analysis of both a crash impact simulation and a static force test. For the front leg the minimal thickness required was 3.5 mm, and for the rear leg support is was 1.5 mm.

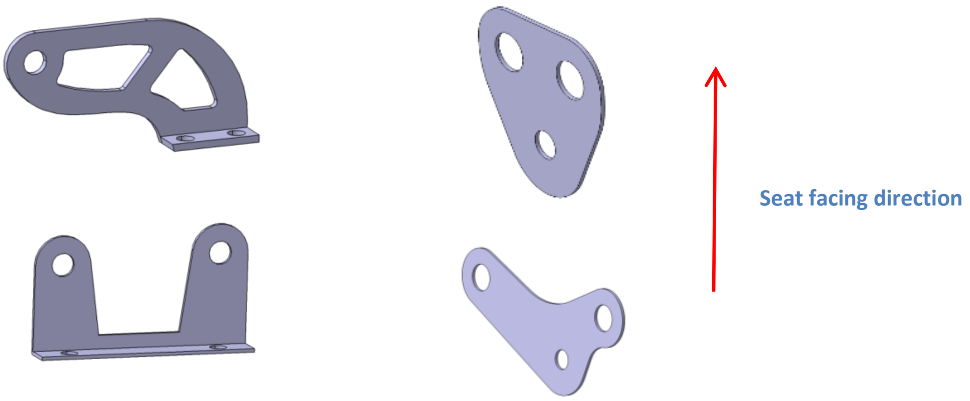


Figure 44: The four different support legs in the position as they would have been under a seat that is facing up relevant to the page

6.4 Final design and assembly procedure

For demonstrational purposes the final assembly procedure of the structure concept has been visualized with the aid of CATIA and PowerPoint. The assembly and suggested manufacturing method of each subcomponent that make up the base frame, back frame, and attachment structure has been included in this visualization. The visual assembly procedure can be found in appendix 15. It is included in text-form here:

Base frame assembly

1. Stamped magnesium side- and front plates welded together make up the main frame
2. Cast magnesium recliner mounts and lower attachment reinforcements welded to the main frame
3. An extruded magnesium support bar is added by welding
4. A cast magnesium rear support beam is added by welding
5. A stamped magnesium seat pan added by welding completes the base frame

Attachment structure assembly

1. Extruded low-alloy steel cylinders are welded to stamped brackets
2. The completed brackets are mounted to the base frame with fastening elements (bolts)
3. The left side rail is extruded from low alloy steel and bolted to the left side mounting brackets
4. The right side rail is similar to the left but mounted in the tunnel before the seat is mounted in the cockpit

Back frame assembly

1. Extruded magnesium tube mounts are welded to stamped magnesium side plates
2. Cylindrical recliner mounts are inserted and welded to the side plates
3. A cast magnesium upper support beam joins the two side plates by welding
4. An extruded magnesium tube, bent to shape, is positioned and welded to the tube mounts

Final assembly

1. The back frame is positioned in the base frame
2. The recliner mechanism is inserted into the recliner mounts on the base and back frame
3. The right side rail is attached to the tunnel structure
4. The complete structure is positioned and slides in to the right side rail and left side floor mounts
5. Fastening elements completes the final assembly procedure

7. Evaluation of the final seat structure design concept

Having arrived at a seat structure design proposal it was now important to close the development loop by analyzing the final design and comparing the results against the target specifications that were set up in the planning phase of this thesis. After this comparison had been done a final decision could be made as to whether the use of optimization methods combined with traditional methods in the concept development process managed to fulfill the thesis purpose: Developing a concept design that solves the identified problem of "lowering the driver seat mass without compromising the safety, cost, or ergonomic performance of the current solution". To be able to compare the final concept design with the target specifications, an analysis of the most important parameters of the driver seat structure has been performed. The outline of this section is as following:

7.1 Ergonomic evaluation of the complete seat structure
7.2 Structural evaluation of the three main concept structure components
7.3 Mass comparison of the complete concept seat and the reference seat
7.4 Cost comparison of the complete concept seat and the reference seat
7.5 Final comparison of concept performance and target specifications

Table 21: A recap of the most important target specifications, these will be used in the final comparison.

Highest rated target specifications	Spec. No.
Adjust driver functions	
Adjusts length of H-point by a minimum of 200 mm	21
Adjusts height of H-point by a minimum of 50 mm	22
Adjusts angle of back more than 14 degrees	23
Ergonomic constraints	
Ankle angle should remain within 90-100 degrees	24
Knee angle should remain within 110-130 degrees	25
Elbow angle should remain within 80-165 degrees	26
Structural support / Safety functions	
Withstand a rear collision moment of 2100 Nm without breaking	12
Withstand an unrestrained cargo moment of 2500 Nm without breaking	13
Withstand a forward submarining force of 4000 N applied to the base without breaking	10
Not deflect more than 2 mm when a static rearward force of 1600 N is applied to the backrest	11
Not deflect more than 1 mm when a static downward force of 1600 N is applied to the seat base	14
Seat-to-floor fastening structure should withstand an individual force of 4000 N, vertically & horizontally, without breaking	16
Seat-to-floor fastening structure should not deflect more than 0.5 mm when subjected to an individual downward force of 1600 N	17
Cost constraints	
Maximum concept structure unit cost, should be equal to the reference unit cost	27
Maximum allowed unit cost increase is 50 SEK per kg reduced mass, compared to the reference unit cost and mass	28
Mass reduction goals	
Total structure mass should be at least 25 percent less than the reference structure mass	18
Total seat mass should be at least 20 percent less than the reference seat mass	19

7.1. Ergonomic evaluation

Having the concept of a combined height and length adjustment left a few question marks regarding what type of seat configuration would satisfy the user in an ergonomically correct way. These questions were crucial to evaluate in order for the concept to be a valid solution. An early investigation of this was made during the concept generation phase of the thesis which showed that this concept could be plausible. But to fully evaluate it, more detailed tests were necessary which would include the finished CAD-model of the seat assembly and correctly sized manikins. From the pre-study of this thesis, angle intervals of the human limbs during a seating position were acquired and are summarized below.

Table 22: The comfortable angle intervals (Dreyfuss 2002; Lee, Schneider & Ricci 1990)

Body Part	Ankle	Knee	Leg/Torso	Torso/Neck	Torso/ Upper	Elbow	Seat angle
Angle interval	90°-110°	110°-130°	100°-120°	20°-25°	20°-40°	80°-165°	10°-22°

After having gathered which angle intervals the different body limbs had to be within in order to for the driver to be in an ergonomically correct position, it was time to investigate in more detail where the seat had to be positioned. Having the combined adjustments in a linear motion resulted in the fact that the rail segments would have to be tilted 14° in order to fit a human size range from 5 percent to 95 percent of the total population. To acquire this angle value a series of iterative tests were carried out using CATIA V5's manikin models and the previously gathered data of the ergonomically correct limb angles and seating positions from the books '*H-point'* and '*The measure of man & woman'*. Because the CATIA-manikins are dived into gender and the fact that a population normal distribution of each gender is not the same, an assumption was made to consider that 10 percent sized women would be the same as 5 percent of the total population size. The same would be assumed for 90 percent sized male which would be the same as 95 percent of the total population, and that for the 50 percent manikin a mean value of both genders was used. Below is an illustrated figure that displays the generalized height distribution of a total population, the measurements used in CATIA were based on the American population.

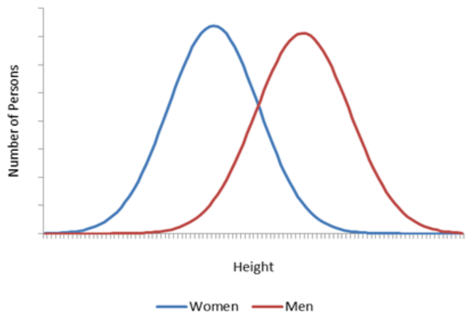


Figure 45: Height distribution differences between males and females

These manikin models were then compared with the seat assembly to verify that the seat was in an optimal position. Because the 10 percent female manikin and the 90 percent male manikin varied in size a great deal, none of them were eventually seated in the 'perfect' position. However they were within the correct interval, which validated the concept. A 50 percent manikin was also created which helped the tinkering of the seat configuration to match the 50 percent manikin almost perfectly. The red lines in the figures represent the line of sight to the instrument cluster panel, and the blue lines represent the line of sight out towards the road. The red lines show that they are near perpendicular to the steering wheel which validates that they all can see the instrument panel, and the blue lines prove that they all have a clear visibility out front. The lines of sight were important factors when designing the rail inclination and position. The results can be observed below, in order they are 90 percent male, 50 percent and 10 percent female.

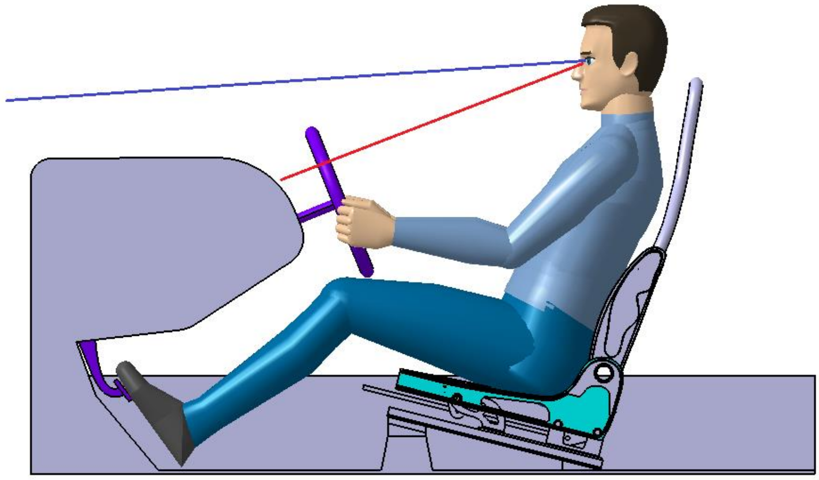


Figure 46: A 90 percent male manikin in a comfortable yet not optimal seating position, satisfying all ergonomic angle constraints. The combined height-length adjuster design solution is here in its lowest most rearward position.

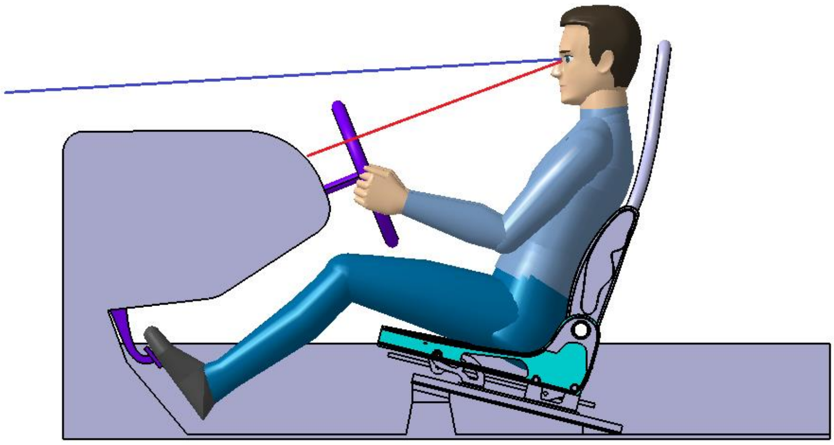


Figure 47: A mean of 50 percent, between male and female size, manikin in an optimal seating position, satisfying all ergonomic angle constraints. The combined height-length adjuster design solution is here in its mid position.

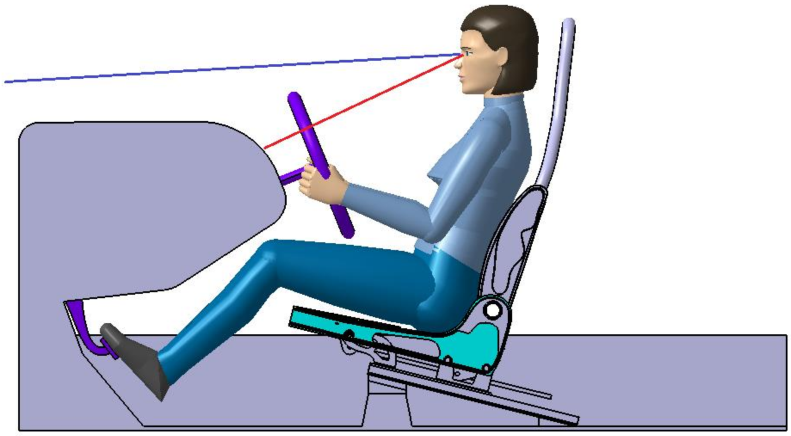


Figure 48: A 10 percent male manikin in a comfortable yet not optimal seating position, satisfying all ergonomic angle constraints. The combined height-length adjuster design solution is here in its highest most forward position.

In figure 46, 47, and 48, the manikins are intentionally positioned to allow space in between their bodies and the seat frame to make room for the seat pads. The 10 percent female manikin is positioned slightly higher than the other two, this is because of the compensation needed for their different body weights which would deflect the pads differently.

One gathered data (Lejon & Thorsén 2013) suggested that a length adjustment interval above 168 mm and a height adjustment interval more than 60 mm are rarely needed for humans between 5 percent and 95 percent in size. But in order to make an independent research and to validate these numbers the CATIA V5 manikins were used. After the investigation of a combined adjustment function it was revealed that the adjustment possible with the final concept was enough to cover the 5 and 95 percent interval. This investigation assumed a fixed ball of foot position for all human sizes and that the steering wheel would be able to be adjusted in length as well. The ergonomic analysis has revealed that the final concept is able to adjust the drivers H-point in the following intervals:

- 210 mm in length
- 53 mm in height

Having retained the recliner mechanism solution the concept is also able to adjust the driver's back more than 14 degrees. The analysis performed with test manikins of different size also validates the concept design in the aspects of ergonomic knee, ankle, and elbow angles.

7.2. Structural evaluation

With safety being one of the main sales arguments for current car manufacturers it is important that the safety performance of the concept seat structure is up to par with industry standards (as determined in the background study). For this reason the structural performance was among the highest rated requirements in the target specifications set up earlier in this thesis. This performance has also been one of the main constraints during the development work of the seat structure concept. This final structural evaluation was important as to make sure that safety requirements had been met by the final concept design.

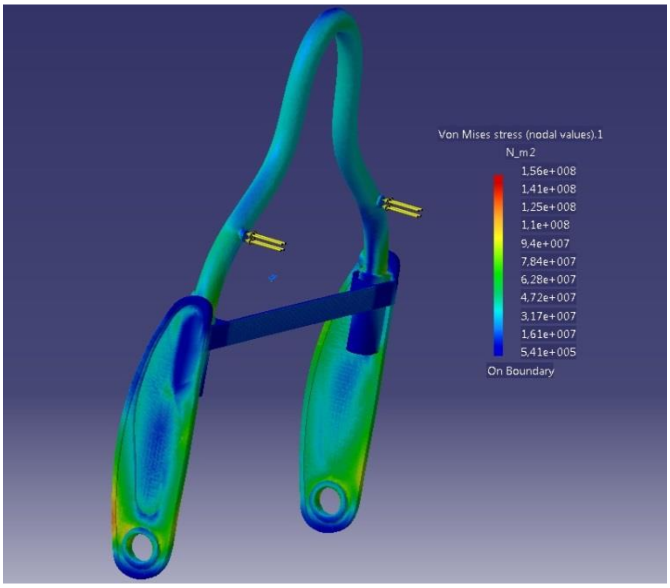


Figure 49: The concept back structure easily managed the worst load case without being close to the yield limit

The load cases for the structural analysis had already been elicited in the early phases of this thesis, as these were necessary input for the topology optimization procedure. As a result three dynamic, impact, load cases had been identified: Rear impact, unrestrained cargo, and submarining. As a complement two static load cases were used to simulate the weight of the driver during non-impact conditions: Vertical static load, and horizontal static load. For the structural analysis all of these load cases were evaluated individually on the three main components of the seat structure concept. These analyses were done in CATIA's FE-module with a mesh size of 2.5 mm. When subjected to the given load cases the concept models were analyzed mainly in terms of parameters including dynamic and static stresses, as well as dynamic and static deflection. As it turned out different parameters would act as constraints on different components of the structure. For instance the geometry and mass of the back frame structure is highly dependent on the horizontal deflection when subjected to the unrestrained cargo impact scenario while the base frame is largely dependent on the stress resulting from the impact scenario and the placement of floor mounting positions. The most important results from the structural analysis will follow, but for a detailed description see appendix 12 (Structural analysis).

7.2.1 Base frame structure

The structural evaluation of this component revealed a certain sensitivity to stresses near the rail mounts, especially in the concept component with the heightened recliner mount. As can be seen in the table below, stiffness of the general structure is not an issue even if Magnesium is a rather "soft" material. The static deflection due to driver weight was however an issue which required the implementation of a seat pan as mentioned in the *design considerations* section. The final concept base structure easily fulfills the performance requirements of strength and stiffness as can be seen when comparing the measured values with the limiting values seen in red text in the table.

Table 23: Results from the base frame structure analysis; the reference base results are included for comparison.

Parameters	Reference Base	Concept Base		Limiting values
Material	Low alloy steel	Magnesium (AZ)		
Max. Von Mises Stress during Unr. Cargo (Mpa)	696	148		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Von Mises Stress during Rear Imp. (Mpa)	513	117		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Dynamic Deflection during Unr. Cargo (mm)	0,35	1,4		14 mm
Max. Dynamic Deflection during Rear Impact (mm)	0,3	1,1		14 mm
Max. Dynamic Deflection during Submarining (mm)	0,9	1,64		10 mm
Max. Static Deflection (mm)	0,8	0,6		1 mm for base, 2mm for back

7.2.2 Back frame structure

When evaluating this component it became clear that stiffness was a limiting factor for the concept design as compared to yield strength for the reference design. Although the heightened recliner mount significantly reduces both the stresses and deflection, the switch to magnesium calls for structural reinforcements near the recliner mounts. The final concept back structure clearly fulfills the structural performance requirements when compared to the reference design.

Table 24: Results from the back frame analysis, deflection proved to be a limiting parameter for the concept.

Parameters	Reference Back	Concept Back		Limiting values
Material	Low alloy steel	Magnesium (AZ)		
Max. Von Mises Stress during Unr. Cargo (Mpa)	700	140		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Von Mises Stress during Rear Imp. (Mpa)	663	105		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Dynamic Deflection during Unr. Cargo (mm)	10,7	13,9		14 mm
Max. Dynamic Deflection during Rear Impact (mm)	6,3	8		14 mm
Max. Dynamic Deflection during Submarining (mm)	N/a	N/a		10 mm
Max. Static Deflection (mm)	1,9	2		1 mm for base, 2mm for back

7.2.3 Seat-to-floor attachment structure

When evaluating the support legs using FEM two types of tests were performed. The first was a simulated crash scenario where the forces would reach 4 000 N for each leg support. This value was taken from the requirement specification that stated that each fixating point of the rail attachment had to withstand 4 000 N in any direction, therefore it could be assumed that the support legs themselves also had to withstand the same amount of force. For this case stiffness was not an issue but rather the strength of the material. By assuming that a low alloy steel with a yield strength of 800 MPa is used for all leg supports this stress value was the one that to be designed against. The reason for choosing low alloy steel was because magnesium was not stiff enough and would deflect too much during the static test. Because the seat is attached to the tunnel in the x-direction, any dislocations in that direction could be set to zero and would therefore not be an issue. This would also help any buckling to occur on the leg supports. The thicknesses of the different support leg plates were then minimized until the maximum stress level reached 750 MPa. The second test was a static simulation which evaluated how the support legs would act during a force of 1600 N for each leg. Here the stresses were no longer a problem since the support leg thicknesses had been designed for a load of 4000 N. However the test was conducted to see if there were any large dislocations or buckling that would lead to user dissatisfaction. For the right leg supports the cylinders that attach the seat to the tunnel are included in these FEM-analyses. The result can be found in the table below.

Table 25: Evaluating results of attachment structure components

	Front Left Leg	Rear Left Leg	Front Right Leg	Rear Right Leg	Left Rail	Rail Support Bracket
Max. Stress [MPa]	753	101	654	723	559	60
Max. Disp. [mm]	0,313	0,497	0,153	0,524	0,14	0,341

As can be seen in the table above, the attachment structure including the rails and leg supports manages the applied loads without reaching the material yield limit or experiencing any major buckling or deflection, except for the rear right leg which deflected 0.024 mm passed what was allowed. However, the assumption was made that it was such a small error that it could be eluded.

7.2.4. Summary of structural performance

The structural evaluation has shown that the final structure concept achieves the following structural performance:

- The back & base frame is able to withstand a rear collision moment of 2100 Nm without reaching the yield limit
- The back & base frame is able to withstand an unrestrained cargo moment of 2500 Nm without reaching the yield limit
- The base frame is able to withstand a forward submarining force of 4000 N without reaching the yield limit
- The back deflects 2 mm when subjected to a static rearward force of 1600 N
- The base deflects 0.6 mm when subjected to a static downward force of 1600 N

- The seat-to-floor fastening structure is able to withstand an individual force of 4000 N, vertically & horizontally, without reaching the yield limit
- The seat-to-floor fastening structure deflects 0.5 mm when subjected to an individual downward force of 1600 N

7.3. Mass evaluation & Comparison

Since the primary aim of this thesis was to develop a driver seat concept with lower mass than the current driver seat design, it was vital to include a mass analysis of the complete final concept and compare these results with an analysis of the reference seat mass. A factor in deciding how to conduct this mass analysis was a request from Semcon, who wanted a complete bill of materials (BOM) of the completed seat concept. A BOM is a list of all the parts that make up the complete product, resembling a table of contents. It is also common to include at which level the parts are assembled, this way the assembly procedure is included in the BOM. Based on this it was decided to include mass and cost of each part in this bill of materials, so that the BOM could be used as a basis for both the mass and cost analysis. In order to compare the final concept with the reference design, a similar bill of materials had to be made for the reference seat. The BOM was produced by weighing each part of the concept CAD sub-assemblies, and the reference CAD, in CATIA. Not only the structural components are included in the BOM but also the remaining parts that make up the finished driver seat, such as seat foam and upholstery. These other parts were included for clarity, as this would allow to see how many percent of the total seat mass that could be reduced by redesigning the frame structure. Another advantage of this layout is that it will show where future mass reduction efforts of the remaining seat components should be directed.

Table 26: A section of the bill-of-materials for the final concept. The total mass includes parts not seen here but they are listed in the full BOM included in appendix 14.

Final Concept BOM						Chosen	From assembly	Chosen	Measured in CAD
BOM level	0	1	2	3	4	Part name	Quantity	Part material	Part mass (kg)
0	x					Driver seat	1		14,264
1		x				**Driver seat structure assembly**	1		8,08
2			x			*Base Frame assembly*	1		1,599
3				x		Side Plate	2	Mg	0,176
3				x		Front plate	1	Mg	0,12
3				x		Rear reinforcement	2	Mg	0,13
3				x		Front reinforcement	2	Mg	0,03
3				x		Seat pan support bar	1	Mg	0,1
3				x		Rear susp. beam	1	Mg	0,21
3				x		Seat pan	1	Mg	0,497
2			x			*Back Frame assembly*	1		1,624
3				x		Side plate	2	Mg	0,292
3				x		Upper support	1	Mg	0,14
3				x		Upper tube	1	Mg	0,704
				x		Tube holder	2	Mg	0,098
2			x			*Seat-to-floor attachment structure*	1		3,457
3				x		*Seat Legs*	4	Low Alloy Steel	0,361
4					x	Left Rear Leg	1	Low Alloy Steel	0,111
4					x	Left Front Leg	1	Low Alloy Steel	0,175
4					x	Right Rear Leg	1	Low Alloy Steel	0,046
4					x	Right Front Leg	1	Low Alloy Steel	0,029
3				x		*Rail support brackets*	2	Low Alloy Steel	0,17
4					x	Rail support bracket top	1	Low Alloy Steel	0,052
4					x	Rail support bracket bottom	1	Low Alloy Steel	0,118

The seat structure mass of the final concept is measured to 8.08 kg, which includes the base structure, back structure, recliner mechanism, and the entire seat-to-floor attachment structure including the rails. The reference seat structure mass is estimated at 13.3 kg, and includes all of the components that the concept structure has plus an additional height adjuster mechanism and added structural parts for the height adjuster. The final concept seat structure thus achieves a mass reduction of 39.4 percent when compared to the reference structure. The reasons for this mass reduction is a synergetic result of combining the new design solution concepts (combined height-length adjuster, heightened recliner, tunnel mount) with optimized geometry (topology optimization, optimized design process) and a lower density material (magnesium alloy). However the mass reduction target set in the beginning of this thesis was measured on the total seat, complete with foam and upholstery, which means that the comparison should be between the total mass in the two BOMs. The concept total seat mass is estimated at 14.26 kg this is to be compared to the total reference seat mass estimated at 19.52 kg. The final achieved mass reduction is thus 26.9 percent.

Table 27: A section of the bill-of-materials for the reference seat. The total mass includes parts not seen here but they are listed in the full BOM included in appendix 13.

Reference seat BOM						Chosen	From assembly	Chosen	Measured in CAD
BOM level	0	1	2	3	4	Part name	Quantity	Part material	Part mass (kg)
0	x					Driver seat	1		19,514
1		x				**Driver seat structure assembly**			13,33
2			x			*Base frame assembly*			3,2
3				x		Base side plates	1	Low alloy steel	1
3				x		Base reinforcement plates	1	Low alloy steel	0,4
3				x		Base side plate	1	Low alloy steel	0,6
3				x		Base back plate	1	Low alloy steel	0,6
3				x		Base front plate	1	Low alloy steel	0,6
2			x			*Back frame assembly*			3,6
3				x		Lower Support Frame	1	Low alloy steel	0,5
3				x		Back side plate	1	Low alloy steel	0,8
3				x		Back side plate	1	Low alloy steel	0,8
3				x		Upper Support Frame	1	Low alloy steel	0,16
3				x		Mid support frame	1	Low alloy steel	0,3
3				x		Neck support bar	1	Low alloy steel	0,05
3				x		Neck support bar	1	Low alloy steel	0,05
3				x		Head rest frame	1	Low alloy steel	0,5
3				x		Active Head Restraint	1	Low alloy steel	0,44
2			x			*Seat-to-floor attachment structure*			3,65
3				x		Height Front Rod	1	Low alloy steel	0,5
3				x		Height Back rod	1	Low alloy steel	0,5
3				x		Legs	4	Low alloy steel	0,25
3				x		Outer track	2	Low alloy steel	0,65
3				x		Inner track	2	Low alloy steel	0,35

Although the achieved mass reduction is fairly high (compared to Lotus that achieved 17 %) there is still potential for further mass reduction if a redesign of other components were considered, the seat foam for instance could perhaps be reduced by using more ergonomic shapes of the seat back. It is also interesting to know how much of the mass reduction that was enabled due to the design changes as compared to simply switching the material to magnesium. As an extra control evaluation one more design was analyzed, the reference base & back structure with magnesium instead of low alloy steel. This would reveal how much the change in geometry and adjustment functions actually contributed to the final mass reduction. The design was made in the same way as the final concept design, with values of stiffness and strength acting as constraints and mass being reduced as much as possible, however this time without making any serious geometry changes, instead the wall thickness was increased.

Table 28: A comparison between the reference structure with Magnesium alloy and the final concept

Parameters	Reference Base	Reference base Mg	Concept Base	Reference Back	Reference back Mg	Concept Back
Material	Low alloy steel	Magnesium (AZ)	Magnesium (AZ)	Low alloy steel	Magnesium (AZ)	Magnesium (AZ)
Max. Von Mises Stress during Unr. Cargo (Mpa)	696	184	148	700	170	140
Max. Von Mises Stress during Rear Imp. (Mpa)	513	155	117	663	153	105
Max. Dynamic Deflection during Unr. Cargo (mm)	0,35	0,32	1,4	10,7	13	13,9
Max. Dynamic Deflection during Rear Impact (mm)	0,3	0,22	1,1	6,3	8,1	8
Max. Dynamic Deflection during Submarining (mm)	0,9	1,49	1,64	N/a	N/a	N/a
Max. Static Deflection (mm)	0,8	1	0,6	1,9	2,4	2
Mass (kg)	3,1	2,4	1,59	3,6	2,36	1,62
Savings compared to steel reference (%)	Reference	22,6	48,7	Reference	23,9	47,7
		Material choice	Structural Geometry		Material choice	Structural Geometry
Percentage of mass savings		46	54		50	50
Comment		*Material accounts for almost half of the mass savings*			*Material accounts for almost half of the mass savings*	

This concept did not reach the numbers that the redesigned concept did, but in fact the redesign is responsible for about half of the final achieved mass reduction. There are two conclusions to be drawn from this:

1. If only the frame is considered for a mass comparison, a redesign of the seat structure on the conceptual level is able achieve at least 22 percent mass reduction (which validates the numbers that the concept selection was based on).
2. Simply switching material from low alloy steel to magnesium would achieve almost as much (based on a structure mass savings of 37 percent).

As have been shown the final concept achieves the following mass reduction:

- Concept frame structure mass is 37 percent lower than the reference structure mass
- Total concept seat mass is 26.9 percent lower than the total reference seat mass

7.4. Cost evaluation & Comparison

Cost is of major importance for car manufacturers as identified in the planning phase of this thesis. It was also one of the determining constraints that remained prominent throughout the development effort, especially when the material was chosen. It was also stated in the purpose of this thesis that the cost of the developed concept should not exceed the cost of the reference seat. This means that a cost comparison between the developed final concept and the reference seat was validated. Utilizing the established BOMs for both the concept and the reference seat, cost estimations for each part were made in the CES EduPack 2013 software. By entering the mass and dimensions, as well as the chosen material and manufacturing method for each part, CES was able to give a low and high cost estimate. All parts have been estimated using 100 000 units as a basic production size, which is an average car's yearly production series according to experts at Semcon. As done previously in this thesis the mean value of the low and high cost estimates were used, both due to lack of knowledge of the actual estimates and the fact that this is still at an early concept stage. Since all part costs were estimated in the same way, even for the reference seat, it should result in a fair comparison.

Table 29: An excerpt of the cost estimations for the final concept

Final Concept BOM						Chosen	From assembly	Est. In CES (Mean)	From CES (Mean)
BOM level	0	1	2	3	4	Part name	Quantity	Part Cost (SEK)	Tooling Cost (SEK)
0	x					Driver seat	1	2458,11	
1		x				**Driver seat structure assembly**	1	682,11	1290682
2			x			*Base Frame assembly*	1	134,885	468124
3				x		Side Plate	2	12,435	69850
3				x		Front plate	1	10,535	69850
3				x		Rear reinforcement	2	12,93	73508
3				x		Front reinforcement	2	12,93	73508
3				x		Seat pan support bar	1	11,43	38050
3				x		Rear susp. beam	1	12,93	73508
3				x		Seat pan	1	23,4	69850
2			x			*Back Frame assembly*	1	103,51	181408
3				x		Side plate	2	19,75	69850
3				x		Upper support	1	12,93	73508
3				x		Upper tube	1	28,3	38050
				x		Tube holder	2	11,39	
2			x			*Seat-to-floor attachment structure*	1	147,21	641150
3				x		*Seat Legs*	4	27,73	69850
4					x	Left Rear Leg	1	7,1	69850

Table 30: An excerpt of the cost estimation for the reference seat

Reference seat BOM						Chosen	From assembly	Est. In CES (Mean)	From CES (Mean)
BOM level	0	1	2	3	4	Part name	Quantity	Part Cost (SEK)	Tooling Cost (SEK)
0	x					Driver seat	1	2485,0	
1		x				**Driver seat structure assembly**		709,0	1072750
2			x			*Base frame assembly*		56,5	349250
3				x		Base side plates	1	9,8	69850
3				x		Base reinforcement plates	1	17,3	69850
3				x		Base side plate	1	9,8	69850
3				x		Base back plate	1	9,8	69850
3				x		Base front plate	1	9,8	69850
2			x			*Back frame assembly*		90,74	501450
3				x		Lower Support Frame	1	9,2	69850
3				x		Back side plate	1	10,9	69850
3				x		Back side plate	1	10,9	69850
3				x		Upper Support Frame	1	7,3	69850
3				x		Mid support frame	1	8,14	69850
3				x		Neck support bar	1	9	38050
3				x		Neck support bar	1	9	38050

As can be seen in the two tables the cost for the concept design structure is 682 SEK, compared to the reference structure cost of 709 SEK. The difference depends mostly on the fact that in the concept design a non-adjustable neck support is used, and that the height adjuster mechanism with all the complementary parts needed for it is removed in the concept design. Development costs are not included in this cost analysis. The final concept is thus cheaper than the current solution. However much like in the mass evaluation section the cost comparison needed to include not only the structural parts, but also all the components needed to assemble a complete driver seat. The same parts as in the mass analysis were used for the cost analysis but for these parts the costs could not be estimated using CES, instead these costs were compiled from actual costs belonging to the reference seat. The final comparison pitches the concept seat cost of 2458 SEK against the cost of the reference seat at 2485, a small reduction in cost but far from exceeding it.

Initial estimates of unit costs have shown that:

- The concept structure cost is 682 SEK

- The reference structure cost is 709 SEK
- The concept total seat cost is 2458 SEK
- The reference total seat cost is 2485 SEK

7.5. Final comparison with target specifications

In order to verify that the outcome of this thesis has fulfilled the goal and achieved acceptable values of the evaluated parameters, a comparison has been made between the target specifications set up in the planning phase, and the final concept specifications achieved in the final analysis phase.

Table 31: After comparing the concept analysis results with the target specifications, all important requirements could be marked as approved.

Highest rated target specifications	Spec. No.	
Adjust driver functions		
Adjusts length of H-point by a minimum of 200 mm	21	✓
Adjusts height of H-point by a minimum of 50 mm	22	✓
Adjusts angle of back more than 14 degrees	23	✓
Ergonomic constraints		
Ankle angle should remain within 90-100 degrees	24	✓
Knee angle should remain within 110-130 degrees	25	✓
Elbow angle should remain within 80-165 degrees	26	✓
Structural support / Safety functions		
Withstand a rear collision moment of 2100 Nm without breaking	12	✓
Withstand an unrestrained cargo moment of 2500 Nm without breaking	13	✓
Withstand a forward submarining force of 4000 N applied to the base without breaking	10	✓
Not deflect more than 2 mm when a static rearward force of 1600 N is applied to the backrest	11	✓
Not deflect more than 1 mm when a static downward force of 1600 N is applied to the seat base	14	✓
Seat-to-floor fastening structure should withstand an individual force of 4000 N, vertically & horizontally, without breaking	16	✓
Seat-to-floor fastening structure should not deflect more than 0.5 mm when subjected to an individual downward force of 1600 N	17	✓
Cost constraints		
Maximum concept structure unit cost, should be equal to the reference unit cost	27	✓
Maximum allowed unit cost increase is 50 SEK per kg reduced mass, compared to the reference unit cost and mass	28	✓
Mass reduction goals		
Total structure mass should be at least 25 percent less than the reference structure mass	18	✓
Total seat mass should be at least 20 percent less than the reference seat mass	19	✓

As can be seen in table 31, the final concept fulfills all the important target specifications set up in the beginning of this thesis. It should be mentioned that the ergonomic requirements are what is needed from an anthropometric view. This does not take personal preference into consideration. As such it can be discussed whether or not the concept achieves the same comfort performance as the reference seat, this is treated further in the discussion section of this report. Regardless of personal preference the concept achieves the same safety performance as the reference seat. The concept also has a marginally lower unit cost. Most importantly the final concept achieves a mass reduction of close to 27 percent when compared to the reference seat, the goal of this development project has thus been met: The seat sub-system mass has been reduced, without compromising the safety, cost, or ergonomic performance of the current solution.

8. Discussion

This section aims to clarify the meaning of the results and whether or not the thesis goal has been achieved. This is done by first describing the main goal and the fulfilment of that goal. The relevance of the findings is then discussed in order to understand why they are important. A discussion of the reliability of the methods used, and thereby the results produced are included together with an explanation of their validity. Finally some thoughts are presented regarding what the team has learnt during the thesis process.

8.1 The findings and their meaning

The aim of this project was to find and develop a driver seat structure concept that solved the previously identified problem of:

How can the driver's seat mass be reduced, without compromising the safety, cost or ergonomic performance of the current solution?

The team has shown that through the use of topology optimization, CAD-modeling, FE-analysis, material selection, and various product development methods, it is possible to reduce the driver's seat mass without compromising the safety, cost or ergonomic performance of the reference driver's seat design. More specifically it has been shown that it is possible to achieve this goal by focusing on redevelopment of the seat support structure and adjustment system, whilst leaving the remaining seat components untouched. A brief summary of the results is presented to support this.

The final concept is:

- 27 percent lighter than the reference seat
- 1 percent cheaper than the reference seat in terms of unit cost
- Able to withstand the same impact load cases as the reference seat
- Able to fulfill the same *basic* ergonomic requirements as the reference seat

What this basically means is that the reference seat design, which is also the dominant design, is not optimal in terms of mass and cost, two of the most prominent drivers of new development in the automotive industry. If the current seat design had been optimal it would not be possible to develop a new design that is both lighter and cheaper. Thus if a company such as Semcon were to develop a car seat today, with the purpose of being lightweight and cost effective, it would be wise to start from scratch instead of conducting an incremental development project based on the current solution. With that said there were two other areas of comparison, or constraints, which have to be discussed as well. The structural performance, i.e. safety, of the concept design is believed to be at the same level as the reference solution, this has been shown through FE-analysis, the reliability of which will be discussed later in this section. The main question mark however lies within the ergonomic performance of the concept design, as even though the basic ergonomic requirements are fulfilled from an objective point-of-view, there is a subjective part of the ergonomic performance which can only be evaluated through physical testing with real drivers. There are two design solutions which are directly affected by this subjective element, the combined height-length adjuster and the heightened recliner mount. The combined adjuster manages to fulfill both the length and height adjustment requirements which were based on statistical findings; however it eliminates the possibility to individually adjust the length and the height of the seat. For some drivers that don't fit the statistical profile, perhaps due to personal preference, this would be a problem. Although it should be mentioned that the usability on the other hand is increased since there are less adjustment controls to keep track of. Since the production of a physical prototype was not in the scope of this thesis it was assumed that since the seating position would be statistically correct for all drivers within the 5 to 95 percentile range, the combined length-height adjuster is a feasible design solution. For the heightened recliner mount there were concerns regarding the placement of the side airbag unit, the team did not want to relocate this as it would have required more research into the side collision dynamics which were not a part of the thesis scope. If the airbag unit could be relocated the recliner could probably be mounted even higher yielding even better results in terms of mass reduction. There is an ergonomic concern regarding this design solution as well, how the heightened recliner mount will influence the driver's lower back when tilting back the seat. Although this was not studied in detail, a consultation with an expert in ergonomics hinted that this wouldn't be an issue. Further strengthening the feasibility of the heightened recliner concept was the fact that several current designs analyzed in the benchmarking section had a heightened recliner mount as well, although exactly how high was difficult to determine.

In order to use these results to show that the thesis purpose has been achieved it is important to discuss both the reliability of the methods used in the development process and validity of the chosen areas of redevelopment.

8.2 Reliability

The reliability of the ergonomic analyses conducted both in the concept generation phase and in the final evaluation phase rests on manikin models created in CATIA. All measurements for the manikins were taken from '*The measure of man and woman'* (Dreyfuss 2002). Three different manikins were produced to cover the size range in the 5-95 percentile range. It can be said with a fair amount of certainty that these analyses gave a good indication of which seating positions and geometry that are ergonomically correct for a driver's seat. They did not however reveal if it is possible for all the drivers within the 5-95 percent interval to be able to adjust the seat position according to their personal preference, which might be different from the seating position the research suggests is optimal.

The reliability of the structural performance analysis, evaluated by FEM and Inspire, rests on several factors. First the load cases that have been used as input to the analyses might be different from the actual load cases that occur in an impact, these load cases were derived from an actual driver's seat product specification using simplified physics, i.e. laws of motion. There could be inherent errors in the product specification used that the team has no knowledge of. There are most likely some differences in the simplified mechanics used to calculate the resulting forces and moments and the real life physics that take place in an impact.

The detail of the CAD-models used in the analyses affect the outcome as well. There is a saying amongst analysts that says that "The results are only as good as the model". What this means is that the reliability level of the FE-analysis will never exceed that of the level of detail in the CAD-model which is used in the analysis. In this thesis modeling and analysis have been used in different phases of development. In the very early concept generation stage they were used to give the team hints of mass reduction potential inherent in the different concepts, for the sake of being efficient in this phase neither the models nor the analyses conducted were not highly accurate. In the case of using Inspire for topology optimizing the design domains the mesh size had to be drastically enlarged in order to even run an analysis in the timeframe of an entire day. In the final stages, further development and the final evaluation, the team spent more effort on achieving a higher level of detail of both the model and FE-analysis. For instance mesh size was reduced to between 1 and 2.5 mm in the final evaluation analysis compared to 4 mm in the generation phase. However since this thesis only covers the concept generation and selection phase of an actual development project the models and analyses are still not accurate enough to provide a result that is production ready. Even though there are inaccuracies of the load cases used, and the models produced, as well as the FEM mesh size, it is important to understand that all concepts and the reference design have been modeled and evaluated in the same level of detail throughout the thesis process. Thus for the sake of being a concept design study, which is actually more of a pre-study to an actual industry development project, the comparisons made in this thesis are highly indicative of the differences between the concepts generated as well as the reference design. The final outcome is thus reliable in terms of a design comparison.

The reliability of the cost analyses performed in this thesis needs to be discussed as well. To start with it should be mentioned that neither of the two team members had any previous experience of cost estimations. Although not believed to be so important at first, it became more and more apparent as the thesis went along that cost was one of the most important factors for the development process. Thus after discussions with the supervisor at Semcon it was decided that cost estimations of a rather high level of detail were needed already in the concept selection phase. This was to not select a final concept just by intuition but rather based on facts. These early cost estimations proved to be one of the most difficult tasks in this thesis, mostly due to the fact that the uncertainty regarding the final geometry and manufacturing processes was very high. It was difficult to estimate the cost of a component before the most effective manufacturing process and geometry had been selected. Although difficult at the time, the information gathered in this phase could later be used to aid the in the final concept design, specifically when choosing geometry and manufacturing methods. Regarding the accuracy of these cost analyses it is most likely not very high at a component level but on a complete concept level it is not particularly inaccurate. To support this is the fact that the team used an actual driver's seat cost specification to normalize the cost evaluation of the reference seat and the same was done for the concept design. This means that even though the internal distribution of costs across the different components might be different from reality, the total cost is accurate. For all the cost estimations, information from the CES materials database has been used, even for the estimating and normalizing the cost of the reference seat. This ensures that all designs have been compared on equal ground. Seeing as this has been a concept selection project, the cost estimations could not be 100 percent accurate in this phase, there were simply too many unknown factors that aren't determined until the final phases of development.

The reliability of the concept selection process should be discussed as well. In this thesis several concept screenings have been carried out, and not all of them have been as detailed as the final selection matrices. In fact the level of detail in screenings went from purely subjective feasibility analysis in the idea generation stage to elaborate concept scoring matrices in the final selection, where the criteria values were based on results from FE-analyses and cost estimations. However during all of these screenings there were always elements of subjective judgment present. At several occasions engineers at Semcon were involved in the selection process which means that the result could be influenced by their previous experience and interests. Generally it can be said though that the level of objective evaluation was high. The fact that extensive analyses were performed prior to the screening sessions supports this.

8.3 Validity

In this thesis the development work has been concentrated to two functional criteria of the driver's seat, *Adjust driver* and *Provide structural support*. The reason for choosing these two was that these were the ones most directly related to the seat frame structure, the seat component which accounts for the largest fraction of the seat mass, as identified in the background section. It was thus believed that it would be most effective if the development effort was spent redeveloping the design solutions of the seat structure and adjustment system. If this assumption was correct the end result would yield a substantial amount of mass savings compared to the reference seat. Evidently this has indeed been the case. By redeveloping the seat frame and adjustment system a total seat mass reduction of close to 27 percent has been reached, without compromising any other important requirements. This validates the choice of focusing the development effort on the *Adjust driver* and *Provide structural support* functional criteria.

The next question concerns the validity of limiting the development project to only include the driver's seat and exclude the passenger and rear seats. The reason for doing this was that it was assumed that if successful results could be achieved on the driver's seat then the proven solutions could be applied to the passenger seat and yield similar results. Seeing as the passenger seat is often of a similar design as the driver's seat, albeit with less adjustability functions, it is very likely that applying the final design solutions to the passenger seat would yield a substantial mass reduction as well. The backseat is however fundamentally different from the driver's seat, the backseat does not have any adjustability functions and both the interface and geometrical layout are different. Because of these fundamental differences the final concept result cannot be extrapolated to the back seat design.

Since a different material has been used it was important to determine how much of the final mass savings result depended on this material choice and how much the developed design contributed to the mass savings. The final design is validated by the comparison with a reference design using magnesium as well. This showed that the concept design accounts for half of the mass savings and the switch to magnesium for the other half. Important lessons here are thus that by conducting a complete redesign of the seat structure it is possible to achieve a 25 percent reduction in frame mass compared to the reference but also that simply by switching to magnesium it is possible to achieve almost as much.

Manufacturing processes have not been focused on in this thesis, it was deemed unnecessary to go into the manufacturing method at this early concept stage. It was later realized that the more information that was available about the manufacturing strategy, the more information could be gathered regarding the seat costs and possible geometry. The choice of production method would most likely influence the result, specifically in terms of mass reduction and cost.

There is an issue regarding the optimization aspect of this thesis that should be addressed as well. In this thesis optimization has been used in several different ways but if one would look at the entire development process as an optimization procedure, the best possible final concept should equal the global optimum of the available solution space. In order to simplify the work in the development process the main problem was divided into two sub-problems, the two main functional criteria already mentioned. The work was focused on finding optimal solutions to these two sub-problems, where after the two optimal design solutions were combined into one final main concept. There is a risk that these two sub-solutions were local optima and that the global optimum was never found. But tackling the seat design problem head on and trying to scan the entire available solution space would not have been possible within the duration of this thesis. Thus there is apparently a trade-off between finding the globally optimal solution and spending too much effort searching for that solution. In conclusion although it might not be the truly optimal solution, the concept developed in this thesis still manages to achieve the goal of the thesis within the available amount of time. Furthermore this indicates that there might be even more mass reduction possible if other more optimal solutions can be found. At several times during the development process the team found themselves forced to eliminate concepts that had not yet been thoroughly researched or completely solved function-wise. For the sake of trying to find a truly innovative design perhaps even more effort should have been spent refining the ideas in the early concept generation phase.

8.4 Lessons learned throughout the process

Since the master's thesis is the final course in the Mechanical engineering/Product Development program at Chalmers University it is important to mention that the team, which are both mechanical engineering students, has had the possibility to show most of what they've learnt in all previous courses, and learned some new things along the way. This project has been mainly focused on the mechanical engineering aspects of seat development; this is due to focusing on the seat structure specifically. The development work has included many aspects taught at the University, such as mechanical calculations in the load case research, finite element theory used in the topology optimization and structural analysis, general analytical and creative thinking when designing in CATIA, material selection theory, product development methods such as function analysis and selection matrices, as well as project management skills. It is safe to say that the team has got to try many of the methods previously learnt on an interesting industry application. Looking back at the thesis process several interesting aspects have been realized. First it should be mentioned that above all the team has realized that costs are very important in the automotive industry and that this is the main driver of product development in this sector. Interestingly it has been realized that implementation of optimization techniques and FE-analysis by design engineers as early as in the concept generation phase can have a positive impact on the end result, this is contrary to how many automotive companies work today were the design engineers and analysis engineers are separated and work more sequentially. While working with both design and analysis simultaneously the team felt that a better understanding of the structural demands put on the design was reached early on. The self-conducted analysis also provided immediate feedback which was very satisfying and made the process more fun. It was also realized that a development process such as this one is seldom linear; the team had to perform many iterations in all of the thesis phases to reach an interesting result. There is a difference here between the thesis project and previous school projects where it hasn't really been required or possible to conduct this more accurate iterative approach, it was very interesting to be able to spend more effort doing this in the thesis work. Finally it should be mentioned that the use of analysis software, and product development tools such as selection matrices, should not constitute the ultimate truth as there is always a degree of error present when using them. These tools are very useful to guide the development process but the engineer's own sense of reasoning must be present throughout the development process.

9. Conclusions

- It has been shown that the reference seat design is not optimal in terms of mass and cost, two of the most prominent drivers of new development in the automotive industry.
- The team has shown that it is possible to reduce the driver's seat mass without compromising the safety, cost or ergonomic performance of the reference driver's seat design.
- This thesis has focused on the seat structure, specifically on the Adjust driver and Provide structural support criteria, implying that redeveloping the seat frame is highly effective if a future development project would be undertaken.
- The concept adjustment system has been verified with virtual ergonomic analyses, however personal adjustment preference has not been accounted for. To truly validate the concept it should be tested with physical prototypes.
- Although being simplified, the models and analyses have been done equally for all concepts and the reference, implying that the end result is a strong indication of a lightweight concept.
- Cost estimations may differ from reality on a component level but is normalized to actual specifications on a complete level, they have also been done equally for all concepts and the reference, implying that the end result is a strong indication of a cost effective lightweight concept.
- Manufacturing processes have not been focused on in this thesis, conducting a more detailed analysis of production methods will affect the end result, most likely in a positive way.
- The optimal solutions derived in this thesis might be locally optimal solutions due to the dividing of development work in different main criteria. There is most likely a global optimum in the available solution space which is yet to be found, indicating that even more mass reduction is possible to achieve.
- If only the frame is considered for a mass comparison, a redesign of the seat structure on the conceptual level is able achieve at least 22 percent mass reduction (which validates the numbers that the concept selection was based on).
- Simply switching material from low alloy steel to magnesium would achieve almost as much (based on a structure mass savings of 37 percent).

10. Recommendations

- Due to the lack of possibility to evaluate driver adjustment preference without building physical prototypes, it is recommended that this be further looked into if a continued development effort is to be undertaken. The same goes for evaluating the new height of the recliner mounting position.
- As the choice of switching material to magnesium was made, the production methods of this material need to be researched further. In a continued development project the team should contact magnesium producers such as STOLFIG and get exact quotes and specifications.
- Customer needs should be investigated more thoroughly prior to a future development project.
- Structural performance should be evaluated using a full scale FE-analysis with revised load cases.
- Spend even more time in the early stages of concept generation.
- If overall vehicle mass is to be reduced, the passenger and rear seats should be redeveloped as well.
- For the passenger seat a further study should consider the rigid seat concept.
- More detailed cost analyses should be performed in conjunction with a further study of manufacturing processes.

11. Alternative concept and further recommendations

During this thesis there was one particular concept that stood out from the rest, both when it came to mass and cost reduction potentials. That concept was the one with a rigid seat frame and a combined height, length and recline adjustment (AC2, SS6). The benefits of having a fixed seat frame can be seen in chapter 5 where it received the highest scores overall during the concept selection phase.

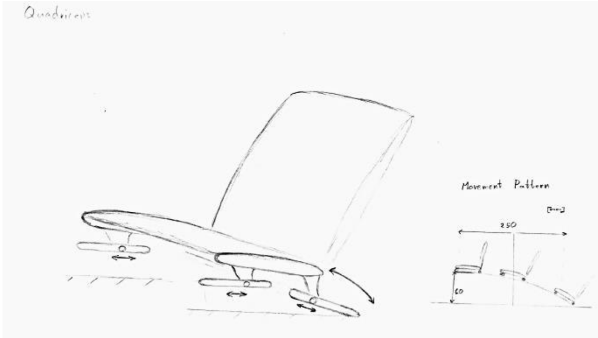


Figure 50: Concept sketch of the rigid seat with combined length, height, and tilt adjustment.

To compensate for the lack of recline function the seat had to be able to change tilt angle by moving the whole seat at once. As the seat would move forward, it would also rise in height and the tilt angle would be changed slightly in a forward rotation. In this way the idea was that it still could fulfill the ergonomic requirements, stated in chapter 3, and be feasible for a population size between 5 and 95 percent. But after having discussed this concept with an ergonomics expert it was rejected due to the belief that the customer (driver) still would require a separate recline function, same as in the current reference seat, even though it could theoretically fulfill the basic ergonomic requirements. However, the use of this concept as a passenger seat was not directly dismissed and could possibly, by the expert's estimates, be accepted by the customer (passenger). The main reason for this was that the passenger would not feel the same need for adjustment capabilities as for the driver. But in order to truly know if this concept would work, a full sized prototype would be necessary to be built, and then tested by potential customers. Since the passenger seat was out of scope for this thesis the development stopped during the concept selection stage when this issue was first discovered.

Another aspect of this concept is that it is compatible with a tunnel attachment, the same as for the final concept for this thesis, and would therefore not require a higher tunnel level than the final concept. If a rigid seat were to be installed as a front passenger seat it would reduce the passenger seat mass with approximately 32 percent, and reduce unit cost even further (compared to the final solution). A rigid seat frame enables for a more optimized structure design to be made and also reduces the amount of parts needed. Together they make up a simpler seat design which is more beneficial in regards to mass reduction and cost savings than the final chosen concept, which is divided into a base part and a back part. Though, it should be mentioned that having different designs for the driver and passenger seats, without interchangeable components, could increase the cost of production. This needs to be considered in a future project.

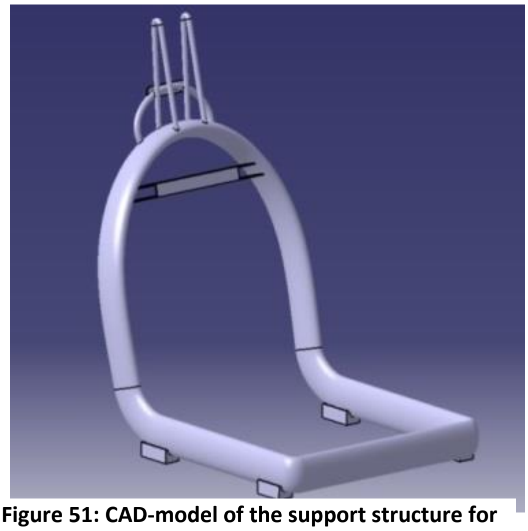


Figure 51: CAD-model of the support structure for the rigid seat concept.

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Appendix 1 - Calculation of load cases for the seat structure

General formulas used

Energy principle (Work performed by slowing down object)

$$W_{net} = \frac{m \times v_{final}^2}{2} - \frac{m \times v_{initial}^2}{2}$$

Average force required

$$F_{avg} \times d_{stop} = \frac{m \times v_{final}^2}{2} - \frac{m \times v_{initial}^2}{2}$$

In case of an impact final velocity, v_final, = 0

$$F_{avg} = \frac{m \times v_{initial}^2}{2 \times d_{stop}}$$

Load case 1: Rearward impact with another car, initial velocity 54 km/h.

$$F_{rear} = \frac{v^2 \times (m_d + m_b)}{2 \times d_{stop}}$$

Where v=7,78 m/s, m_d= 75 kg, m_b= 7,5 kg, d_stop=0,3 m, d_CoG = 0,25 m

And the resulting moment is: $M_{rear} = F_{rear} \times d_{CoG} = 2081\ Nm$

Load case 2: Forward impact with another car, unrestrained cargo, initial velocity 54 km/h.

$$F_{unrest.} = (m_c + m_b) \times a_c \times 9.86$$

Where a_c =28 g, m_c=18 kg, m_b= 7,5 kg, d_CoG = 0,4 m

And the resulting moment is: $M_{unrest.} = F_{unrets.} \times d_{CoG} = 2505\ Nm$

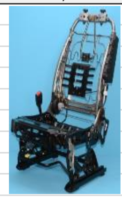
Load case 3: Submarining, initial velocity 54 km/h. (From Req. Spec.)

$$F_{Sub} = 4000\ N$$

Attachment structure (From Req. Spec.)

$$F_{att} = 4000\ N$$

Appendix 2 - Competitive Benchmarking

No.	Need No.	Metric	Importance	Units	Reference	Car A	Car B	Car C	Car D	Car E	Car F	Car G	Car H	Car I	Car J
		Adjustment system													
1	6,7	Length adjustment interval of H-point (X-direction)	5	mm	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)	(+125, -125)
2	7,6	Height adjustment interval of H-point (Z-direction)	5	mm	305(+30,-30)	300(+30,-30)	345(+30,-30)	300(+30,-30)	330(+30,-30)	320(+30,-30)	300(+30,-30)	300(+30,-30)	350(+0,-0)	300(+0,-0)	300(+0,-0)
3	8	Back angle adjustment interval (around Y-axis)	4	degrees	,-25,(+15,-30)	,-25,(+15,-30)	,-25,(+15,-30)	,-25,(+15,-40)	,-25,(+15,-30)	,-25,(+15,-40)	,-25,(+15,-45)	,-25,(+15,-45)	,-25,(+15,-50)	,-25,(+15,-50)	,-25,(+15,-50)
9	9	Time to adjust seat	2	s	3	3	7	7	7	7	5	7	5	7	6
		Base structure													
10	5	Max. allowed deflection from driver weight (Z-direction)	4	mm	1	1	1	1	1	1	1	1	1	1	1
11	5	Max. allowed deflection from submarining (X-direction)	5	mm	4	4	4	4	4	4	4	4	4	4	4
12	5	Max. allowed stress during impact	5	Mpa	700	700	700	700	700	700	700	700	700	700	700
13	1,2	Width	3	mm	495	500	500	495	510	490	480	490	500	500	525
		Back structure													
15	5	Max. allowed deflection during impact (Pos. X-direction)	5	mm	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
16	5	Max. allowed stress during impact	5	Mpa	700	700	700	700	700	700	700	700	700	700	700
17	5	Max. allowed deflection from driver weight (Neg. X-direction)	4	mm	1.2	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
		Has side support	3	Binary	Yes	Yes	Yes	Yes	Yes	Yes	Only on back	Yes	Only on back	Little	Only on back
18	5	Has whiplash protection	4	Binary	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	1,2	Width	3	mm	515	540	530	500	515	485	520	515	535	520	535
		Attachment structure													
21	5	Max. allowed deflection from driver weight (Z-direction)	4	mm	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
22	5	Max allowed stress during impact (any direction)	5	Mpa	700	700	700	700	700	700	700	700	700	700	700
		General													
23	3	Unit manufacturing cost (Frame + Padding)	5	SEK	860	N/a	958	N/a	N/a	834	692	617	N/a	N/a	593
25	4	Potential for reducing overall car weight	4	Subjective	1	1	1	1	1	1	1	1	1	1	1
N/a	4	Frame mass	4	kg	7,85	9,4	11,267	10,59	7,336	7,882	7,983	7,469	8,688	7,431	7,676
N/a	4	Adjusters mass	4	kg	7,8	N/a	5,882	N/a	N/a	5,372	3,905	4,01	N/a	N/a	2,248
N/a	4	Seat mass	5	kg	25,376	24,858	23,422	22,373	20,107	18,472	18,13	18,011	16,701	15,824	14,57
26	4	Total mass / Reference mass	5	%	100	98	92,3	88,2	79,2	72,8	71,4	71	65,8	62,4	57,4
															

Appendix 3 -Reformulation of Criteria

Extraction & abstraction of functional criteria

In target spec.	After extraction & widening	
Base structure	**Constraint**	**Functional requirement**
Support driver when subjected to a static load of 1600 N in Z-direction. Max. allowed deflection = 1 mm.	Rigid when subjected to a load of 1600 N in Z-direction. Max. allowed deflection = 1 mm.	
Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max allowed stress = Yield limit of material.	No yield when subjected to a load of 2100 Nm around recliner axis. Max. allowed stress = Yield limit of material	FR1 = Support driver from below
Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed stress = Yield limit of material.	No yield when subjected to a load of 2500 Nm around (-)recliner axis. Max. allowed stress = Yield limit of material	
Support driver when subjected to a submarining load of 4000 N in X-direction. Max allowed deflection = 5 mm.	Rigid when subjected to a load of 4000 N in X-direction. Max. allowed deflection = 5 mm.	FR2 = Protect driver from submarining
Back structure		
Support driver when subjected to a static load of 1600 N in X-direction. Max. allowed deflection = 2 mm.	Rigid when subjected to a load of 1600 N in X-direction. Max. allowed deflection = 2mm.	
Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max. allowed stress = Yield limit of material.	No yield when subjected to a load of 2100 Nm around recliner axis. Max. allowed stress = Yield limit of material	
Support driver when subjected to a rear impact load of 2100 Nm in X-direction. Max. allowed deflection = 14 mm.	Rigid when subjected to a load of 2100 Nm around recliner axis. Max. allowed deflection = 14mm.	
Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed stress = Yield limit of material.	No yield when subjected to a load of 2500 Nm around (-)recliner axis. Max. allowed stress = Yield limit of material	FR3 = Support driver from the rear
Support driver when subjected to an unrestrained cargo load of 2500 Nm in (-X)-direction. Max allowed deflection = 14 mm.	Rigid when subjected to a load of 2500 Nm around (-)recliner axis. Max. allowed deflection = 14mm.	
Support driver during hard cornering	Has side support	FR4 = Support driver from the side
Protects driver from whiplash during rear impact.	Has neck support	FR5 = Protect driver from whiplash

In target spec.	After extraction & widening	
Base structure	**Constraint**	**Functional requirement**
Attachment structure		
Support driver & seat when subjected to an individual load of 4000 N in Z- and X-direction. Max. allowed stress = Yield limit of material	No yield when subjected to an individual load of 4000 N in Z- and X-direction. Max. allowed stress = Yield limit of material	FR6 = Transfer load to BIW
Support driver & seat when subjected to an individual load of 4000 N in Z-direction. Max. allowed deflection = 0.5 mm	Rigid when subjected to a load of 4000 N in Z-direction. Max. allowed deflection = 0.5 mm.	
Adjustment mechanisms		
Adjust length of H-point in X-direction. Min. interval = 210 mm.	Min. length adjustment interval = 210 mm	FR7 = Adjust length of H-point
Adjust height of H-point in Z-direction. Min interval = 60 mm.	Min. height adjustment interval = 50 mm	FR8 = Adjust height of H-point
Adjust back angle around Y-axis. Min interval = 14 degrees.	Min. back angle adjustment interval = 14 degrees.	FR9 = Adjust angle of back

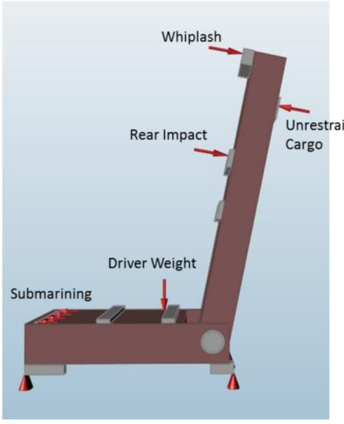
Appendix 4 - Brainstorming ideas

Original Idea List

No	Pict.	Final Prio	Type	Weight saving potential	How easy to realize	Semcon Prio	Description
x		x	x	x	x	x	xxxxx
1			C		2	3	Thin backrest saves vehicle weight
2			C		1	3	Extruded backrest profile, bent to form
3			C		2	2	Lightweight seats for aircraft
4			M		3	2	3D knitted textile stretched over a frame
5			M		2	2	Woven stripe textiles, Mattsson seat
6			M, L		1	2	Tempur mattress onto shell
7			L		4	1	Seat hanged in cross beam
8			F		2	2	Inflatable cushions
9			F		4	1	Conserve energy when sitting down/ jumping arround (energy to adjustment)
10			F		4	1	Seat generating energy when car moves up/down (mechanical charge)
11			F		3	1	Self adjusting cushion
12			M		2	3	Different foam hardness at different locations
13			L		2	Dupl.	Individual seat loafs + fixed back
14			F		3	1	Upper support at B-pillar (rollover protection principle)
15			F		3	1	Pneumatic instead of electrical
16			C		3	3	Spine support plus local side supports (skeleton shaped)
17			C		3	3	Support where body optimal (static + at impact) (heat map)
18			L		3	1	Fixed seat, adjustable steering and pedals
19			M		4	1	Welcro attachments
20			M		2	3	EPP etc foam materials
21			M		4	1	Foamed metals
22			C		2	3	Eggshell
23			C		2	3	Roman arch (apelsinklyftemönster)
24			M		2	3	Sandwich material
25			M		1	3	MuCell
26			C		3	2	Hyphae lamp
27						3	Which sections give best rigidity? Bending and twisting
28			C		3	3	Body shaped support structure + comfort foam
29			L		3	2	Rearward facing support leg to floor
30			F		3	2	Pyrotechnical wire connecting seat and back
31			F		4	1	Pyrotechnical wire connecting back and roof
32			F		3	1	Pyrotechnical wire connecting back and B-pillar
33			F		3	2	Electrical wire activated over 20 kmph between seat and back
34			L		2	3	Fixed armrest creating framework between seat and back
35			C		3	2	Klättermusen rucksack load circumventor
36			L		3	2	Armrest moves / slides (adjust + load catcher) combine with belt receptable?
37			L		4	1	Roller coaster seat with foldable "bygel"
38			M		4	1	Scales onto inflateable load support
39			C		3	3	Belt strap inserted in seat foam to give maximum width
40			C		3	3	Support hip + shoulder, free at arm height
41			L		4	1	Saddle shaped seat cushion
42			M		4	2	"BMW Gina" flexible core, stretcheable skin
43			P, M		1	3	Honda folding lockseaming (falsningsmetod dubbelfals) for different materials
44			C		1	3	Tubular frame
45						3	Manganese (STOLFIG) (magnesiumplåt)
46			L		1	1	Toyota IQ seat layouts
47			L		3	3	Seat back with integrated head rest slideable horizontal. Seat cushion slideable at a
48			F		3	3	Seat cushion slides forward, leaving variable hole backwards.
49			C		2	3	Split seat cushion, forward parts possible to move more.
50			C		2	2	Cushion spring mat as Smart.
51			L		1	3	Seat back with integrated head rest as Volvo.
52			F		1	2	Whiplash, fixed head rest, collapsable back.
53			L		3	3	Recliner 200 mm higher up than today. (Lastbilsflak cylinder)
54			F		1	2	Pneumatic svankstöd as Saab 9-3 convertible.
55			F		3	2	Pneumatic cushion and back fine adjustment from fixed shape.
56			C		1	3	One rail at tunnel, one at floor (old Saab 900 ?)
57			C		3	3	X shaped seat back.
58			C		1	3	Holes in backrest
59			M		2	3	Balsa wood sandwich
60			L		3	1	Backrest mounted on B-pillar
61			L		3	1	Seats joined in tunnel section
62			L		3	2	Recline bar mounted (railed) on side
63			L		3	3	Fixed joined seat and back, movable pads
64			L		2	1	Insert pads for different sized persons
65			M		2	1	Ski boot type cast insert
66			C		3	1	Weight adjusted = always at same height
67			C		4	1	Self carrying seat, net which stretches when loaded
68			C		3	3	Adjustable insert within fixed frame
69			F		2	1	Jump around seat instead of rails, how many steps?
70			F		3	3	Adjust complete seat instead of just the back (angle)
71			F		3	1	Different sit inserts instead of length adjusment
72			F		3	2	One sit insert which can be mounted in different positions instead of length adjustı
73			C		2	Dupl.	Cross rod between back and cushion to take loads
74			F		4	1	JAS wires to arms and legs, pulls in at crash
75			F		3	2	Back pad height adjustable in rack
76			C		3	3	Dynema wire between rigid frames
77			C		3	3	Back plate in middle, attached to wires between plate and frame
78			C		1	3	Frame in HSS steel
79						3	JEC solution drag pressure (Vilken lösning ?)
80			C		1	2	Torsion rod structure seatback
81			C		2	3	Check different crash load cases, check where body support is needed, topology op
82			F		4	1	Electricity into CF, becomes hot
83			L		1	1	Adjustable belt straps in body instead of in seat
84			C		3	3	Cushion as part of body, only adjustable back
85			L		3	3	Support seat high up in tunnel, only deep structure at outer side
86						Dupl.	Tunnel with dent where the rail is positioned high up
87						3	Integrated seat pans + local small adjustment plates
88			C		3	3	Triangle shaped wire bed (seen from side), support at excenter ==> different long b
89						3	Excenter as fixed part of seat back, moves with the back
90			F		3	2	Seat on wire, sprint lock as in gym, (with nails), fasthållning i krock
91			C		4	1	3D printed structure with different materials (modern rottingstol)
92			M		2	2	PUR foam with different densities and hardness
93						3	Which is the optimal shape for tube, casted, sheet type solutions?
94			L		2	3	Mercedes F700 Concep[illegible]chable seat Frankfurt 2007
95			L		3	3	Backrest mounted direct on floor, no recline bar in seatframe
96						3	Mangesium Frame 50% större volym
97						3	Fixed frame and tiltable back with upper support
98						3	Only one rail

Appendix 5 - Concept generation optimization loop

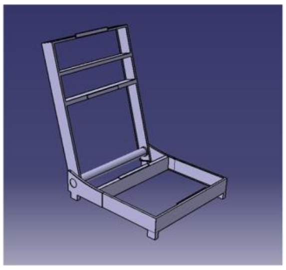
Loadcases



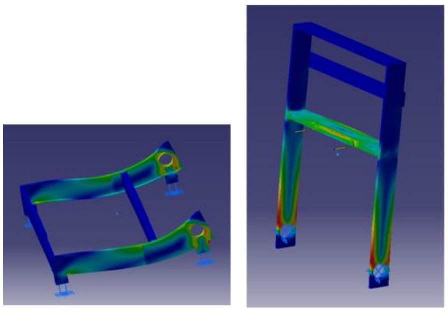
Evaluation of Reference

Needed a reference to compare concepts with

Inspire result using objective: minimize mass



Simplified model, sheet metal 1.5 mm, added 2 mm reinforcement at recliner. Could be optimized with holes as Inspire suggests.

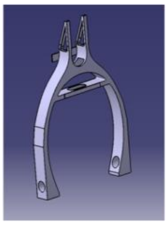


Displacement: 8-12 mm
Stress: 470-570 Mpa
Mass: 7.3 kg

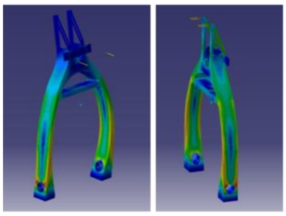
Optimized seat with recliner

Concept design domain entered in Inspire

Inspire: suggests material at outer ends, upper section needs less material



1-1.5 mm sheet metal, open or closed cross section



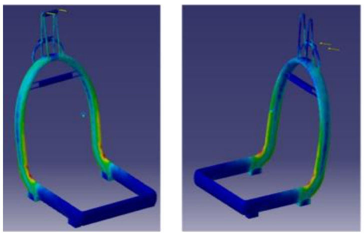
Stiffness increase: 10-20 %
Strength increase: 12-20 %
Mass reduction: 15-20 %

Optimized Quadriceps

Joined solid design domain entered in Inspire

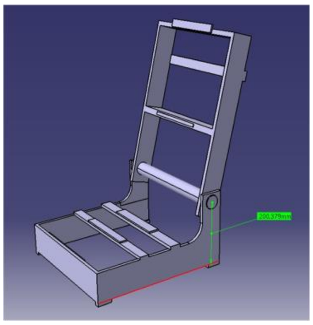
Inspire: Still needs material at outer ends, nothing needed in the center due to the increased stiffness of a one-piece design (Inspire suggests 60 % reduction in mass)

Concept modeled in Catia



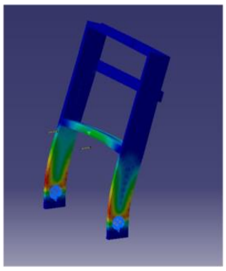
FE-analysis shows potential mass reduction of almost 40 % compared to the reference design, the weight of the removed recliner will add further to this

Moving up Recliner Concept



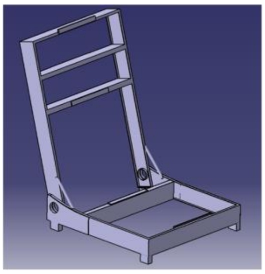
Recliner has been moved 150 mm up from its original position

Analysis of the forces acting on the recliner:

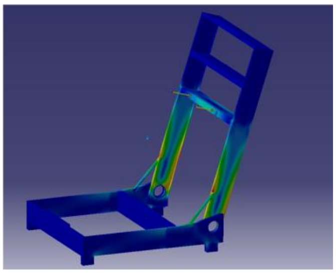


Stiffness increase: 30%
Strength increase: 30-35 %
Mass reduction: Downsizing recliner 30 %

Support strut Concept



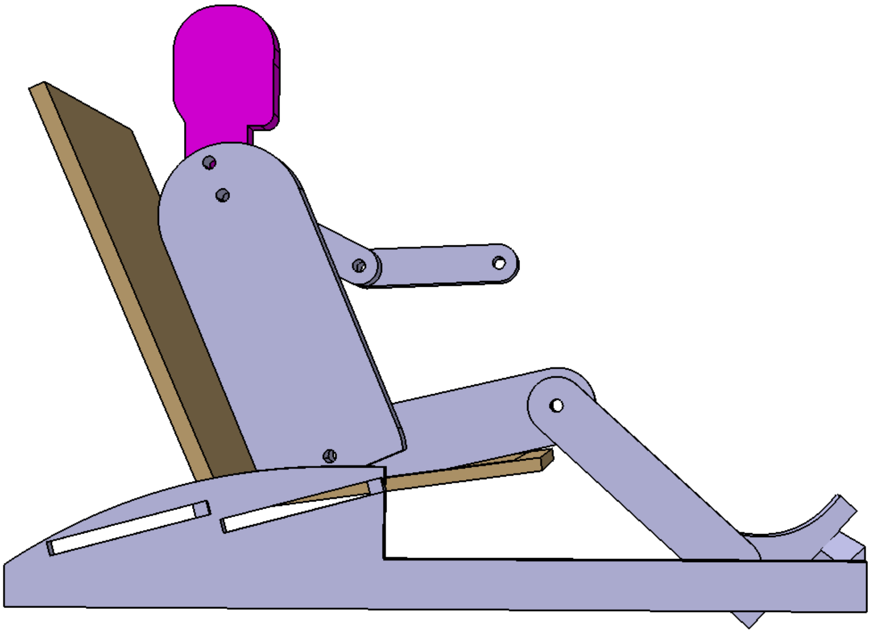
Simplified model, sheet metal 1-1.5 mm, added 2 mm reinforcement at recliner. Reinforcements can be removed due to support strut, which would reduce more mass.



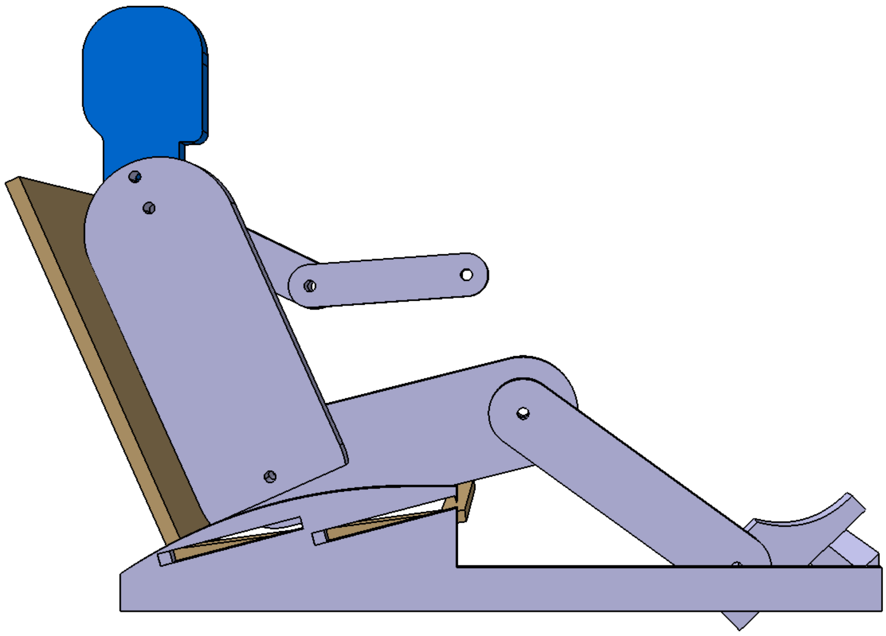
Stiffness increase: 28-30%
Strength increase: 30-35 %
Mass reduction: >20%

The load bearing point has shifted from the recliner to the support strut mounts.

Appendix 6 - Ergonomic analysis of design solution concepts



Early 5% manikin model used during the concept selection phase



Early 95% manikin model used during the concept selection phase

Appendix 7 - Mass analysis of design solution concepts

Mass analysis of adjustment concepts

Reference (Fits w. CAD)	[kg]	Adjustment: Rail+Rail+Recliner		Adjustment: Rail+Rail+No recliner		Adjustment: Rail+Lever+Recliner	
			1		2		3
Head Rest	0,747	Head Rest	0,747	Head Rest	0,747	Head Rest	0,747
Cover	0,198	Cover	0,198	Cover	0,198	Cover	0,198
Padding	0,221	Padding	0,221	Padding	0,221	Padding	0,221
Frame	0,328	Frame	0,328	Frame	0,328	Frame	0,328
Back	5,877	Back	5,877	Back	5,877	Back	5,877
Cover	0,813	Cover	0,813	Cover	0,813	Cover	0,813
Pad	1,11	Pad	1,11	Pad	1,11	Pad	1,11
Frame	3,8	Frame	3,8	Frame	3,8	Frame	3,8
Suspension	0,046	Suspension	0,046	Suspension	0,046	Suspension	0,046
Head Rest Support Bracket	0,035	Head Rest Support Bracket	0,035	Head Rest Support Bracket	0,035	Head Rest Support Bracket	0,035
Bearing Plate	0,073	Bearing Plate	0,073	Bearing Plate	0,073	Bearing Plate	0,073
Cushion	5,756	Cushion	5,756	Cushion	5,756	Cushion	5,756
Cover	0,446	Cover	0,446	Cover	0,446	Cover	0,446
Pad	0,863	Pad	0,863	Pad	0,863	Pad	0,863
Frame	3,5	Frame	3,5	Frame	3,5	Frame	3,5
Suspension	0,341	Suspension	0,341	Suspension	0,341	Suspension	0,341
Garnish	0,606	Garnish	0,606	Garnish	0,606	Garnish	0,606
Side Airbag	0,666	Side Airbag	0,666	Side Airbag	0,666	Side Airbag	0,666
Adjusters	7,041	Adjusters	5,953	Adjusters	3,675	Adjusters	6,641
Lever	0,13	Lever	0,13	Lever	0,13	Lever	0,13
Rails	2	Rails	2	Rails	2	Rails	2
Feet	1,2	Feet	0,8	Feet	0,8	Feet	0,8
Coupling Bar	0,212	Coupling Bar	0,212	Coupling Bar	0,212	Coupling Bar	0,212
Recline system	2,278	Recline system	2,278	Recline system	0	Recline system	2,278
Height	0,688	Height	0	Height	0	Height	0,688
Lumbar	0,533	Lumbar	0,533	Lumbar	0,533	Lumbar	0,533
Support System	0,077	Support System	0,077	Support System	0,077	Support System	0,077
Heating System	0,193	Heating System	0,193	Heating System	0,193	Heating System	0,193
	20,357	Total mass	19,269	Total mass	16,991	Total mass	19,957
		Improvement [%]	5,3	Improvement [%]	16,5	Improvement [%]	2

Adjustment: Rail+Lever+No Recliner	
4	
Head Rest	**0,747**
Cover	0,198
Padding	0,221
Frame	0,328
Back	**5,877**
Cover	0,813
Pad	1,11
Frame	3,8
Suspension	0,046
Head Rest Support Bracket	0,035
Bearing Plate	0,073
Cushion	**5,756**
Cover	0,446
Pad	0,863
Frame	3,5
Suspension	0,341
Garnish	0,606
Side Airbag	**0,666**
Adjusters	**4,363**
Lever	0,13
Rails	2
Feet	0,8
Coupling Bar	0,212
Recline system	0
Height	0,688
Lumbar	0,533
Support System	**0,077**
Heating System	**0,193**
Total mass	17,679
Improvement [%]	13,2

Mass analysis of structural concepts

Reference (Fits w. CAD)	[kg]		Support Structure: Floor+Optimized Ref.Back+Rail-in-rail	
			SS1	
Head Rest	**0,747**		**Head Rest**	**0,747**
Cover	0,198		Cover	0,198
Padding	0,221		Padding	0,221
Frame	0,328		Frame	0
Back	**5,877**		**Back**	**4,742**
Cover	0,813		Cover	0,813
Pad	1,11		Pad	1,11
Frame	3,8		Frame	2,7
Suspension	0,046		Suspension	0,046
Head Rest Support Bracket	0,035		Head Rest Support Bracket	0
Bearing Plate	0,073		Bearing Plate	0,073
Cushion	**5,756**		**Cushion**	**5,456**
Cover	0,446		Cover	0,446
Pad	0,863		Pad	0,863
Frame	3,5		Frame	3,2
Suspension	0,341		Suspension	0,341
Garnish	0,606		Garnish	0,606
Side Airbag	**0,666**		**Side Airbag**	**0,666**
Adjusters	**6,941**		**Adjusters**	**6,941**
Lever	0,13		Lever	0,13
Rails	2		Rails	2
Inner foot	0,5		Inner foot	0,5
Outer foot	0,6		Outer foot	0,6
Coupling Bar	0,212		Coupling Bar	0,212
Recline system	2,278		Recline system	2,278
Height	0,688		Height	0,688
Lumbar	0,533		Lumbar	0,533
Support System	**0,077**		**Support System**	**0,077**
Heating System	**0,193**		**Heating System**	**0,193**
Total mass	**20,257**		**Total mass**	**18,822**
			Improvement over Reference [%]	**7,1**

Support Structure: Tunnel+Optimized Ref.Back+Rail-in-rail		Support Structure: Floor+Fixed+Rail-in-rail		Support Structure: Floor+Supp.Strut+Rail-in-rail		Support Structure: Floor+Move Recliner+Rail-in-rail	
SS2		SS3		SS4		SS5	
Head Rest	**0,747**	**Head Rest**	**0,419**	**Head Rest**	**0,419**	**Head Rest**	**0,419**
Cover	0,198	Cover	0,198	Cover	0,198	Cover	0,198
Padding	0,221	Padding	0,221	Padding	0,221	Padding	0,221
Frame	0	Frame	0	Frame	0	Frame	0
Back	**4,742**	**Back**	**6,642**	**Back**	**4,942**	**Back**	**4,742**
Cover	0,813	Cover	0,813	Cover	0,813	Cover	0,813
Pad	1,11	Pad	1,11	Pad	1,11	Pad	1,11
Frame	2,7	Frame	4,6	Frame	2,9	Frame	2,7
Suspension	0,046	Suspension	0,046	Suspension	0,046	Suspension	0,046
Head Rest Support Bracket	0	Head Rest Support Bracket	0	Head Rest Support Bracket	0	Head Rest Support Bracket	0
Bearing Plate	0,073	Bearing Plate	0,073	Bearing Plate	0,073	Bearing Plate	0,073
Cushion	**5,456**	**Cushion**	**2,256**	**Cushion**	**5,056**	**Cushion**	**5,556**
Cover	0,446	Cover	0,446	Cover	0,446	Cover	0,446
Pad	0,863	Pad	0,863	Pad	0,863	Pad	0,863
Frame	3,2	Frame	0	Frame	2,8	Frame	3,3
Suspension	0,341	Suspension	0,341	Suspension	0,341	Suspension	0,341
Garnish	0,606	Garnish	0,606	Garnish	0,606	Garnish	0,606
Side Airbag	**0,666**	**Side Airbag**	**0,666**	**Side Airbag**	**0,666**	**Side Airbag**	**0,666**
Adjusters	**6,561**	**Adjusters**	**3,975**	**Adjusters**	**5,563**	**Adjusters**	**5,983**
Lever	0,13	Lever	0,13	Lever	0,13	Lever	0,13
Rails	2	Rails	2	Rails	2	Rails	2
Inner foot	0,12	Inner foot	0,5	Inner foot	0,5	Inner foot	0,5
Outer foot	0,6	Outer foot	0,6	Outer foot	0,6	Outer foot	0,6
Coupling Bar	0,212	Coupling Bar	0,212	Coupling Bar	0,212	Coupling Bar	0,212
Recline system	2,278	Recline system	0	Recline system	0,9	Recline system	1,32
Height	0,688	Height	0	Height	0,688	Height	0,688
Lumbar	0,533	Lumbar	0,533	Lumbar	0,533	Lumbar	0,533
Support System	**0,077**	**Support System**	**0,077**	**Support System**	**0,077**	**Support System**	**0,077**
Heating System	**0,193**	**Heating System**	**0,193**	**Heating System**	**0,193**	**Heating System**	**0,193**
Total mass	**18,442**	**Total mass**	**14,228**	**Total mass**	**16,916**	**Total mass**	**17,636**
Improvement over Reference [%]	**9**	**Improvement over Reference [%]**	**29,8**	**Improvement [%]**	**16,5**	**Improvement [%]**	**12,9**

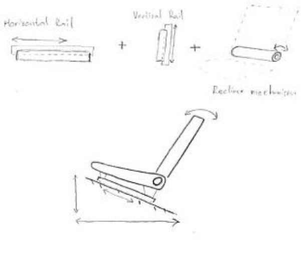
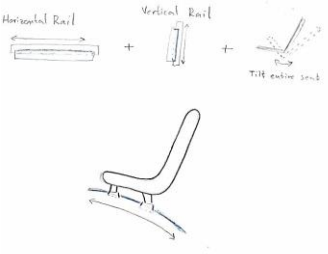
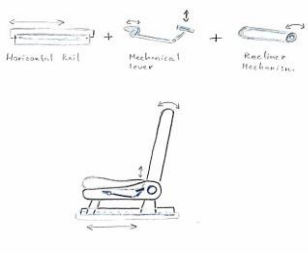
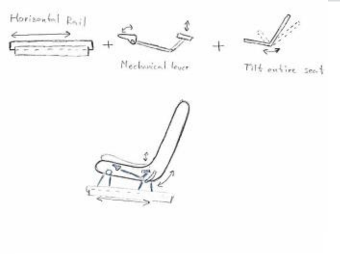
Support Structure: Tunnel+Fixed+Rail-in-rail	
SS6	
Head Rest	**0,419**
Cover	0,198
Padding	0,221
Frame	0
Back	**6,642**
Cover	0,813
Pad	1,11
Frame	4,6
Suspension	0,046
Head Rest Support Bracket	0
Bearing Plate	0,073
Cushion	**2,256**
Cover	0,446
Pad	0,863
Frame	0
Suspension	0,341
Garnish	0,606
Side Airbag	**0,666**
Adjusters	**3,595**
Lever	0,13
Rails	2
Inner foot	0,12
Outer foot	0,6
Coupling Bar	0,212
Recline system	0
Height	0
Lumbar	0,533
Support System	**0,077**
Heating System	**0,193**
Total mass	**13,848**
Improvement [%]	**31,6**

Support Structure: Tunnel+Support Strut+Rail-inRail	
SS7	
Head Rest	**0,419**
Cover	0,198
Padding	0,221
Frame	0
Back	**4,942**
Cover	0,813
Pad	1,11
Frame	2,9
Suspension	0,046
Head Rest Support Bracket	0
Bearing Plate	0,073
Cushion	**5,056**
Cover	0,446
Pad	0,863
Frame	2,8
Suspension	0,341
Garnish	0,606
Side Airbag	**0,666**
Adjusters	**5,183**
Lever	0,13
Rails	2
Inner foot	0,12
Outer foot	0,6
Coupling Bar	0,212
Recline system	0,9
Height	0,688
Lumbar	0,533
Support System	**0,077**
Heating System	**0,193**
Total mass	**16,536**
Improvement [%]	**18,4**

Support Structure: Tunnel+MoveRecliner+Rail-in-Rail	
SS8	
Head Rest	**0,419**
Cover	0,198
Padding	0,221
Frame	0
Back	**4,742**
Cover	0,813
Pad	1,11
Frame	2,7
Suspension	0,046
Head Rest Support Bracket	0
Bearing Plate	0,073
Cushion	**5,556**
Cover	0,446
Pad	0,863
Frame	3,3
Suspension	0,341
Garnish	0,606
Side Airbag	**0,666**
Adjusters	**5,603**
Lever	0,13
Rails	2
Inner foot	0,12
Outer foot	0,6
Coupling Bar	0,212
Recline system	1,32
Height	0,688
Lumbar	0,533
Support System	**0,077**
Heating System	**0,193**
Total mass	**17,256**
Improvement [%]	**14,8**

Appendix 8 - Cost analysis of design solution concepts

Adjustment concepts

	Cost analysis of adjustment concepts			
Unit costs evaluated using processing cost calculations in CES material selection software, using CAD geometry and presumptive assembly as inputs. Materials is assumed steel at 4,2 kr/kg.				
Adjustment type	**AC1. Horizontal rail + Vertical rail + Recliner**	**AC2. Horizontal rail + Vertical rail + Adjust complete seat**	**AC3. Horizontal rail + Lever + Recliner**	**AC4. Horizontal rail + Lever + Adjust complete seat**
Length adjuster	85,35	93,4	85,35	85,35
Height adjuster	0	0	75,98	75,98
Tilt adjuster	100	0	100	40
Total adjuster cost	**185,35**	93,4	261,33	**201,33**

Cost analysis of adjustment concepts

Structural concepts

	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Lowest Cost per unit	Highest cost per unit	Median Cost per unit	Process in CES
Active Head Restraint	1,5	Impact extrusion, tube	1600	28 diameter	1,5	8,75	22,1	15,4	Impact Extrusion
Lower Support Frame	0,5	Sheet	415	52	1,5	5,39	13,1	9,2	Stamping
Back side plate	0,8	Sheet	400	125	1,5	7,07	14,8	10,9	Stamping
Back side plate	0,8	Sheet	400	125	1,5	7,07	14,8	10,9	Stamping
Upper Support Frame	0,16	Sheet	410	35	1,5	3,48	11,2	7,3	Stamping
Mid support frame	0,3	sheet	18	500	1,2	4,27	12	8,135	Sheet (Stamping)
Base side plate	0,6	Sheet	500	125	1,5	5,95	13,6	9,8	Stamping
Base reinforcement plates	0,4	Sheet	215	70	1,5	9,66	25	17,3	Stamping
Base side plate	0,6	Sheet	500	125	1,5	5,95	13,6	9,8	Stamping
Base back plate	0,6	Sheet	440	45	1,5	5,95	13,6	9,8	Stamping
Base front plate	0,6	Sheet	440	45	1,5	5,95	13,6	9,8	Stamping
Neck support bar	0,05	extrusion	50	10	1,5	2,31	15,6	9,0	Impact Extrusion
Neck support bar	0,05	extrusion	50	10	1,5	2,31	15,6	9,0	Impact Extrusion
Head rest frame	0,5	Impact extrusion, tube	850	14 diameter	1,5	4,28	17,6	10,9	Impact Extrusion
Total reference frame	**7,46**					**78,39**	**216,2**	**147,295**	
Height Front Rod	0,5	Impact extrusion, tube	430	12 diameter	1,5	4,28	17,6	10,9	Impact Extrusion
Recliner Rod	0,4	Impact extrusion, tube	440	10 diameter	1,5	3,83	17,1	10,5	Impact Extrusion
Height Back rod	0,5	Impact extrusion, tube	430	13 diameter	1,5	4,28	17,6	10,9	Impact Extrusion
	0,7	Sheet	35 x 12	50 x 12	1,5	30,12	114,36	72,2	Stamping
Legs (4 legs without rails)	0,3	Impact extrusion, tube	490	13 diameter	1,5	3,38	16,7	10,0	Impact Extrusion
Total reference adjusters	**2,4**					**45,89**	**183,36**	**114,625**	
Recliner, Height Adjuster									
Welding						**50**	**80**	**65**	
Painting						60	100	80	
Assembly						5	15	10	
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Total reference structure	**9,86**					**239,28**	**594,56**	**416,92**	

Cost analysis of reference seat frame

					Optimized Reference Sheet metal				
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness	Cost per unit (Min)	Cost per unit (Max)	Mean cost/unit	CES Process
Back Frame	**3,096**								
Back rear panel	**0,36**	**Welded assy.**	**695**	**475**	**1,2**				
Rear panel lower left	0,11	Sheet	405	68		3,2	10,9	7,05	Sheet (Stamping)
Rear panel lower right	0,11	Sheet	405	68		3,2	10,9	7,05	Sheet (Stamping)
Rear panel upper left	0,07	Sheet	132	167		2,97	10,7	6,835	Sheet (Stamping)
Rear panel upper right	0,07	Sheet	132	167		2,97	10,7	6,835	Sheet (Stamping)
Back front Panel	**0,36**	**Welded assy.**	**695**	**475**	**1,2**				
Front panel lower left	0,11	Sheet	405	68		3,2	10,9	7,05	Sheet (Stamping)
Front panel lower right	0,11	Sheet	405	68		3,2	10,9	7,05	Sheet (Stamping)
Front panel upper left	0,07	Sheet	132	167		2,97	10,7	6,835	Sheet (Stamping)
Front panel upper right	0,07	Sheet	132	167		2,97	10,7	6,835	Sheet (Stamping)
Back profile panel	**1,704**	**Welded assy.**			**1,2**				
Profile outer left	0,433	sheet	585	70		5,01	12,7	8,855	Sheet (Stamping)
Profile outer right	0,433	sheet	585	70		5,01	12,7	8,855	Sheet (Stamping)
Profile inner	0,838	sheet	1155	70		7,28	15	11,14	Sheet (Stamping)
Neck support	**0,332**	**Bending/Welding**			**1,2**				
Left bar	0,086	Extrusion	312	10		2,42	15,7	9,06	Extrusion (Impact)
Right bar	0,086	Extrusion	312	10		2,42	15,7	9,06	Extrusion (Impact)
Support plate	0,08	sheet	70	14		3,03	10,7	6,865	Sheet (Stamping)
Support plate	0,08	sheet	70	14		3,03	10,7	6,865	Sheet (Stamping)
Upper Support Frame	0,16	Sheet	18	302	1,2	3,48	11,2	7,34	Sheet (Stamping)
Lower Support Frame	0,18	Sheet	18	310	1,2	3,59	11,3	7,445	Sheet (Stamping)
Base Frame	**3,392**	**Welding**	**515**	**500**					
Left panel	0,9	Sheet	75	515	1,5	7,63	15,3	11,465	Sheet (Stamping)
Right panel	0,9	sheet	75	515	1,5	7,63	15,3	11,465	Sheet (Stamping)
front panel	0,74	sheet	70	500	1,5	6,73	14,4	10,565	Sheet (Stamping)
Rear support frame	0,2	sheet	16	500	1,2	3,71	11,4	7,555	Sheet (Stamping)
Mid support frame	0,3	sheet	18	500	1,2	4,27	12	8,135	Sheet (Stamping)
Reinforcement panel	0,176	sheet	215	75	1,5	3,57	11,3	7,435	Sheet (Stamping)
Reinforcement panel	0,176	sheet	215	75	1,5	3,57	11,3	7,435	Sheet (Stamping)
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost sheet frame	**6,488**					**89,99**	**270,6**	**195,08**	**Different design two halv**
			Stamping	**Impact Extrusion**					**Total investment**
Investment cost			4,5						
					Optimized Reference Cast				
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit		CES Process
Back Frame	**3,234**	**Bolted assembly**							
Back main structure	2,814	Cast	695	475	1,5				
Main part	2,514	Cast	695	475	1,5	26,9	87,8	57,35	High pressure die casting
Reinforcements	0,3	Cast							High pressure die casting
Upper Support Frame	0,2	Sheet	18	302	1,2	3,71	11,4	7,555	Sheet (Stamping)
Lower Support Frame	0,22	Sheet	18	310	1,2	3,82	11,5	7,66	Sheet (Stamping)
Base Frame	**3,2**	**Bolted assembly**	**515**	**500**					
Main U	2,5	Cast	515	500	1,5	28,3	89,2	58,75	High pressure die casting
Reinforcements	0,2	Cast				Included in U	Included in U		High pressure die casting
Rear support frame	0,2	sheet	16	500	1,2	3,71	11,4	7,555	Sheet (Stamping)
Mid support frame	0,3	sheet	18	500	1,2	4,27	12	8,135	Sheet (Stamping)
Reinforcement panel	0,176	Cast	215	75	1,5	Included in U	Included in U		High pressure die casting
Reinforcement panel	0,176	Cast	215	75	1,5	Included in U	Included in U		High pressure die casting
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost cast frame	**6,434**					**70,71**	**223,3**	**147,005**	
			Casting	**Stamping**					**Total investment**
Investment cost (Million)			3	0,4					3,4
					Optimized Reference Tubular				
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit		CES Process
Back Frame	**2,674**	**Welded Assy.**							
Back main structure	1,89	Extrusion	1200	70x35	1,5	10,5	23,8	17,15	Extrusion(Impact)
Neck support	**0,444**	**Bending/Welding**			**1,2**				
Left bar	0,052	Extrusion	312	10		2,27	15,6	8,935	Extrusion(Impact)
Right bar	0,052	Extrusion	312	10		2,27	15,6	8,935	Extrusion(Impact)
Upper Support Frame	0,16	Sheet	18	302	1,2	3,48	11,2	7,34	Sheet(Stamping)
Lower Support Frame	0,18	Sheet	18	310	1,2	3,59	11,3	7,445	Sheet(Stamping)
Base Frame	**3,04**	**Welding**	**515**	**500**					
Left panel	0,9	Sheet	75	515	1,5	7,63	15,3	11,465	Sheet (Stamping)
Right panel	0,9	sheet	75	515	1,5	7,63	15,3	11,465	Sheet (Stamping)
front panel	0,74	sheet	70	500	1,5	6,73	14,4	10,565	Sheet (Stamping)
Rear support frame	0,2	sheet	16	500	1,2	3,71	11,4	7,555	Sheet (Stamping)
Mid support frame	0,3	sheet	18	500	1,2	4,27	12	8,135	Sheet (Stamping)
Reinforcement panel	0,176	sheet	215	75	1,5	3,57	11,3	7,435	Sheet (Stamping)
Reinforcement panel	0,176	sheet	215	75	1,5	3,57	11,3	7,435	Sheet (Stamping)
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost tubular frame	**5,714**					**59,22**	**168,5**	**113,86**	**100 SEK addition for hydroforming if needed**
			Extrusion	**Stamping**					**Total investment**
Investment cost			20	0,4					
Mean for all processes:	6,21					73,31	220,8	151,98	

Cost analysis of optimized reference seat

Support strut sheet metal									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness	Cost per unit	Cost per unit	Median	CES Process
Back Frame	**3,256**								
Back rear panel	**0,36**	**Welded assy.**	**695**	**475**	**1,2**				
Rear panel lower left	0,11	Sheet	405	68	1,2	2,79	9,81	6,3	Stamping
Rear panel lower right	0,11	Sheet	405	68	1,2	2,79	9,81	6,3	Stamping
Rear panel upper left	0,07	Sheet	132	167		2,56	9,59	6,075	Stamping
Rear panel upper right	0,07	Sheet	132	167		2,56	9,59	6,075	Stamping
Back front Panel	**0,36**	**Welded assy.**	**695**	**475**	**1,2**				
Rear panel lower left	0,11	Sheet	405	68		2,79	9,81	6,3	Stamping
Rear panel lower right	0,11	Sheet	405	68		2,79	9,81	6,3	Stamping
Rear panel upper left	0,07	Sheet	132	167		2,56	9,59	6,075	Stamping
Rear panel upper right	0,07	Sheet	132	167		2,56	9,59	6,075	Stamping
Back profile panel	**1,704**	**Welded assy.**			**1,2**				
Profile outer left	0,433	sheet	585	70		4,6	11,6	8,1	Stamping
Profile outer right	0,433	sheet	585	70		4,6	11,6	8,1	Stamping
Profile inner	0,838	sheet	1155	70		6,87	13,9	10,385	Stamping
Neck support	**0,332**	**Bending/Welding**			**1,2**				
Left bar	0,086	Extrusion	312	10		2,34	13	7,67	Impact Extrusion
Right bar	0,086	Extrusion	312	10		2,34	13	7,67	Impact Extrusion
Support plate	0,08	sheet	70	14		2,62	9,64	6,13	Stamping
Support plate	0,08	sheet	70	14		2,62	9,64	6,13	Stamping
Upper Support Frame	0,16	Sheet	18	302	1,2	3,07	10,1	6,585	Stamping
Lower Support Frame	0,18	Sheet	18	310	1,2	3,18	10,2	6,69	Stamping
Mounting bearing for strut	0,08	Cast	40	40	5	11,6	60,4	36,0	High Pressure Die Casting
Mounting bearing for strut	0,08	Cast	40	40	5	11,6	60,4	36,0	High Pressure Die Casting
Base Frame	**3,37**	**Welding**	**515**	**500**					
Left panel	0,9	Sheet	75	515	1,5	7,22	14,3	10,8	Stamping
Right panel	0,9	sheet	75	515	1,5	7,22	14,3	10,8	Stamping
front panel	0,74	sheet	70	500	1,5	6,32	13,4	9,9	Stamping
Rear support frame	0,2	sheet	16	500	1,2	3,29	10,3	6,8	Stamping
Mid support frame	0,3	sheet	18	500	1,2	3,86	10,9	7,4	Stamping
Mounting track for strut	0,1	Cast	60	15	5	11,7	60,5	36,1	High Pressure Die Casting
Mounting track for strut	0,1	Cast	60	15	5	11,7	60,5	36,1	High Pressure Die Casting
Support strut	0,065	Extrusion	250	10	1,2	2,25	12,9	7,6	Impact Extrusion
Support strut	0,065	Extrusion	250	10	1,2	2,25	12,9	7,6	Impact Extrusion
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Total sheet frame	**6,626**					**132,65**	**511,08**	**321,865**	
			Stamping	**Impact Extrusion**	**Casting**				**Total investment**
Investment cost			3,5		0,4				

Support strut Cast									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	Median	CES Process
Back Frame	**3,394**	**Bolted assembly**							
Back main structure	**2,814**	**Cast**	**695**	**475**	**1,5**				
Main part	2,514	Cast	695	475	1,5	25,9	74,8	50,4	High Pressure Die Casting
Reinforcements	0,3	Cast							
Upper Support Frame	0,2	Sheet	18	302	1,2	3,29	10,3	6,795	Stamping
Lower Support Frame	0,22	Sheet	18	310	1,2	3,29	10,3	6,795	Stamping
Mounting bearing for strut	0,08	Cast	40	40	5	11,6	60,4	36,0	High Pressure Die Casting
Mounting bearing for strut	0,08	Cast	40	40	5	11,6	60,4	36,0	High Pressure Die Casting
Base	**3,51**	**Bolted assembly**	**515**	**500**					
Main U	2,5	Cast	515	500	1,5	25,3	74,2	49,8	High Pressure Die Casting
Reinforcements	0,2	Cast							
Rear support frame	0,2	sheet	16	500	1,2	3,29	10,3	6,8	Stamping
Mid support frame	0,3	sheet	18	500	1,2	3,86	10,9	7,4	Stamping
Mounting track for strut	0,09	Cast	60	15	5	11,6	60,5	36,1	High Pressure Die Casting
Mounting track for strut	0,09	Cast	60	15	5	11,6	60,5	36,1	High Pressure Die Casting
Support strut	0,065	Extrusion	250	10	1,2	2,25	12,9	7,6	Impact Extrusion
Support strut	0,065	Extrusion	250	10	1,2	2,25	12,9	7,6	Impact Extrusion
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Total cast frame	**6,904**					**115,83**	**458,4**	**287,115**	
			Casting	**Impact Extrusion**	**Stamping**				**Total investment**
Investment cost			3,4		0,8				

Support strut tubular									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	Median	CES Process
Back Frame	**2,834**	**Welded Assy.**							
Back main structure	**1,89**	**Extrusion**	**1200**	**70x35**	**1,5**	**10,4**	**21,1**	**15,75**	**Impact Extrusion**
Neck support	**0,444**	**Bending/Welding**			**1,2**				
Left bar	0,052	Extrusion	312	10		2,19	12,9	7,5	Impact Extrusion
Right bar	0,052	Extrusion	312	10		2,19	12,9	7,5	Impact Extrusion
Upper Support Frame	0,16	Sheet	18	302	1,2	3,07	10,1	6,585	Stamping
Lower Support Frame	0,18	Sheet	18	310	1,2	3,18	10,2	6,69	Stamping
Mounting bearing for strut	0,08	Cast	40	40	5	11,6	60,4	36,0	High Pressure Die Casting
Mounting bearing for strut	0,08	Cast	40	40	5	11,6	60,4	36,0	High Pressure Die Casting
Base	**3,35**	**Welding**	**515**	**500**					
Left panel	0,9	Sheet	75	515	1,5	7,22	14,3	10,8	Stamping
Right panel	0,9	sheet	75	515	1,5	7,22	14,3	10,8	Stamping
front panel	0,74	sheet	70	500	1,5	6,32	13,4	9,9	Stamping
Rear support frame	0,2	sheet	16	500	1,2	3,29	10,3	6,8	Stamping
Mid support frame	0,3	sheet	18	500	1,2	3,86	10,9	7,4	Stamping
Mounting track for strut	0,09	Cast	60	15	5	11,6	60,5	36,1	High Pressure Die Casting
Mounting track for strut	0,09	Cast	60	15	5	11,6	60,5	36,1	High Pressure Die Casting
Support strut	0,065	Extrusion	250	10	1,2	2,25	12,9	7,6	Impact Extrusion
Support strut	0,065	Extrusion	250	10	1,2	2,25	12,9	7,6	Impact Extrusion
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Total tubular frame	**6,184**					**99,84**	**398**	**248,92**	
Mean for all processes:	**6,57**					**116,11**	**455,83**	**285,97**	

Cost analysis of support strut

	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness	Cost per unit	Cost per unit	Median	CES Process
Heightened Recliner Sheet metal									
Back Frame	**2,578**								
Back rear panel	**0,32**	**Welded assy.**	**695**	**475**	**1,2**				
Rear panel lower left	0,09	Sheet	255	68	1,2	2,68	9,7	6,2	Stamping
Rear panel lower right	0,09	Sheet	255	68		2,68	9,7	6,2	Stamping
Rear panel upper left	0,07	Sheet	132	167		2,56	9,59	6,1	Stamping
Rear panel upper right	0,07	Sheet	132	167		2,56	9,59	6,1	Stamping
Back front Panel	**0,32**	**Welded assy.**	**695**	**475**	**1,2**				
Rear panel lower left	0,09	Sheet	405	68		2,68	9,7	6,2	Stamping
Rear panel lower right	0,09	Sheet	405	68		2,68	9,7	6,2	Stamping
Rear panel upper left	0,07	Sheet	132	167		2,56	9,59	6,1	Stamping
Rear panel upper right	0,07	Sheet	132	167		2,56	9,59	6,1	Stamping
Back profile panel	**1,266**	**Welded assy.**			**1,2**				
Profile outer left	0,323	sheet	585	70		3,99	11	7,5	Stamping
Profile outer right	0,323	sheet	585	70		3,99	11	7,5	Stamping
Profile inner	0,62	sheet	1155	70		5,65	12,7	9,2	Stamping
Neck support	**0,332**	**Bending/Welding**			**1,2**				
Left bar	0,086	Extrusion	312	10		2,34	13	7,7	Impact Extrusion
Right bar	0,086	Extrusion	312	10		2,34	13	7,7	Impact Extrusion
Support plate	0,08	sheet	70	14		2,62	9,64	6,1	Stamping
Support plate	0,08	sheet	70	14		2,62	9,64	6,1	Stamping
Upper Support Frame	0,16	Sheet	18	302	1,2	3,07	10,1	6,585	Stamping
Lower Support Frame	0,18	Sheet	18	310	1,2	3,18	10,2	6,69	Stamping
Base	**3,3**	**Welding**	**515**	**500**					
Left panel	0,9	Sheet	75	515	1,5	7,22	14,3	10,8	Stamping
Right panel	0,9	sheet	75	515	1,5	7,22	14,3	10,8	Stamping
front panel	0,74	sheet	70	500	1,5	6,32	13,4	9,9	Stamping
Rear support frame	0,2	sheet	16	500	1,2	3,29	10,3	6,8	Stamping
Mid support frame	0,3	sheet	18	500	1,2	3,86	10,9	7,4	Stamping
Recliner mount	0,13	sheet	100	120	1,6	2,9	9,93	6,4	Stamping
Recliner mount	0,13	sheet	100	120	1,6	2,9	9,93	6,4	Stamping
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost: sheet frame	**5,878**					**84,47**	**260,5**	**172,485**	
			Stamping	**Impact Extrusion**					**Total investment**
Investment cost			4,5						

	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	Median	CES Process
Heigthened recliner cast									
Back Frame	**2,79**	**Bolted assembly**							
Back main structure	**2,37**	**Cast**	**695**	**475**	**1,5**				
Main part	2,12	Cast	695	475	1,5	23,6	72,5	48,1	High Pressure Die Casting
Reinforcements	0,25	Cast							
Upper Support Frame	0,2	Sheet	18	302	1,2	3,29	10,3	6,795	Stamping
Lower Support Frame	0,22	Sheet	18	310	1,2	3,29	10,3	6,795	Stamping
Base	**3,4**	**Bolted assembly**	**515**	**500**					
Main U	2,76	Cast	515	500	1,5	26,9	75,8	51,4	High Pressure Die Casting
Reinforcements	0,24	Cast							
Rear support frame	0,2	sheet	16	500	1,2	3,29	10,3	6,8	Stamping
Mid support frame	0,2	sheet	18	500	1,2	3,29	10,3	6,8	Stamping
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost: cast frame	**6,19**					**63,66**	**189,5**	**126,58**	
			Casting	**Stamping**					**Total investment**
Investment cost			3	0,4					

	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	Median	CES Process
Heightened Recliner Tubular									
Back Frame	**2,224**	**Welded Assy.**							
Back main structure	1,44	Extrusion	1200	70x35	1,5	8,4	19,1	13,75	Impact Extrusion
Neck support	**0,444**	**Bending/Welding**			**1,2**				
Left bar	0,052	Extrusion	312	10		2,19	12,9	7,5	Impact Extrusion
Right bar	0,052	Extrusion	312	10		2,19	12,9	7,5	Impact Extrusion
Upper Support Frame	0,16	Sheet	18	302	1,2	3,07	10,1	6,585	Stamping
Lower Support Frame	0,18	Sheet	18	310	1,2	3,18	10,2	6,69	Stamping
Base	**3,3**	**Welding**	**515**	**500**					
Left panel	0,9	Sheet	75	515	1,5	7,22	14,3	10,8	Stamping
Right panel	0,9	sheet	75	515	1,5	7,22	14,3	10,8	Stamping
front panel	0,74	sheet	70	500	1,5	6,32	13,4	9,9	Stamping
Rear support frame	0,2	sheet	16	500	1,2	3,29	10,3	6,8	Stamping
Mid support frame	0,3	sheet	18	500	1,2	3,86	10,9	7,4	Stamping
Recliner mount	0,13	sheet	100	120	1,6	2,9	9,93	6,4	Stamping
Recliner mount	0,13	sheet	100	120	1,6	2,9	9,93	6,4	Stamping
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost: tubular frame	**5,524**					**52,74**	**148,26**	**100,5**	
			Impact Extrusion	**Stamping**					**Total investment**
Investment cost			20	0,4					
Mean for all processes:	5,86					66,96	199,42	133,19	

Cost analysis of heightened recliner

Joined frame Sheet metal									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness	Cost per unit	Cost per unit	Median	CES Process
Main structure		**Welded assembly**							
Left base beam	0,8	Sheet	370	65	1,2	6,11	14,2	10,155	Roll forming
Right base beam	0,8	Sheet	370	65	1,2	6,11	14,2	10,155	Roll forming
Front Beam	0,73	Sheet	474	65	1,2	5,79	13,9	9,845	Roll forming
Upper beam	1,7	Sheet	1200	65	1,2	13,7	37,6	25,65	Roll forming
Upper structure		**Welded assembly**							
Left bar	0,052	Extrusion	312	10	1,2	2,27	15,6	8,935	Extrusion(Impact)
Right bar	0,052	Extrusion	312	10	1,2	2,27	15,6	8,935	Extrusion(Impact)
Rear bar	0,05	Extrusion	300	10	1,2	2,26	15,6	8,93	Impact
Upper Support Frame	0,16	Sheet	18	302	1,2	3,48	11,2	7,34	Sheet (Stamping)
Lower Support Frame	0,18	Sheet	18	310	1,2	3,59	11,3	7,445	Sheet (Stamping)
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost: sheet frame	**4,524**					**45,58**	**149,2**	**97,39**	
			Stamping	Impact Extrusion					Total investment
Investment cost			3,9						
Joined frame cast (Incompatible)									
Joined frame Tubular									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	CES Process	
Main structure		**Welded assembly**							
Main Beam	3,19	Extrusion	1940	65	1,2	16,3	29,7	23	Extrusion (Impact)
Front Beam	0,72	Extrusion	474	65	1,2	5,26	18,6	11,93	Extrusion (Impact)
Upper structure		**Welded assembly**							
Left bar	0,052	Extrusion	312	10	1,2	2,27	15,6	8,935	Extrusion(Impact)
Right bar	0,052	Extrusion	312	10	1,2	2,27	15,6	8,935	Extrusion(Impact)
Rear bar	0,05	Extrusion	300	10	1,2	2,26	15,6	8,93	Extrusion(Impact)
Upper Support Frame	0,16	Sheet	18	302	1,2	3,48	11,2	7,34	Sheet (Stamping)
Lower Support Frame	0,18	Sheet	18	310	1,2	3,59	11,3	7,445	Sheet (Stamping)
	Total mass					Min cost/unit	Max cost/unit	Mean cost/unit	
Unit cost: tubular frame	**4,404**					**35,43**	**117,6**	**76,515**	
			Stamping	Impact Extrusion					Total investment
Investment cost			0,4	20					

Cost analysis of fixed seat structure

Optimized reference mounts							
	Weight [kg]	Size [mm]	Size [mm]	Lowest Cost per unit	Highest cost per unit	Median Cost per unit	Process in CES
Sheet	0,4	470	125	9,66	25	17,3	Stamping
Cast	0,4	470	125	28,4	150,2	89,3	High Pressure Die
Average Cost				**19,03**	**87,6**	**53,315**	
Tunnel Support x2							
	Weight [kg]	Size [mm]	Size [mm]	Lowest Cost per unit	Highest cost per unit	Median Cost per unit	Process in CES
Extrusion + Sheet	0,15	45	60	5,42	32	18,7	Impact Extrusion
Cast	0,15	45	60	25,8	147,6	86,7	High Pressure Die
Average Cost				**15,61**	**89,8**	**52,705**	
Tunnel Support with wheel x2							
	Weight [kg]	Size [mm]	Size [mm]	Lowest Cost per unit	Highest cost per unit	Median Cost per unit	Process in CES
Extrusion + Sheet	0,15	45	60	5,42	32	18,7	Impact Extrusion
Cast	0,15	45	60	25,8	147,6	86,7	High Pressure Die
Average Cost				**15,61**	**89,8**	**52,705**	

Cost analysis of the mounts

Horizontal rail									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	Median	CES Process
Left side		**Bolted assembly**							
Outer track	0,65	Extrusion	600		1,5	5,24	18,6	11,92	
Inner track	0,35	Extrusion	600		1,5	3,9	17,2	10,55	
Right side		**Bolted assembly**							
Outer track	0,65	Extrusion	600		1,5	5,24	18,6	11,92	
Inner track	0,35	Extrusion	600		1,5	3,9	17,2	10,55	
Adjustment handle	0,2	Extrusion	300		1,2	3,11	16,4	9,755	
Locking mechanism	?	**?**	5 parts	?	?	13,35	47,95	30,65	?
Unit cost: Horizontal adjuster						**34,74**	**135,95**	**85,345**	

Horizontal rail + Vertical Rail (Quadriceps)									
	Weight [kg]	Type of process	Length [mm]	Width [mm]	Thickness [mm]	Cost per unit	Cost per unit	Median	CES Process
Left side		**Bolted assembly**							
Outer track	0,6	Extrusion			1,5	5,24	18,6	11,92	
Inner track	0,3	Extrusion			1,5	3,9	17,2	10,55	
Right side		**Bolted assembly**							
Outer track	0,6	Extrusion			1,5	5,24	18,6	11,92	
Inner track	0,3	Extrusion			1,5	3,9	17,2	10,55	
Adjuster spring	0,15							8	
Adjustment handle	0,2	Extrusion	300		1,2	3,11	16,4	9,755	
Locking mechanism	?	**?**	5 parts	?	?	13,35	47,95	30,65	?
Unit cost: Quadriceps adjuster						**34,74**	**135,95**	**93,345**	

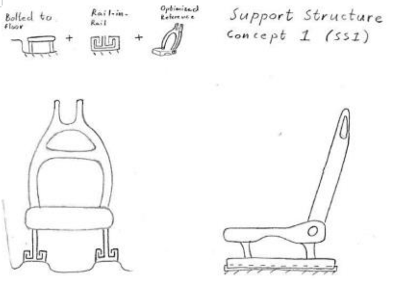
Height adjuster lever									
Number of parts	Weight [kg]	Size [mm]	Lowest Cost per unit	Highest cost per unit	Median Cost per unit	Process in CES			
Mechanical parts (lever)	1,48	80*80	32,22	119,73	75,975	Stamping+ Impact Extrusion+ Plastic			Note: Additional cost for height mechanism
Mechanism		?	?	?	?	?			
Unit cost: Height adjuster			**32,22**	**119,73**	**75,975**				

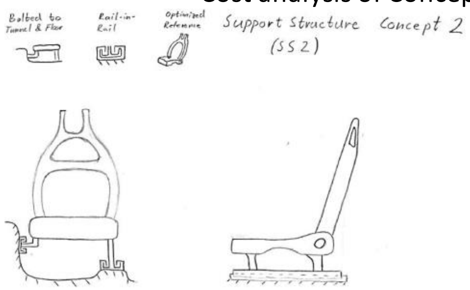
Recliner									
Recliner Rod	0,4	Impact extrusion,	440	10 diameter	1,5	3,83	17,1	10,5	Impact Extrusion
Mechanism	?	?	?	?	?	?	?	?	

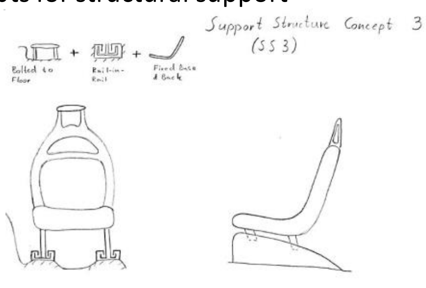
Cost analysis of the adjusters

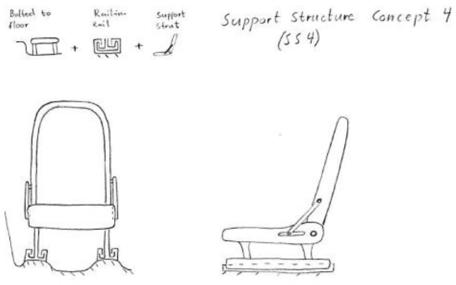
Cost analysis of Concepts for structural support

Unit costs evaluated using processing cost calculations in CES material selection software, using CAD geometry and presumptive assembly as inputs. Materials is assumed steel at 4,2 kr/kg.

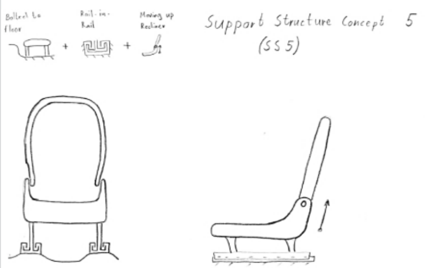


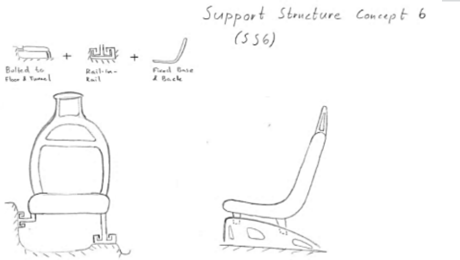


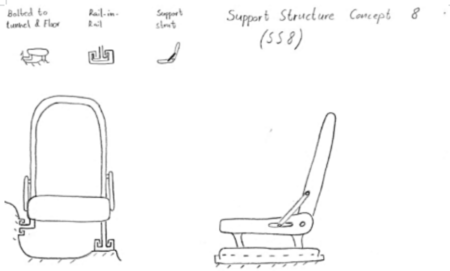


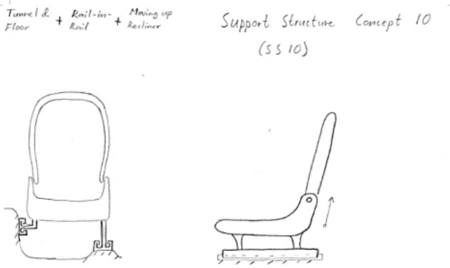


Manufacturing process	SS1. Floor + Optimized Ref.Back + Rail-in-rail	SS2. Tunnel + Optimized Ref.Back + Rail-in-rail	SS3. Floor + Fixed + Rail-in-rail	SS4. Floor + Supp.Strut + Rail-in-rail
Stamping tool cost (M Sek)	4,5	4,5	3,9	4,9
Stamping unit cost (Sek)	**230**	**231**	**134**	**357**
Casting tool cost (M Sek)	3,4	3,4	N/a	4,6
Casting unit cost (Sek)	**182**	**183**	N/a	**322**
Extrusion tool cost (M Sek)	20	20	20	20
Extrusion unit cost (Sek)	**149**	**150**	**113**	**284**
Mean tool cost (M Sek)	9,3	9,3	11,95	9,83
Mean unit cost (Sek)	187	188	123,5	321
			Lowest cost!	Highest cost!
Summary of mass analysis:	**Total mass: 18,822**	**Total mass: 18,44**	**Total mass: 14,23**	**Total mass: 16,916**
	Improvement over Reference [%]: 7,1	**Improvement over Reference [%]: 9**	**Improvement over Reference [%]: 29,8**	**Improvement over Reference [%]: 16,5**









SS5. Floor + Move Recliner + Rail-in-rail	SS6. Tunnel + Fixed + Rail-in-rail	SS8. Tunnel + Support Strut + Rail-in-Rail	SS10. Tunnel + Move Recliner + Rail-in-Rail
4,5	3,9	4,9	4,5
208	**135**	**358**	**209**
3,4	N/a	4,6	3,4
162	N/a	**323**	**163**
20	20	20	20
136	**114**	**285**	**137**
9,3	11,95	9,83	9,3
168,67	124,5	322	169,67
Total mass: 17,64	**Total mass: 13,85**	**Total mass: 16,54**	**Total mass: 16,96**
Improvement over Reference [%]: 12,9	**Improvement over Reference [%]: 31,6**	**Improvement over Reference [%]: 18,4**	**Improvement over Reference [%]: 16,3**

Appendix 9 - Weighted screening criteria matrices

Weigth Decision Matrix 1 (20 000 unit/yr.)

All basic requirements are already fulfilled	Lightweight	Investment Cost	Reduce Unit Cost	Manufactura bility	Bonus Features	Changes to interior architecture	Adoption complexity to car	Quality	Easy to operate	Ind. Sum	Ind. Sum/Tot. Sum	Final weight
Lightweight	-	1	0,5	1	0	1	1	0	0	4,5	0,125	7
Investment Cost	0	-	0,5	1	1	1	1	1	1	6,5	0,181	10
Reduce Unit Cost	0,5	0,5	-	1	1	1	1	0	1	6	0,167	9
Manufacturability	0	0	0	-	0	1	1	0	0	2	0,056	3
Bonus Features	1	0	0	1	-	1	1	0	0	4	0,111	6
Changes to interior architecture	0	0	0	0	0	-	0	0	0	0	0,000	0
Adoption complexity to car	0	0	0	0	0	1	-	0	0	1	0,028	2
Quality	1	0	1	1	1	1	1	-	0	6	0,167	9
Easy to operate	1	0	0	1	1	1	1	1	-	6	0,167	9
									Tot. Sum	36	1	

Weigth Decision Matrix 2 (100 000 units/yr.)

All basic requirements are already fulfilled	Lightweight	Investment Cost	Reduce Unit Cost	Manufactury complexity	Bonus Features	Changes to interior architecture	Adoption complexity to car	Quality	Easy to operate	Ind. Sum	Ind. Sum/Tot. Sum	Final weight
Lightweight	-	1	0,5	0,5	1	1	1	0	0	5	0,139	7
Investment Cost	0	-	0	1	1	1	1	0	1	5	0,139	7
Reduce Unit Cost	0,5	1	-	1	1	1	1	1	1	7,5	0,208	10
Manufactury complexity	0,5	0	0	-	0	1	1	0	0	2,5	0,069	3
Bonus Features	0	0	0	1	-	1	1	0	0	3	0,083	4
Changes to interior architecture	0	0	0	0	0	-	0	0	0	0	0,000	0
Adoption complexity to car	0	0	0	0	0	1	-	0	0	1	0,028	1
Quality	1	1	0	1	1	1	1	-	0	6	0,167	8
Easy to operate	1	0	0	1	1	1	1	1	-	6	0,167	8
									Tot. Sum	36	1	

Weigth Decision Matrix 3 (500 000 units/yr.)

All basic requirements are already fulfilled	Lightweight	Investment Cost	Reduce Unit Cost	Manufactura bility	Bonus Features	Changes to interior architecture	Adoption complexity to car	Quality	Easy to operate	Ind. Sum	Ind. Sum/Tot. Sum	Final weight
Lightweight	-	1	0,5	0,5	1	1	1	0	0	5	0,139	7
Investment Cost	0	-	0	1	1	1	1	0	1	5	0,139	7
Reduce Unit Cost	0,5	1	-	1	1	1	1	1	1	7,5	0,208	10
Manufacturability	0,5	0	0	-	0	1	1	0	0	2,5	0,069	3
Bonus Features	0	0	0	1	-	1	1	0	0	3	0,083	4
Changes to interior architecture	0	0	0	0	0	-	0	0	0	0	0,000	0
Adoption complexity to car	0	0	0	0	0	1	-	0	0	1	0,028	1
Quality	1	1	0	1	1	1	1	-	0	6	0,167	8
Easy to operate	1	0	0	1	1	1	1	1	-	6	0,167	8
									Tot. Sum	36	1	

Three different weight decision matrices depending on production rate.

Appendix 10 - Material Selection

Parameters	*Reference (Steel)*	Low alloy steel	Low alloy steel (High)	Low Carbon steel	Wrought magnesium	Cast Magnesium	Cast Alu
Minimum wall thickness (mm)	*1,5*	1,02	0,8	1,7	3,55	3,55	2,91
Max. Deflection (11,2 mm) or 14 mm	*11,2*	8	13	6,3	13,95	13,95	9,7
Max. V.M. Stress (0,95*Sigma) Mpa	*572*	600	750	300	138	138	170
Material cost (SEK)	*4*	4,2	5	4	26	26	16,3
Minimum mass (kg)	*3,8*	2,7	2,2	4,24	1,78	1,89	2,37
Unit material cost (SEK)	*15,2*	11,34	11	16,96	46,28	49,14	38,631
Added cost per kg saved mass (SEK / kg)		0	-0,68	Non saved	37,98	46,67	82,7
Yield strength (Mpa)		600	1200	300	240	140	170
Youngs modulus (Gpa)		210	214	210	45	45	78
Density (kg/m3)		7860	7860	7860	1700	1800	2700
Wall thickness is considered a variable							
Deflection is a limiting constraint							
Stress is a constraint							
Minimum mass is the optimization objective							
Using Catia Engineering optimizer							

First part of the results from the material optimization performed on the concept back frame, metals.

PF, glassed filled	PP(30% LGF)	PA66(30% LGF)	PA66(60% LGF)	PA6(30% CF)	CFRP	Epoxy SMC CF	PP(30LGF) + CFRP	
16	Solid	solid		8	1,6	2,13		Minimum wall thickness (mm)
5,96	46	39	39	17	12	9,9	14	Max. Deflection (11,2 mm) or 14 mm
57	98	98	120	119	240	239	400	Max. V.M. Stress (0,95*Sigma) Mpa
17	23	35	30	84	265	163		Material cost (SEK)
8	6	7	9	2,62	0,8	1,03	1,954	**Minimum mass (kg)**
136	138	245	270	220,08	212	167,89	106,41	Unit material cost (SEK)
No saved mass	No saved mass	No saved mass	No saved mass	2609,25	105,61	93,74	127,44	
40	100	120	190	200	800	240		Yield strength (Mpa)
16,5	6	7	7	20	110	100		Youngs modulus (Gpa)
1600	1100	1370	1670	1280	1550	1550		Density (kg/m3)

Second part of the material optimization results, Polymers and Composites.

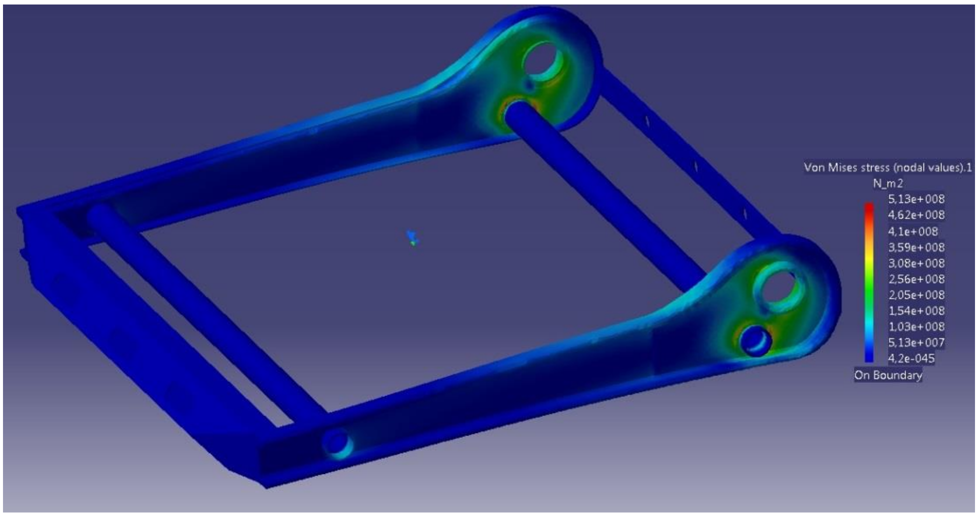
Appendix 11 - Structural analysis of reference design

In order to evaluate the structural integrity and thereby the safety performance of the reference design, CATIA's FE module has been used. The in-data for this analysis has been the load cases described in the *Reference Seat analysis* section; these in-data are as follows:

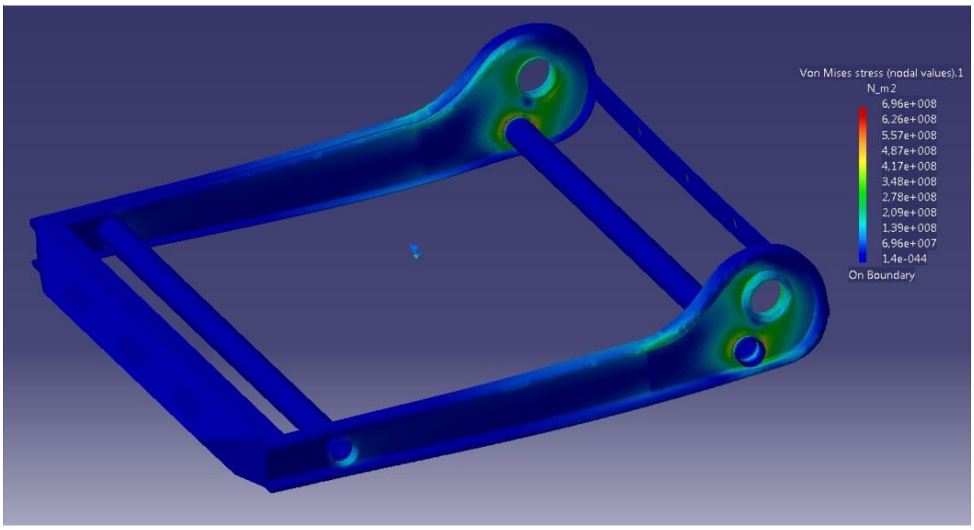
- Moment caused by rearward impact, initial velocity 54 km/h = 2100 Nm
- Moment caused by unrestrained cargo impact, initial velocity 54 km/h = 2500 Nm
- Submarining force = 4000 N
- Static deflection force = 1600 N
- Forces acting on the attachment structure = 4000 N

Together with these load cases the material properties for Low alloy steel and Magnesium, taken from CES EduPack 2012, has been used as well. For each load case the relevant outcome has been measured and documented in a spreadsheet format. The spreadsheet also highlights the values that limit further mass reduction in each load case, as determined by material properties and the target specifications. The most important limiting parameters are maximum von Mises stress and deflection. The FE-results from each load case are presented in this section.

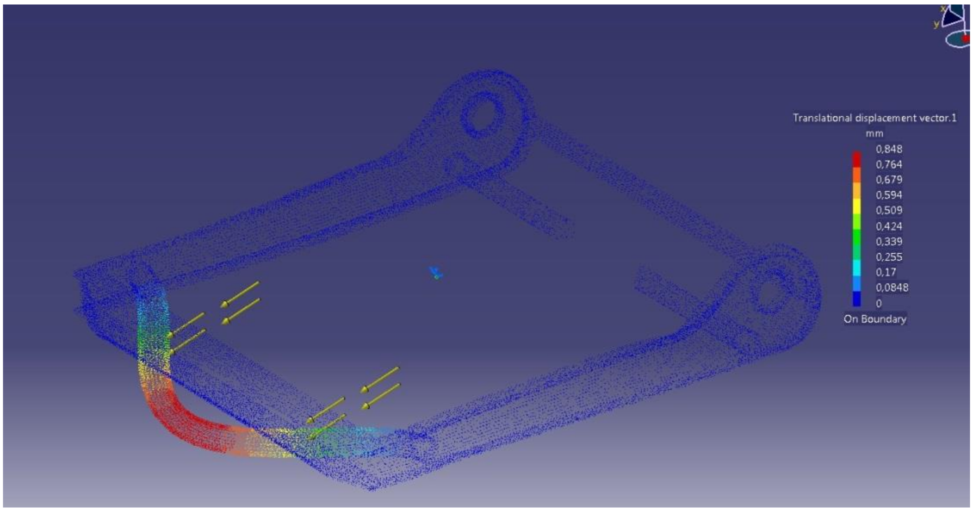
Reference base structure



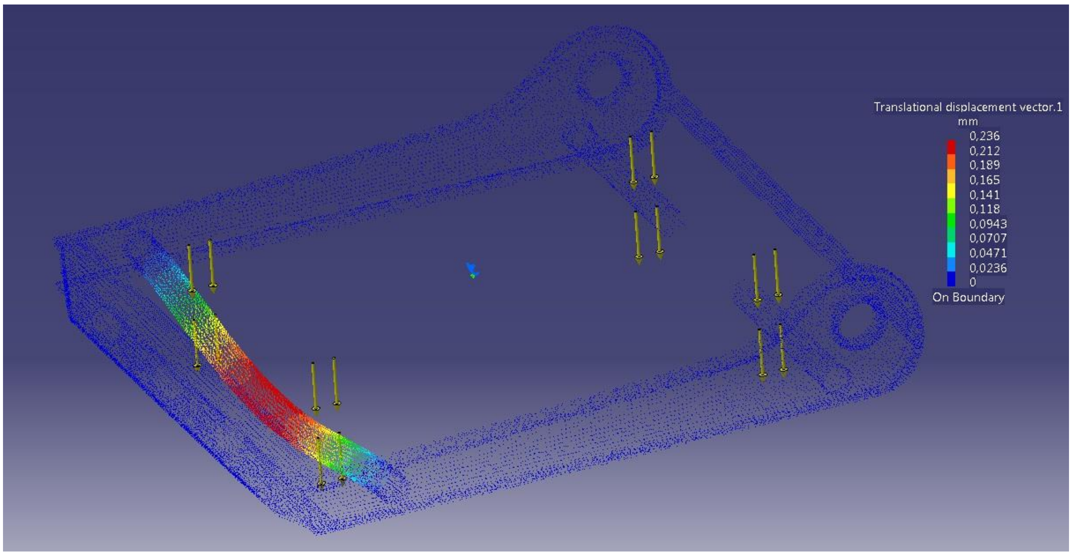
Max. stress when the base is subjected to an unrestrained cargo moment of 2500 Nm



Max. stress when the reference base is subjected to a rear impact moment of 2100 Nm.



Max deflection when the base is subjected to a submarining force of 4000 N.

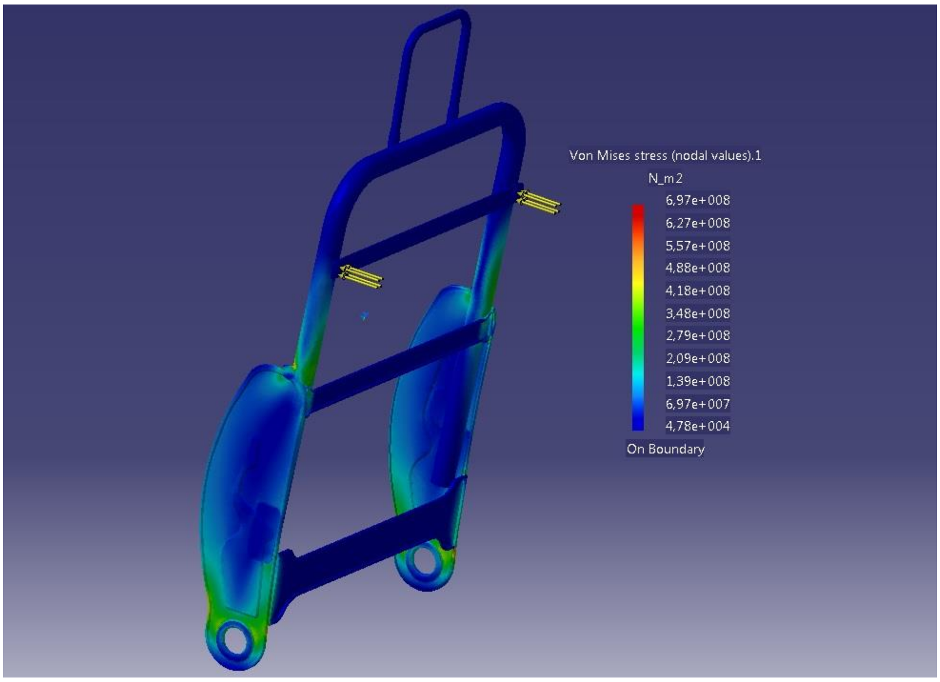


Max. deflection when the base is subjected to a static load of 1600 N.

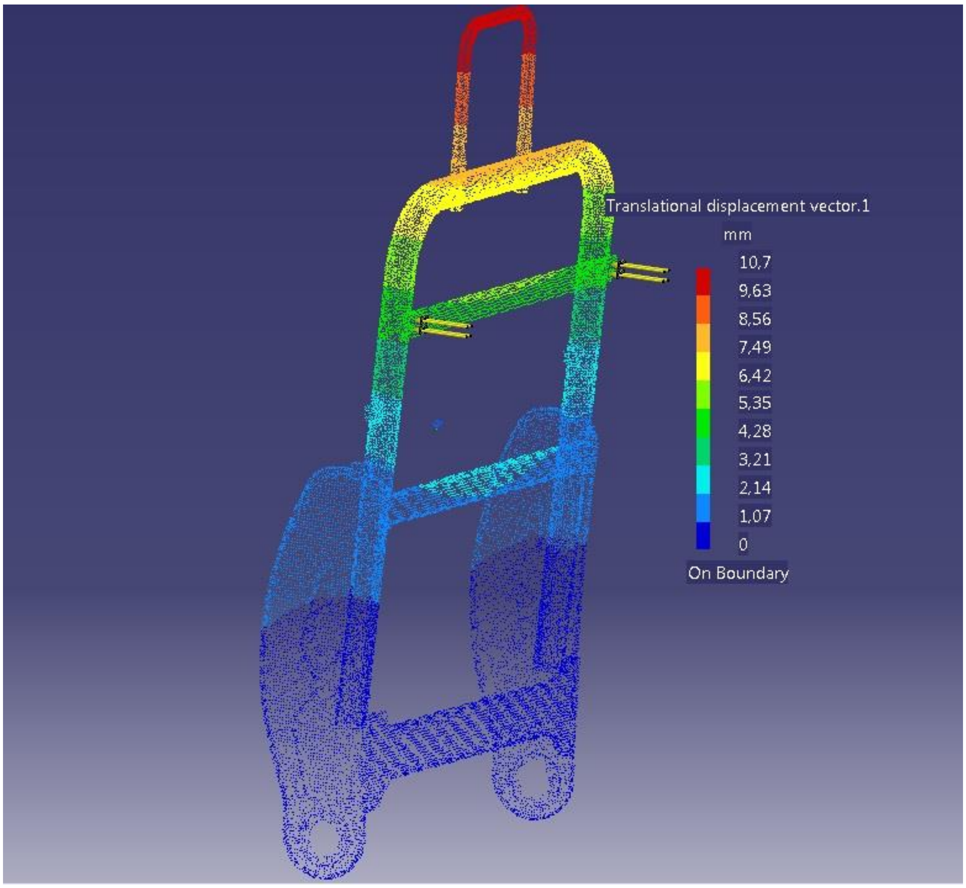
Parameters	Reference Base	Reference base Mg		Limiting values
Material	Low alloy steel	Magnesium (AZ)		
Max. Von Mises Stress during Unr. Cargo (Mpa)	696	184		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Von Mises Stress during Rear Imp. (Mpa)	513	155		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Dynamic Deflection during Unr. Cargo (mm)	0,35	0,32		14,2 mm
Max. Dynamic Deflection during Rear Impact (mm)	0,3	0,22		14,2 mm
Max. Dynamic Deflection during Submarining (mm)	0,9	1,49		10 mm
Max. Static Deflection (mm)	0,24	1		1 mm for base, 2mm for back

Results from the FE-analysis performed on the reference base structure with low alloy steel as well as magnesium.

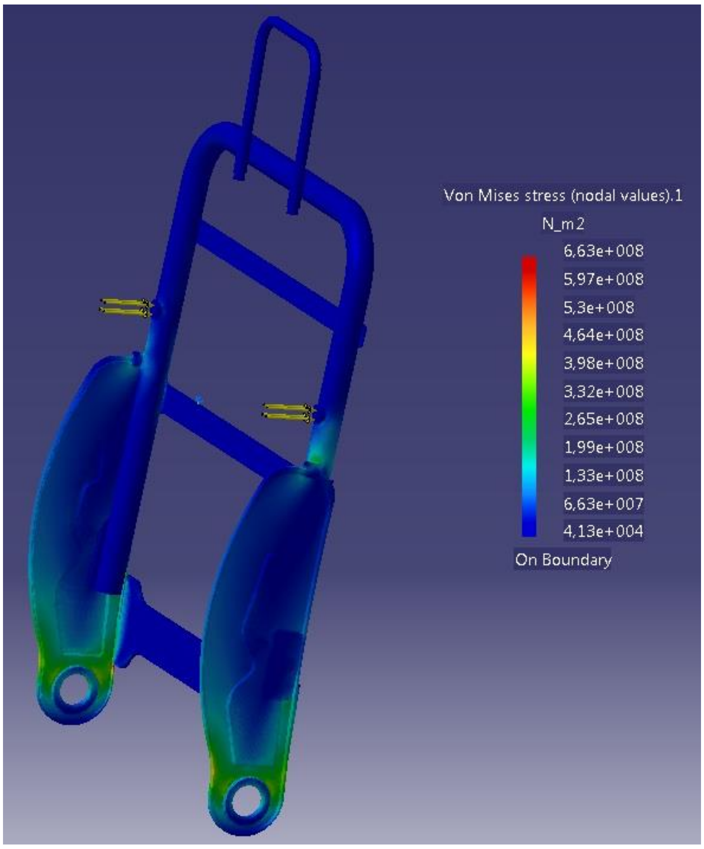
Reference back structure



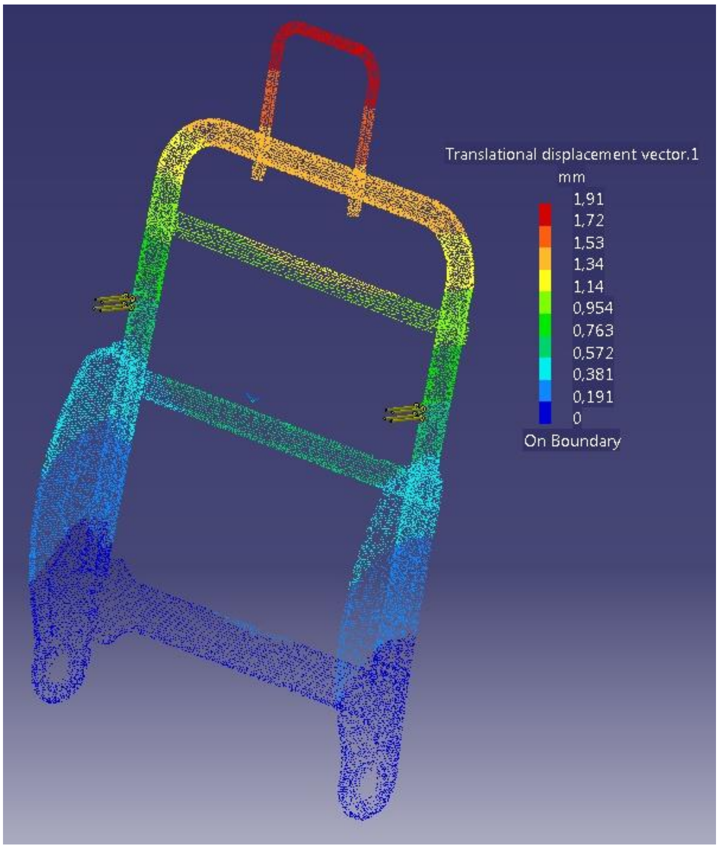
Max. stress when the reference back is subjected to an unrestrained cargo moment of 2500 Nm.



Max. deflection when the reference back is subjected to an unrestrained cargo moment of 2500 Nm.



Max. stress when the back structure is subjected to a rear impact moment of 2100 Nm.



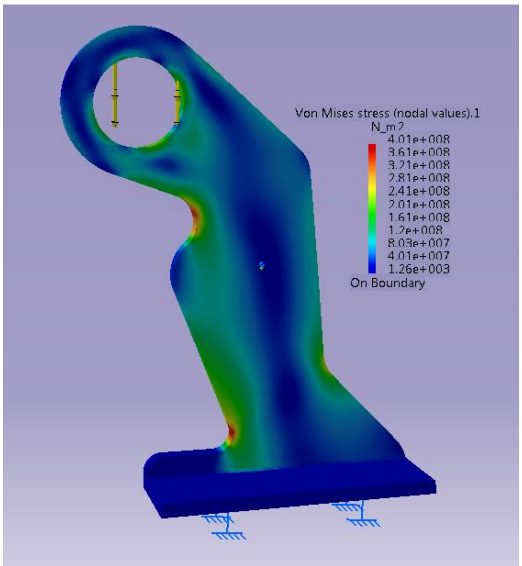
Static deflection when a force of 1600 N is applied.

Parameters	Reference Back	Reference back Mg	Limiting values
Material	Low alloy steel	Magnesium (AZ)	
Max. Von Mises Stress during Unr. Cargo (Mpa)	700	170	700 Mpa for Steel, 190 Mpa for Magnesium
Max. Von Mises Stress during Rear Imp. (Mpa)	663	153	700 Mpa for Steel, 190 Mpa for Magnesium
Max. Dynamic Deflection during Unr. Cargo (mm)	10,7	13	14,2 mm
Max. Dynamic Deflection during Rear Impact (mm)	6,3	8,1	14,2 mm
Max. Dynamic Deflection during Submarining (mm)	N/a	N/a	10 mm
Max. Static Deflection (mm)	1,9	2,4	1 mm for base, 2mm for back

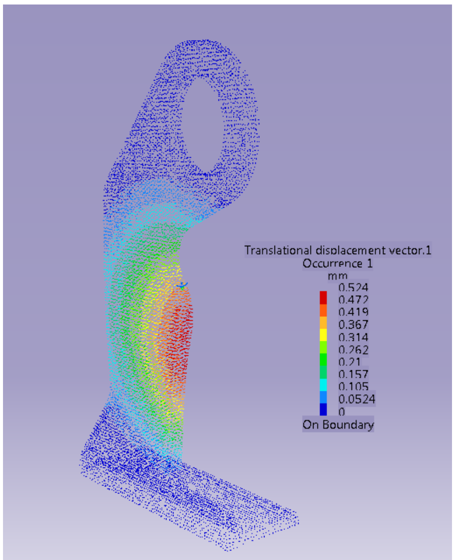
Results from the FE-analysis performed on the reference back.

Reference attachment structure

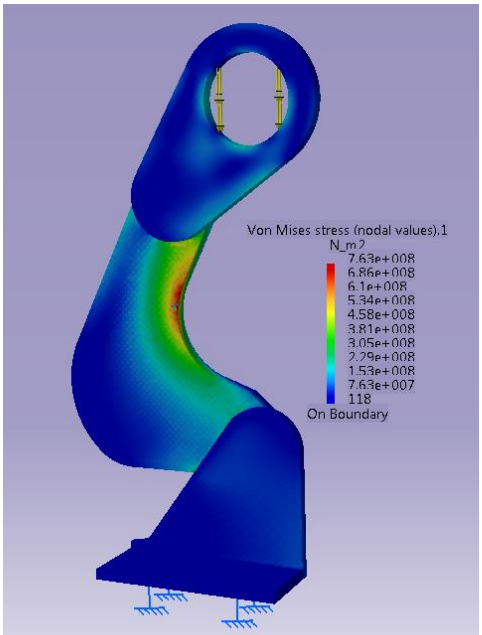
Results showed that there was no difference in stresses between a compressive and tensional force for all legs.



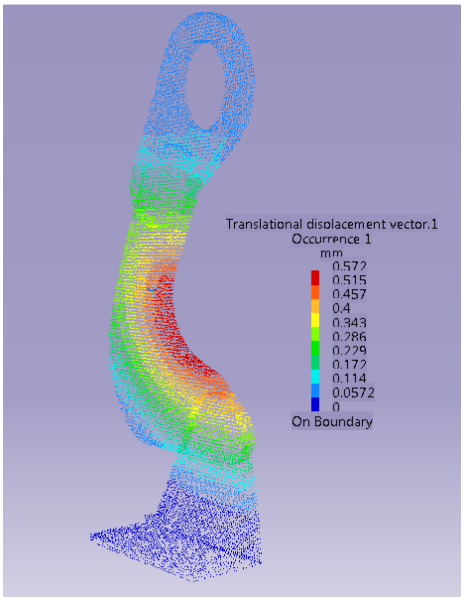
Stresses on rear reference leg during car crash 4000 N



Buckling deflection on rear reference leg during static force 1600 N



Stresses on front reference leg during car crash 4000 N



Buckling deflection on front reference leg during static force 1600 N

Reference legs performance evaluation table

Impact force 4000 N	**Rear leg**	**Front leg**
Max. Stress [MPa]	401	763
Static Force 1600 N		
Max .Deflection [mm]	0,524	0,572

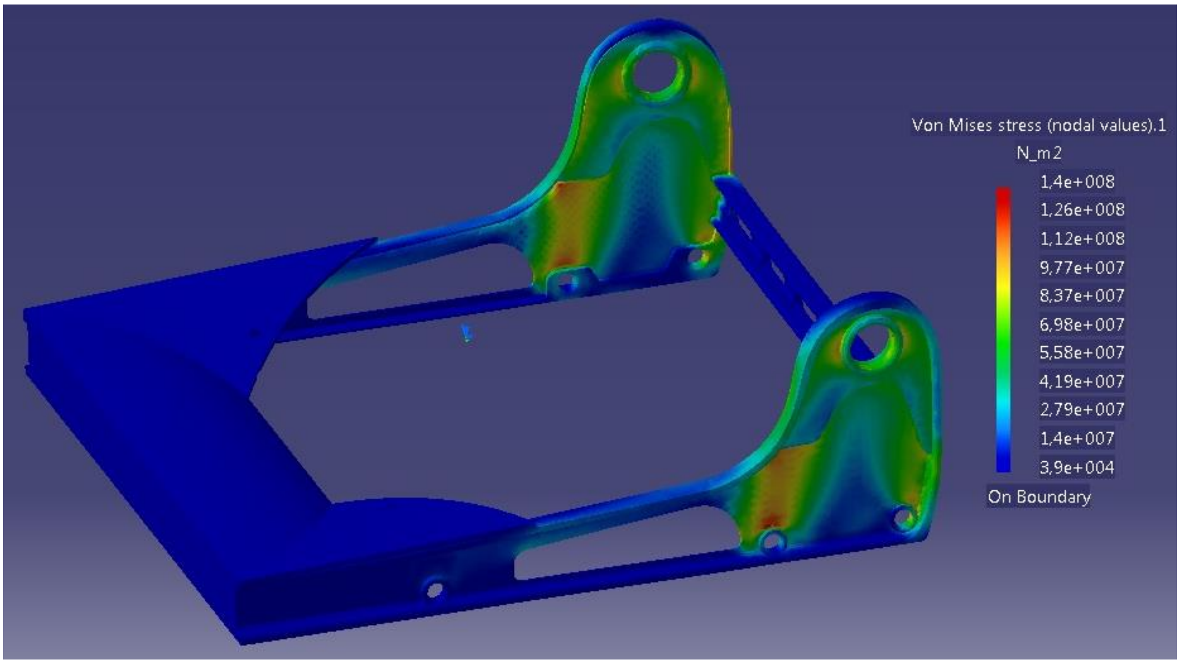
Appendix 12 - Structural analysis of final design

In order to evaluate the structural integrity and thereby the safety performance of the final design, CATIA's FE module has been used. The in-data for this analysis has been the load cases described in the *Reference Seat analysis* section but recalculated due to the change in loads caused by the new recliner mounting position. The recalculated in-data are as follows:

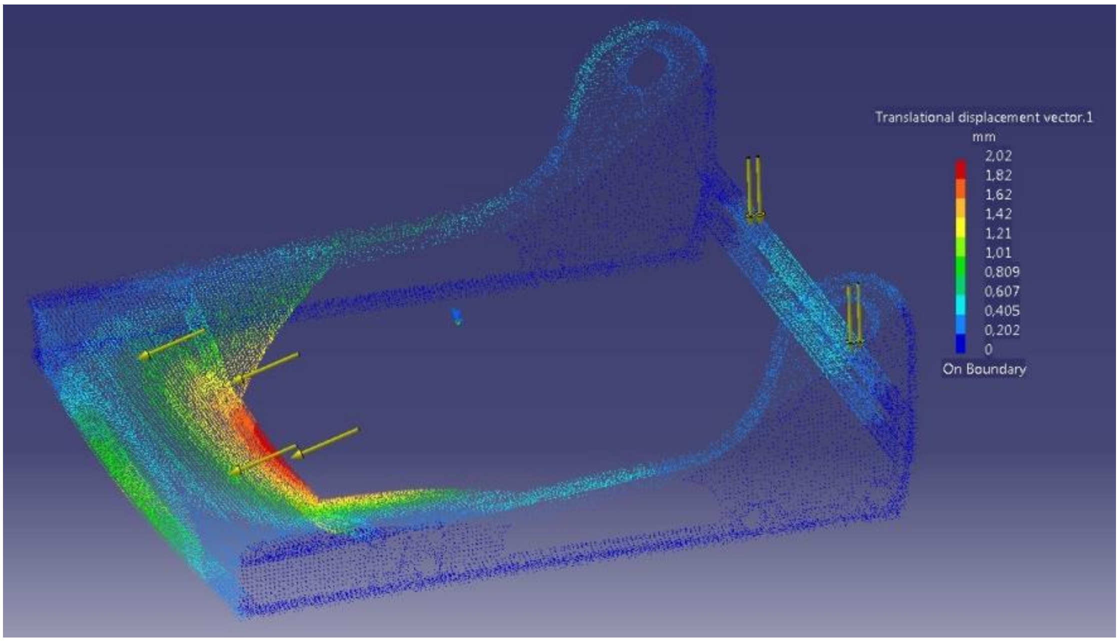
- Moment caused by rearward impact, initial velocity 54 km/h =
- Moment caused by unrestrained cargo impact, initial velocity 54 km/h = 1840 Nm
- Submarining force is assumed equal to the reference seat = 4000 N
- Static deflection force is assumed equal to the reference seat = 1600 N
- Forces acting on the attachment structure are assumed equal to the reference seat = 4000 N

The new moment values have been acquired by taking the impact forces from the Reference seat analysis and applying a 100 mm shorter lever arm between the recliner point and the position of the applied force. Other in-data for the analysis include material properties for Magnesium and low alloy steel taken from CES Edupack 2012. For each load case the relevant outcome has been measured and documented in a spreadsheet format. The spreadsheet also highlights the values that limit further mass reduction in each load case, as determined by material properties and the target specifications. The most important limiting parameters are maximum von Mises stress and deflection. The FE-results from each load case are presented in this section.

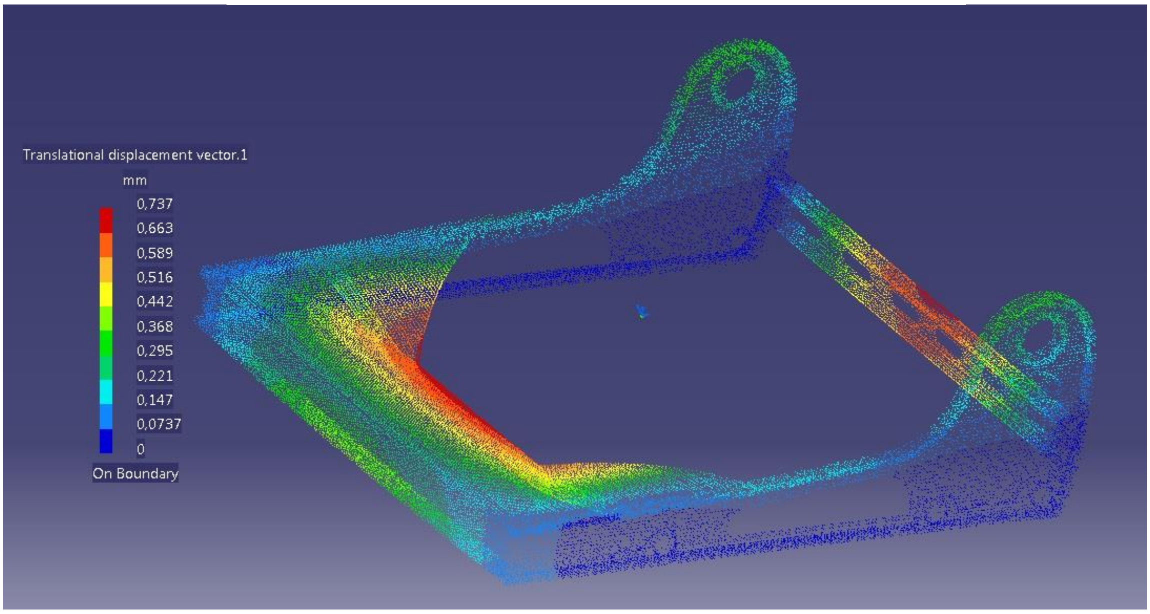
Base structure analysis



Max. stress when the base structure is subjected to an unrestrained cargo load of 1840 Nm at the recliner mount.



Max. displacement when the base is subjected to a submarining load of 4000 N

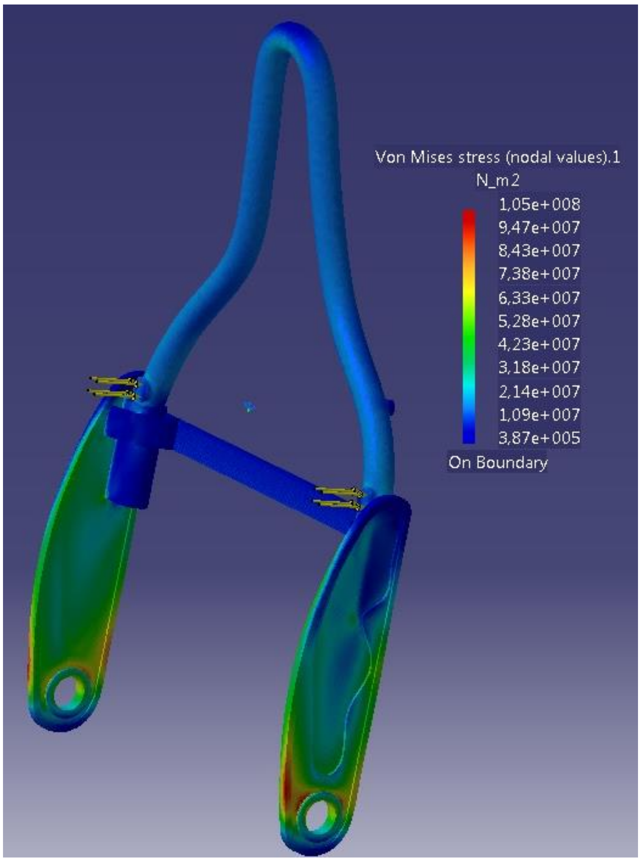


Max. displacement when the base is subjected to a static load of 1600 N.

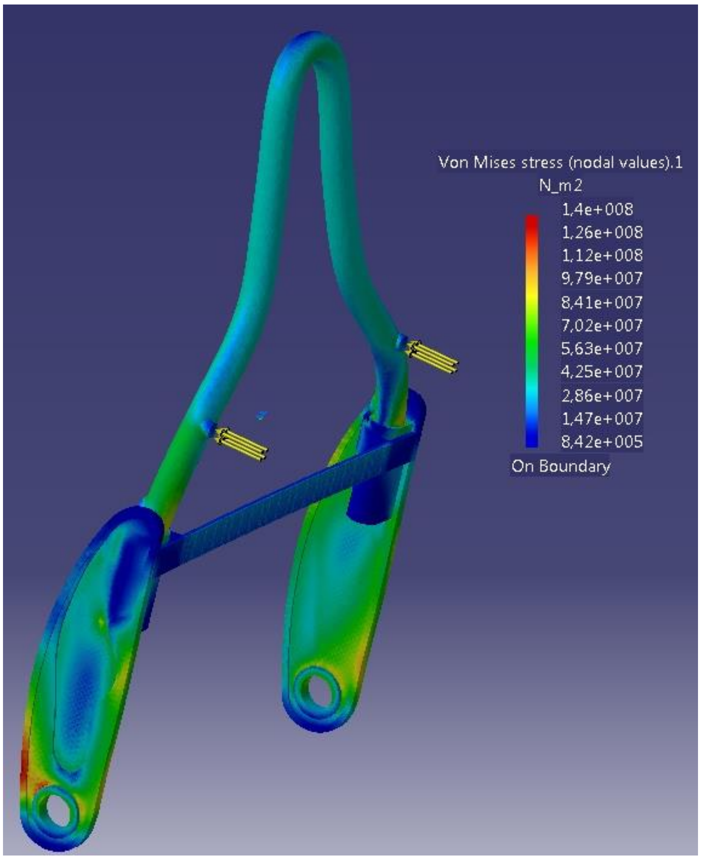
Parameters	Concept Base		Limiting values
Material	Magnesium (AZ)		
Max. Von Mises Stress during Unr. Cargo (Mpa)	148		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Von Mises Stress during Rear Imp. (Mpa)	117		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Dynamic Deflection during Unr. Cargo (mm)	1,4		14,2 mm
Max. Dynamic Deflection during Rear Impact (mm)	1,1		14,2 mm
Max. Dynamic Deflection during Submarining (mm)	1,64		10 mm
Max. Static Deflection (mm)	0,6		1 mm for base, 2mm for back

FE-results for the concept base structure.

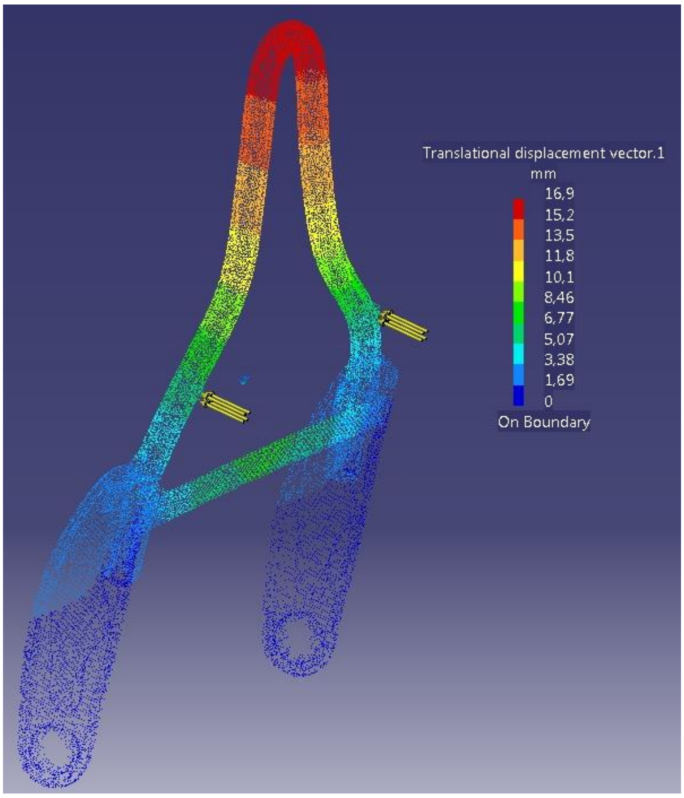
Back frame structure



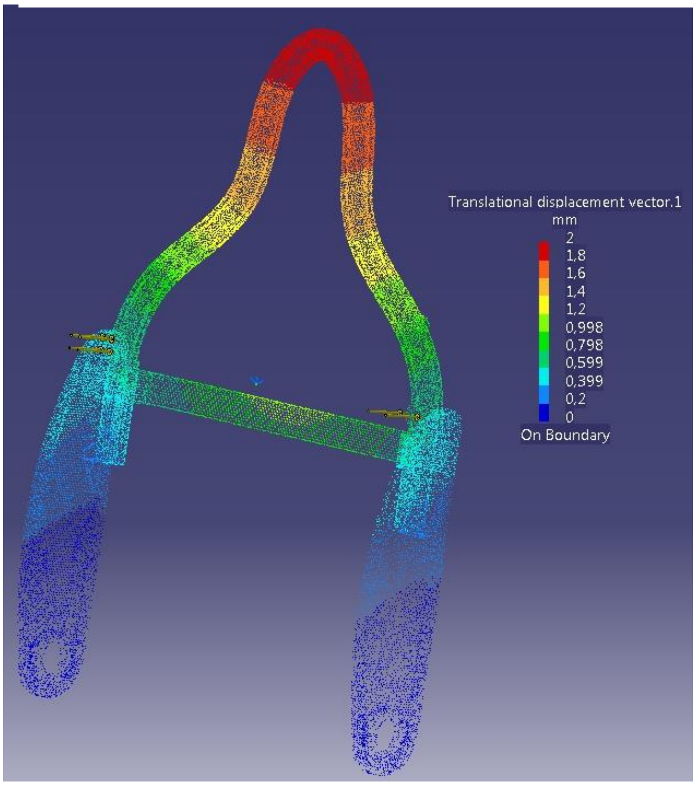
Max. stress when the back frame is subjected to a rear impact load of 1600 Nm.



Max. stress when the back frame is subjected to an unrestrained cargo load of 1840 Nm.



Max. deflection when the back is subjected to an unrestrained cargo load of 1840 Nm. For the comparison the displacement is measured at the same height as the reference seat, this gives a deflection of 13.9 mm.

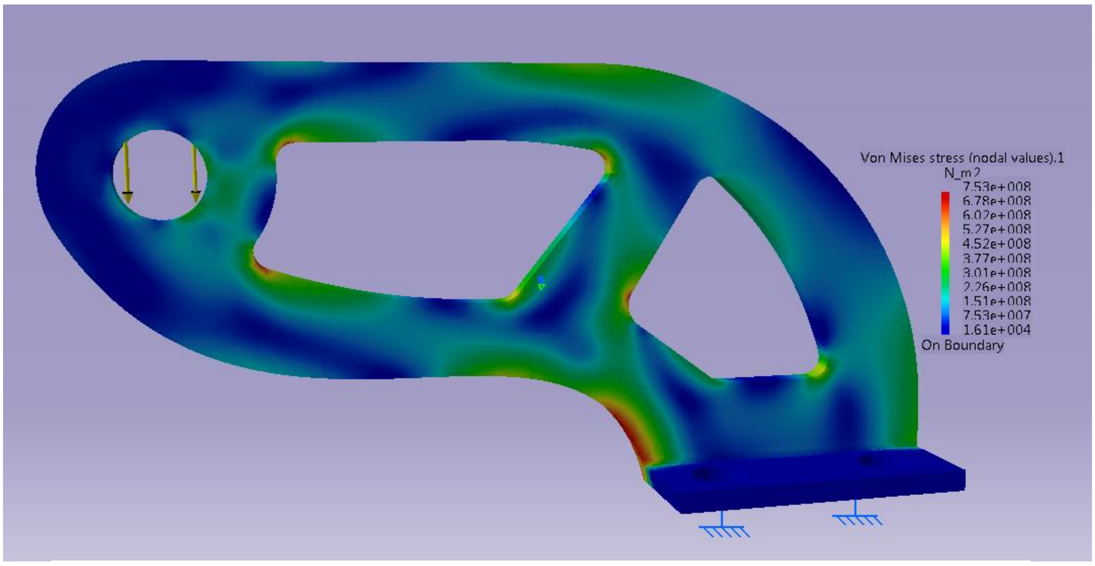


Max deflection when the back is subjected to a static load of 1600 N.

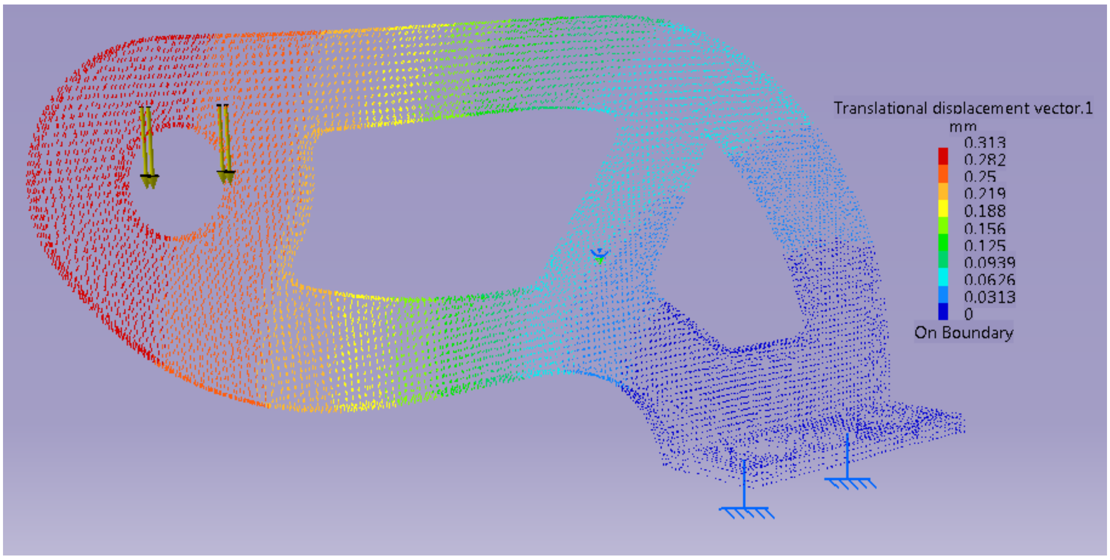
Parameters	Concept Back		Limiting values
Material	Magnesium (AZ)		
Max. Von Mises Stress during Unr. Cargo (Mpa)	140		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Von Mises Stress during Rear Imp. (Mpa)	105		700 Mpa for Steel, 190 Mpa for Magnesium
Max. Dynamic Deflection during Unr. Cargo (mm)	13,9		14,2 mm
Max. Dynamic Deflection during Rear Impact (mm)	8		14,2 mm
Max. Dynamic Deflection during Submarining (mm)	N/a		10 mm
Max. Static Deflection (mm)	2		1 mm for base, 2mm for back

FE-results for the concept back structure.

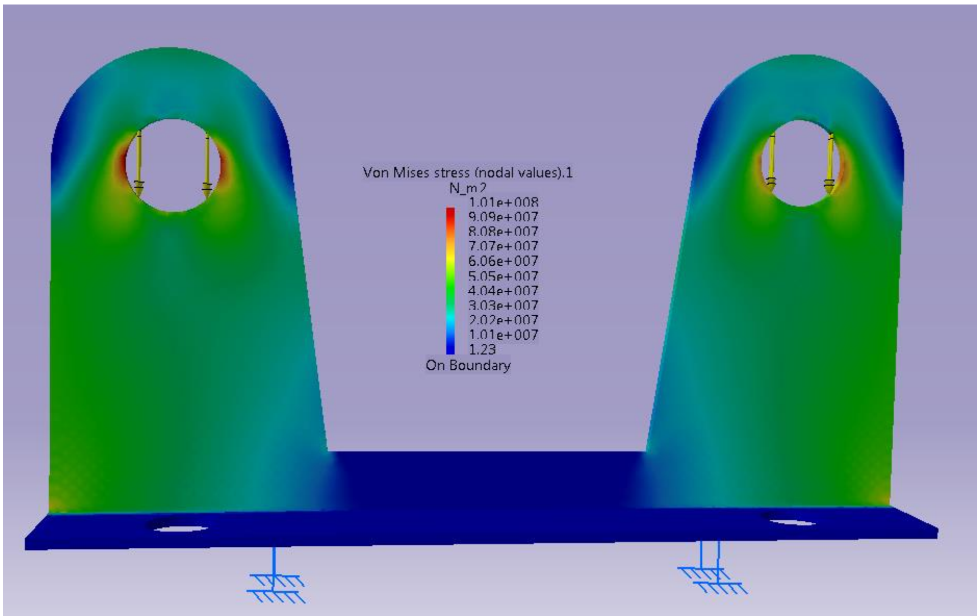
Attachment structure



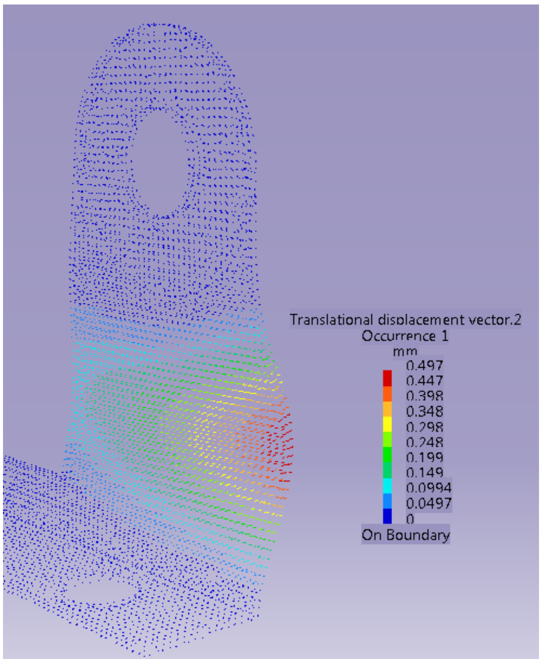
Max. stress when the front left leg is subjected to a load of 4000 N.



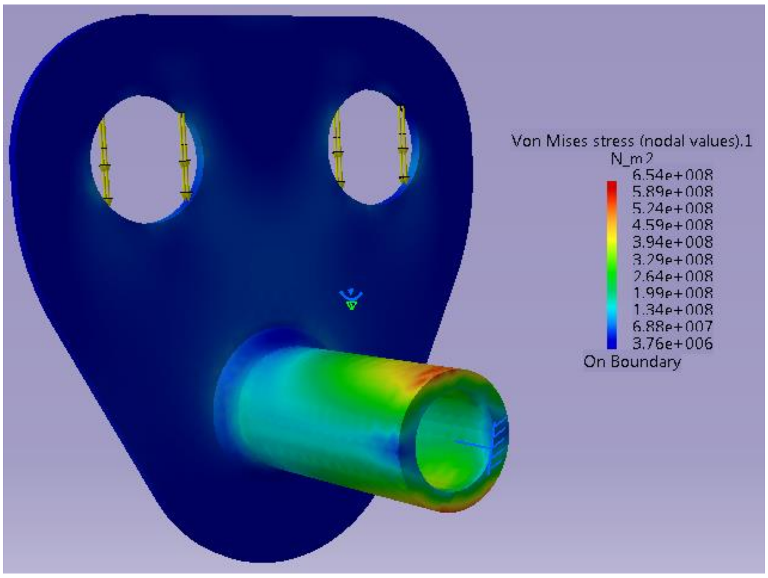
Max. Deflection when the front left leg is subjected to a load of 4000 N



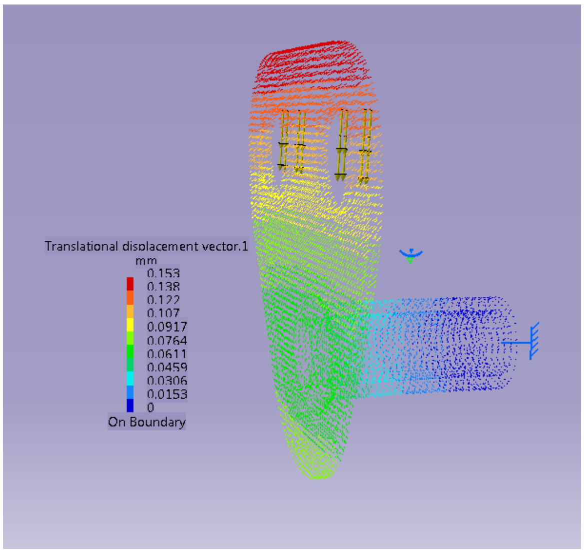
Max. Stress when the rear left leg is subjected to a load of 4000 N.



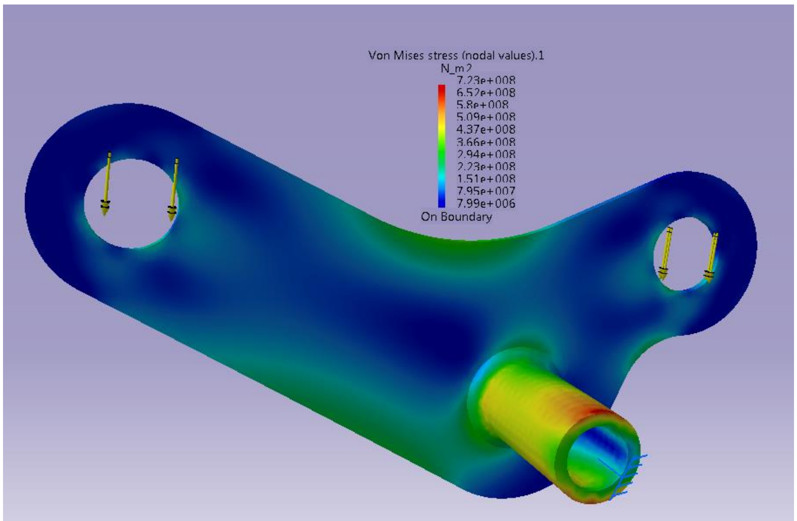
Max. Static Displacement when the rear left leg is subjected to a load of 1600 N



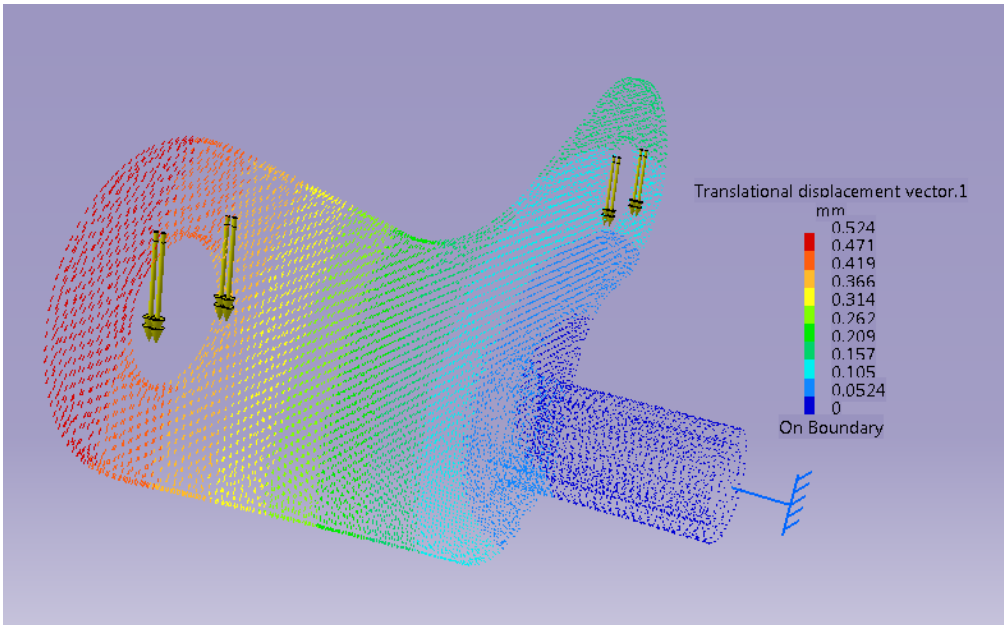
Max. Stress when the front right leg is subjected to a load of 4000 N.



Max. Static deflection when the front right leg is subjected to a force of 1600 N.



Max. Stress when the rear right leg is subjected to a load of 4000 N.



Static deflection when the rear right leg is subjected to a load of 1600 N.

	Front Left Leg	Rear Left Leg	Front Right Leg	Rear Right Leg	Left Rail	Rail Support Bracket
Max. Stress [MPa]	753	101	654	723	559	60
Max. Disp. [mm]	0,313	0,497	0,153	0,524	0,14	0,341

Results from the FE-analysis performed on the attachment structure.

Appendix 13 - Reference seat Bill-of-materials

Reference seat BOM						Chosen	From assembly	Chosen	Measured in CAD	Assumed most likely	Est. In CES (Mean)	From CES (Mean)
BOM level	0	1	2	3	4	Part name	Quantity	Part material	Part mass (kg)	Manufacturing process	Part Cost (SEK)	Tooling Cost (SEK)
0	x					**Driver seat**	1		**16,074**		**2485,0**	
1		x				**Driver seat structure assembly**			9,89		709,0	1072750
2			x			*Base frame assembly*			3,2		56,5	349250
3				x		Base side plates	1	Low alloy steel	1	Stamping	9,8	69850
3				x		Base reinforcement plates	1	Low alloy steel	0,4	Stamping	17,3	69850
3				x		Base side plate	1	Low alloy steel	0,6	Stamping	9,8	69850
3				x		Base back plate	1	Low alloy steel	0,6	Stamping	9,8	69850
3				x		Base front plate	1	Low alloy steel	0,6	Stamping	9,8	69850
2			x			*Back frame assembly*			3,6		90,74	501450
3				x		Lower Support Frame	1	Low alloy steel	0,5	Stamping	9,2	69850
3				x		Back side plate	1	Low alloy steel	0,8	Stamping	10,9	69850
3				x		Back side plate	1	Low alloy steel	0,8	Stamping	10,9	69850
3				x		Upper Support Frame	1	Low alloy steel	0,16	Stamping	7,3	69850
3				x		Mid support frame	1	Low alloy steel	0,3	Stamping	8,14	69850
3				x		Neck support bar	1	Low alloy steel	0,05	Impact extrusion	9	38050
3				x		Neck support bar	1	Low alloy steel	0,05	Impact extrusion	9	38050
3				x		Head rest frame	1	Low alloy steel	0,5	Impact extrusion	10,9	38050
3				x		Active Head Restraint	1	Low alloy steel	0,44	Impact extrusion	15,4	38050
2			x			*Seat-to-floor attachment structure*			3,65		189,29	222050
3				x		Height Front Rod	1	Low alloy steel	0,5	Extrusion	10,9	38050
3				x		Height Back rod	1	Low alloy steel	0,5	Extrusion	10,9	38050
3				x		Legs	4	Low alloy steel	0,25	Stamping	82,2	69850

3			x	Outer track	2	Low alloy steel	0,65	Extrusion	11,9		38050
3			x	Inner track	2	Low alloy steel	0,35	Extrusion	10,6		38050
3			x	Adjustment handle	1	Mixed	0,2	External supplier	9,8	N/a	
3			x	Locking mechanism	1	Mixed	0,2	External supplier	30,6	N/a	
2		x		*After treatment*					155,0		
3			x	Welding	1		0	Process	65		
3			x	Painting	1		0	Process	80		
3			x	Assembly	1		0	Process	10		
2		x		Recliner assembly	1	Mixed	1,4	External supplier	141,5		
2		x		Height adjuster assembly	1	Mixed	1,48	External supplier	76		
				Components not part of the structure			6,184		1776		
1	x			*Suspension*	1				56		
2		x		Back suspension	1	Steel	0,14	External supplier	27		
2		x		Base suspension	1	Steel	0,216	External supplier	29		
1	x			Lumbar support	1	Mixed	0,533	External supplier	37		
1	x			*Foam*	1			External supplier	213		
2		x		Foam back	1	PUR	1,446	External supplier	125		
2		x		Foam base	1	PUR	1,247	External supplier	88		
1	x			*Upholstery*	1			External supplier	1088		
2		x		Upholstery back	1	Leather/Fabric	0,913	External supplier	675		
2		x		Upholstery base	1	Leather/Fabric	0,651	External supplier	340		
2		x		Upholstery headrest	1	Leather/Fabric	0,156	External supplier	73		
1	x			Heating system	1	Mixed	0,23	External supplier	132		
1	x			Side airbag	1	Mixed	0,652	External supplier	224		
1	x			Screws, tape, clips, straps etc.		Mixed		External supplier	26		

Appendix 14 – Complete bill-of-materials for the final concept

Final Concept BOM					Chosen	From assembly	Chosen	Measured in CAD	Assumed most likely	Est. In CES (Mean)	From CES (Mean)
BOM level	0	1	2	3	Part name	Quantity	Part material	Part mass (kg)	Manufacturing process	Part Cost (SEK)	Tooling Cost (SEK)
0	x				**Driver seat**	1		**14,264**		**2458,11**	
1		x			**Driver seat structure assembly**	1		8,08		682,11	1290682
2			x		*Base Frame assembly*	1		1,599		134,885	468124
3				x	Side Plate	2	Mg	0,176	Stamping	12,435	69850
3				x	Front plate	1	Mg	0,12	Stamping	10,535	69850
3				x	Rear reinforcement	2	Mg	0,13	H.P. die casting	12,93	73508
3				x	Front reinforcement	2	Mg	0,03	H.P. die casting	12,93	73508
3				x	Seat pan support bar	1	Mg	0,1	Impact Extrusion	11,43	38050
3				x	Rear susp. beam	1	Mg	0,21	H.P. die casting	12,93	73508
3				x	Seat pan	1	Mg	0,497	Stamping	23,4	69850
2			x		*Back Frame assembly*	1		1,624		103,51	181408
3				x	Side plate	2	Mg	0,292	Stamping	19,75	69850
3				x	Upper support	1	Mg	0,14	H.P. die casting	12,93	73508
3				x	Upper tube	1	Mg	0,704	Impact Extrusion	28,3	38050
				x	Tube holder	2	Mg	0,098	Impact Extrusion	11,39	
2			x		*Seat-to-floor attachment structure*	1		3,457		147,21	641150
3				x	*Seat Legs*	4	Low Alloy Steel	0,361	Sheet Metal	27,73	69850
4					x Left Rear Leg	1	Low Alloy Steel	0,111	Sheet Metal	7,1	69850
4					x Left Front Leg	1	Low Alloy Steel	0,175	Sheet Metal	7,4	69850
4					x Right Rear Leg	1	Low Alloy Steel	0,046	Sheet Metal	6,7	69850
4					x Right Front Leg	1	Low Alloy Steel	0,029	Sheet Metal	6,6	69850
3				x	*Rail support brackets*	2	Low Alloy Steel	0,17	Sheet Metal	13,8	
4					x Rail support bracket top	1	Low Alloy Steel	0,052	Sheet Metal	6,7	69850
4					x Rail support bracket bottom	1	Low Alloy Steel	0,118	Sheet Metal	7,1	69850

First part of the BOM

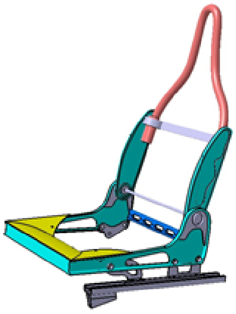
3			x		*Tunnel attachments*	2	Low Alloy Steel	0,04	Extruded	17,5	38050
3			x		*Rails*	2	Low Alloy Steel	2,886	Extruded	88,2	38050
4				x	Rail Base	2	Low Alloy Steel	2,008	Extruded	26,3	38050
4				x	Rail Slider	2	Low Alloy Steel	0,462	Extruded	19,5	38050
4				x	Springs	2	Steel	0,016	Hot Coiled	2,0	N/a
4				x	Adjustment handle	1		0,2	External supplier	9,8	N/a
4				x	Locking mechanism	1		0,2	External supplier	30,6	N/a
2		x			Recliner assembly	1	Steel	1,4	External supplier	141,5	
2		x			*After treatment*					155	
3			x			Welding	1		Process	65	
3			x			Painting	1		Process	80	
3			x			Assembly	1		Process	10	
					Components not part of the structure			6,184		1776	
1	x				*Suspension system*					56	
2		x			Back suspension		Steel	0,14	External supplier	27	
2		x			Base suspension		Steel	0,216	External supplier	29	
1	x				*Lumbar support*	1	Mixed	0,533	External supplier	37	
1	x				*Foam*	1			External supplier	213	
2		x			Foam back	1	PUR	1,446	External supplier	125	
2		x			Foam base	1	PUR	1,247	External supplier	88	
1	x				*Upholstery*	1			External supplier	1088	
2		x			Upholstery back	1	Leather/Fabric	0,913	External supplier	675	
2		x			Upholstery base	1	Leather/Fabric	0,651	External supplier	340	
2		x			Upholstery headrest	1	Leather/Fabric	0,156	External supplier	73	
1	x				*Heating system*	1	Mixed	0,23	External supplier	132	
1	x				*Side airbag*	1	Mixed	0,652	External supplier	224	
1	x				Screws, tape, clips, straps etc.		Mixed		External supplier	26	

Second part of the BOM

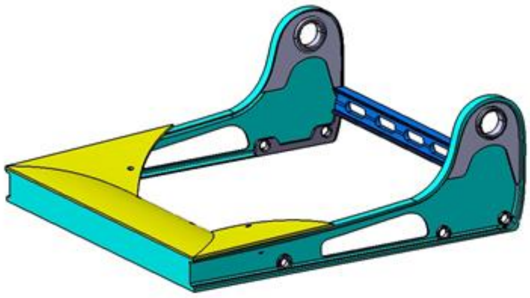
Appendix 15 - Assembly procedure visualization

Driver seat structure concept assembly procedure

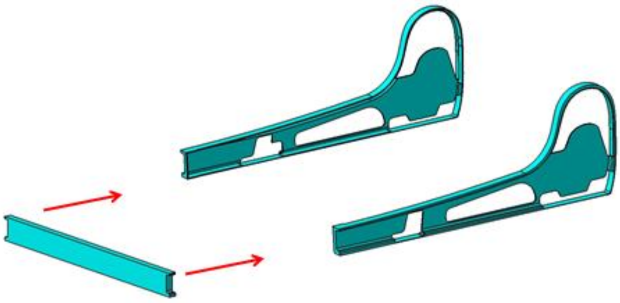
- Base frame assembly
- Attachment structure assembly
- Back frame assembly
- Final assembly



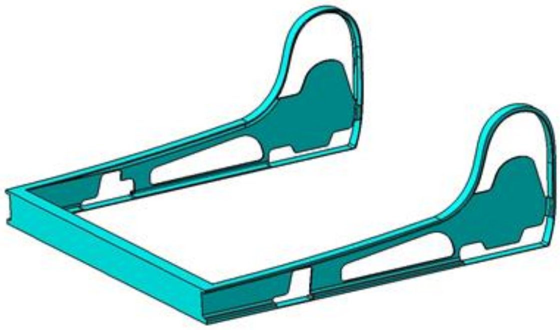
Base frame assembly



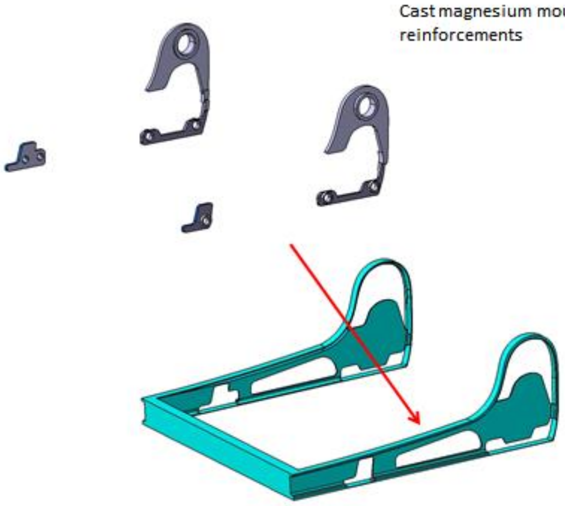
Stamped magnesium sideplates and front



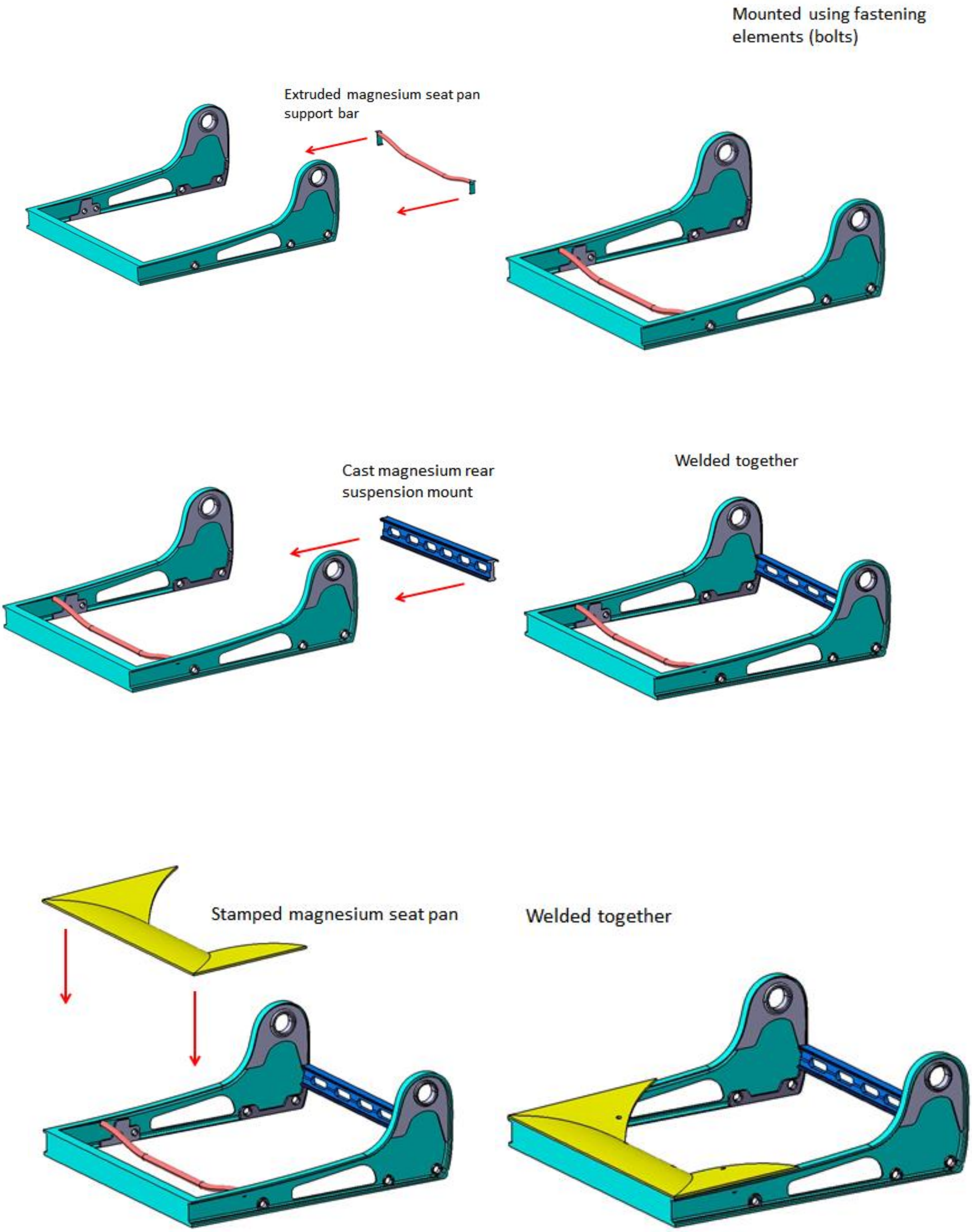
Welded together



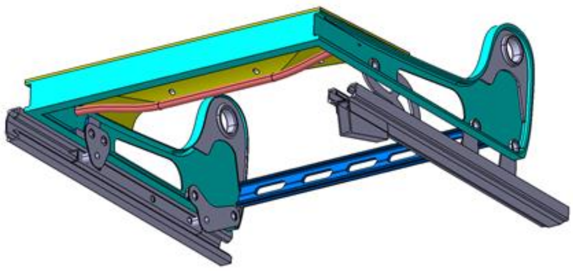
Cast magnesium mounting reinforcements



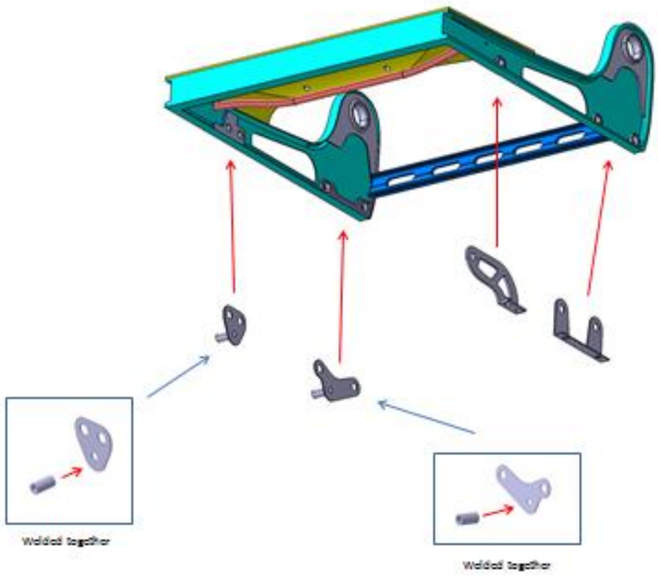
Welded together


Mounted using fastening elements (bolts)
Extruded magnesium seat pan support bar
Cast magnesium rear suspension mount
Welded together
Stamped magnesium seat pan
Welded together

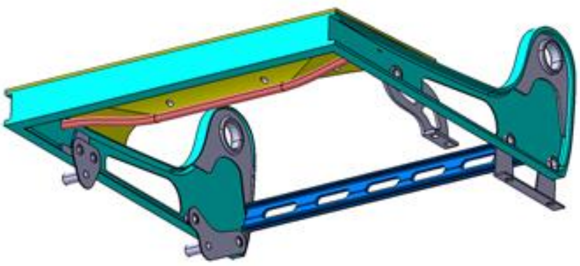
Seat-to-Floor Attachments assembly



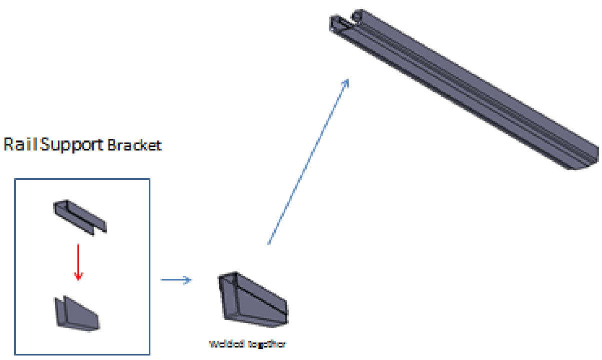
Leg assembly



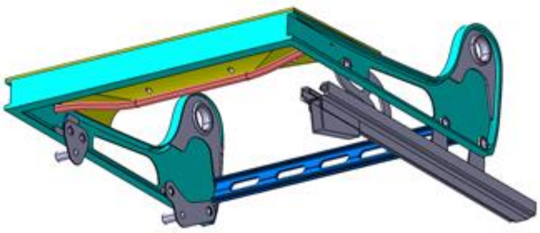
Bolted together



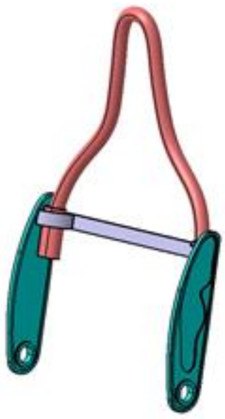
Welded or bolted together

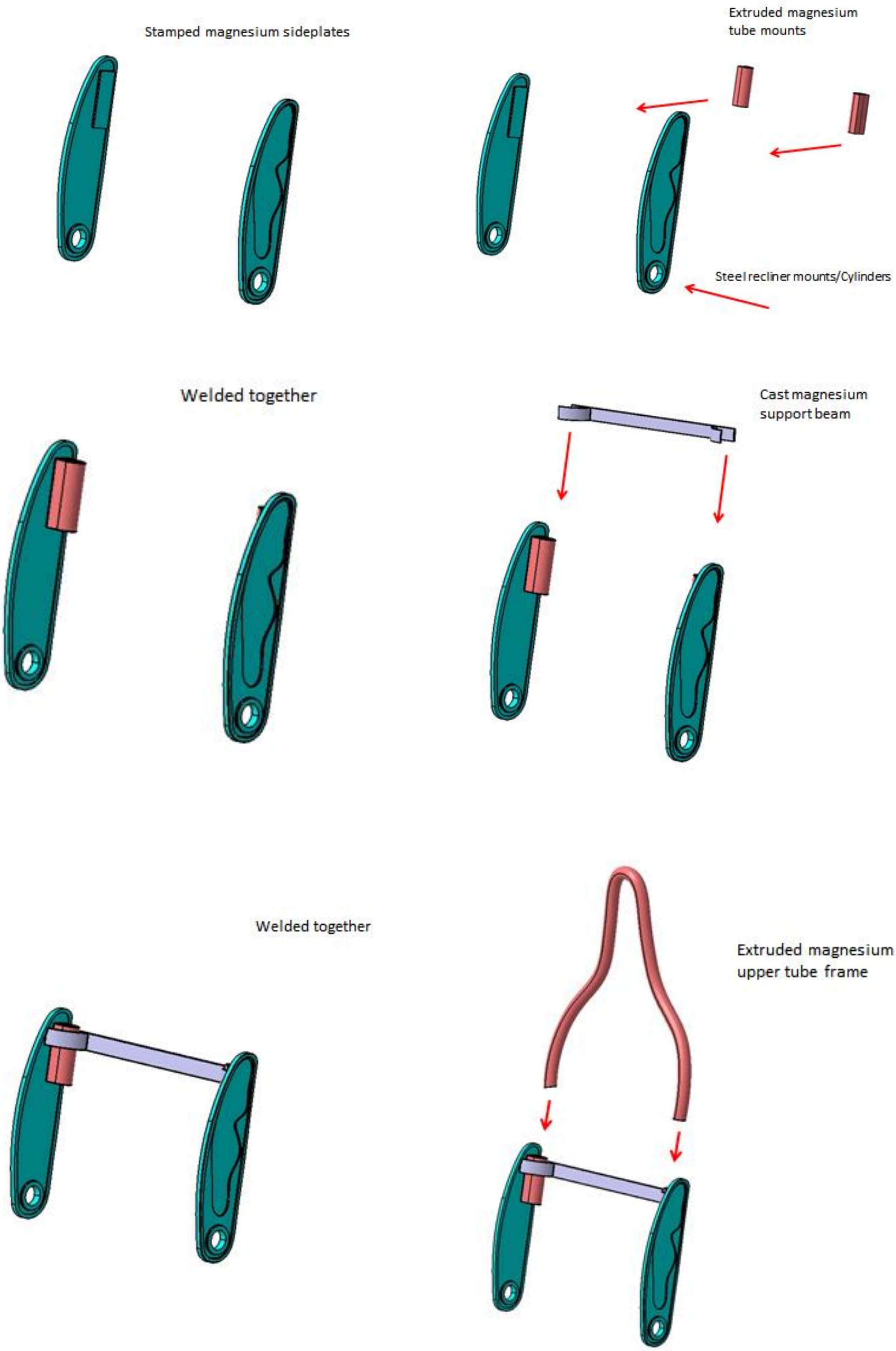


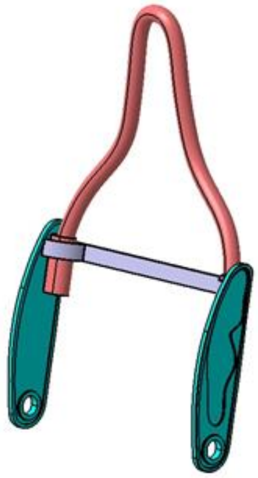
Bolted to the left legs



Back frame assembly

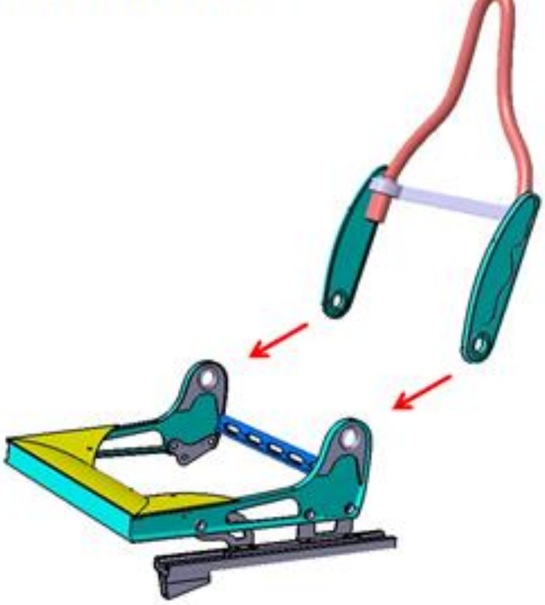



Stamped magnesium sideplates
Extruded magnesium tube mounts
Steel recliner mounts/Cylinders
Welded together
Cast magnesium support beam
Welded together
Extruded magnesium upper tube frame

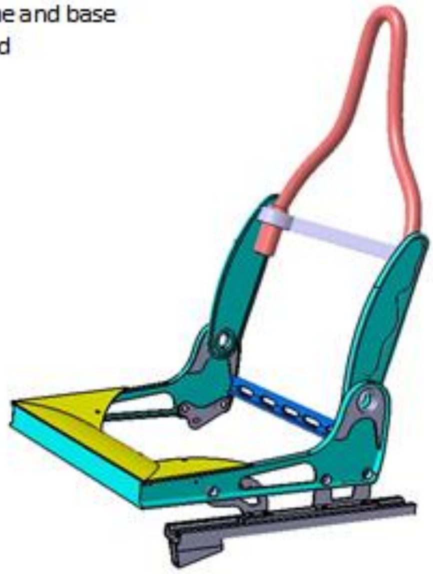


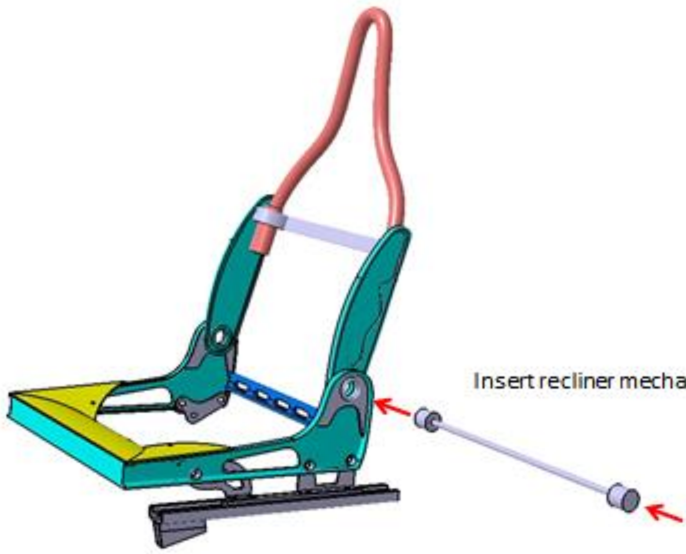
Clamped and welded together

Position back frame within the base

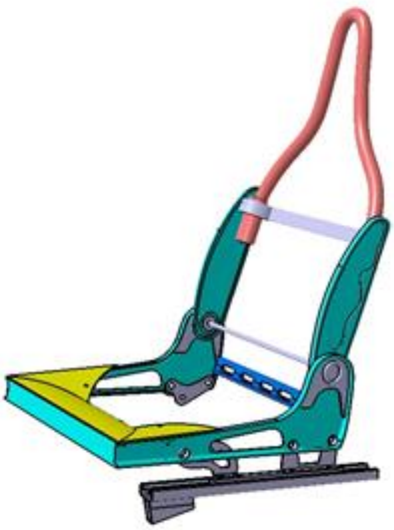


Back frame and base positioned

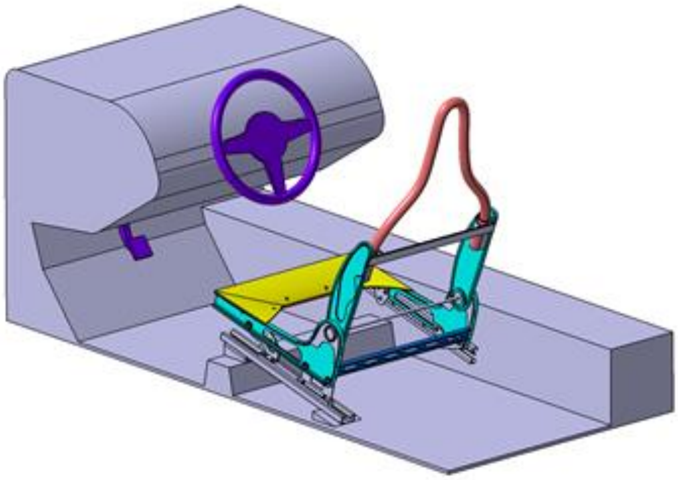




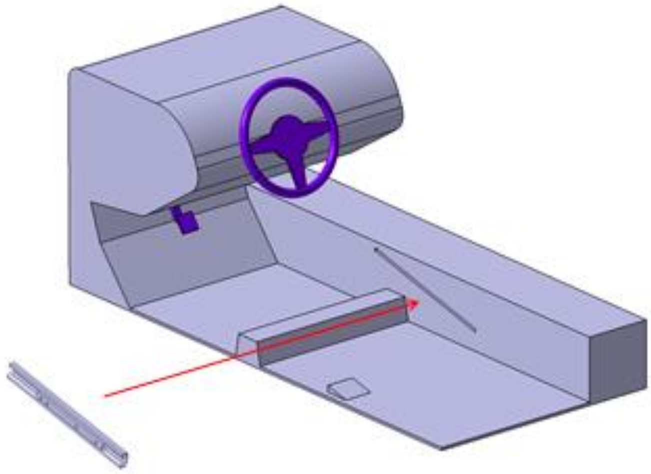
Completed driver seat structure



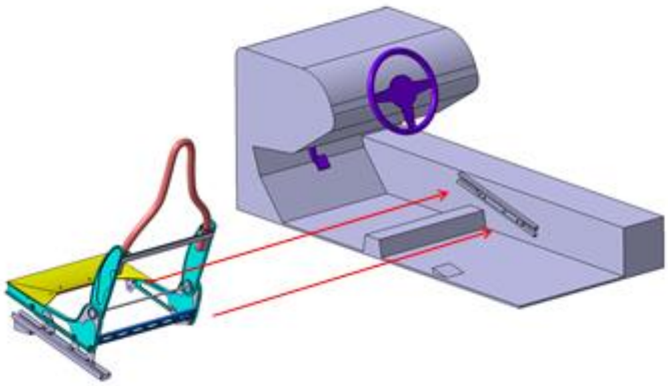
Mounting the seat in the car



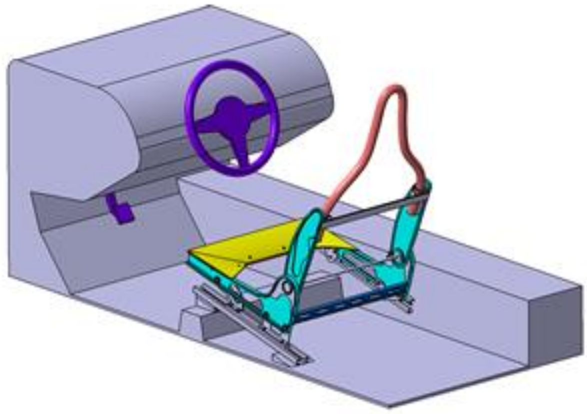
Right Rail attached to the tunnel



Positioning the seat structure to the inside rail and floor



Attaching fastening elements



Completed final assembly