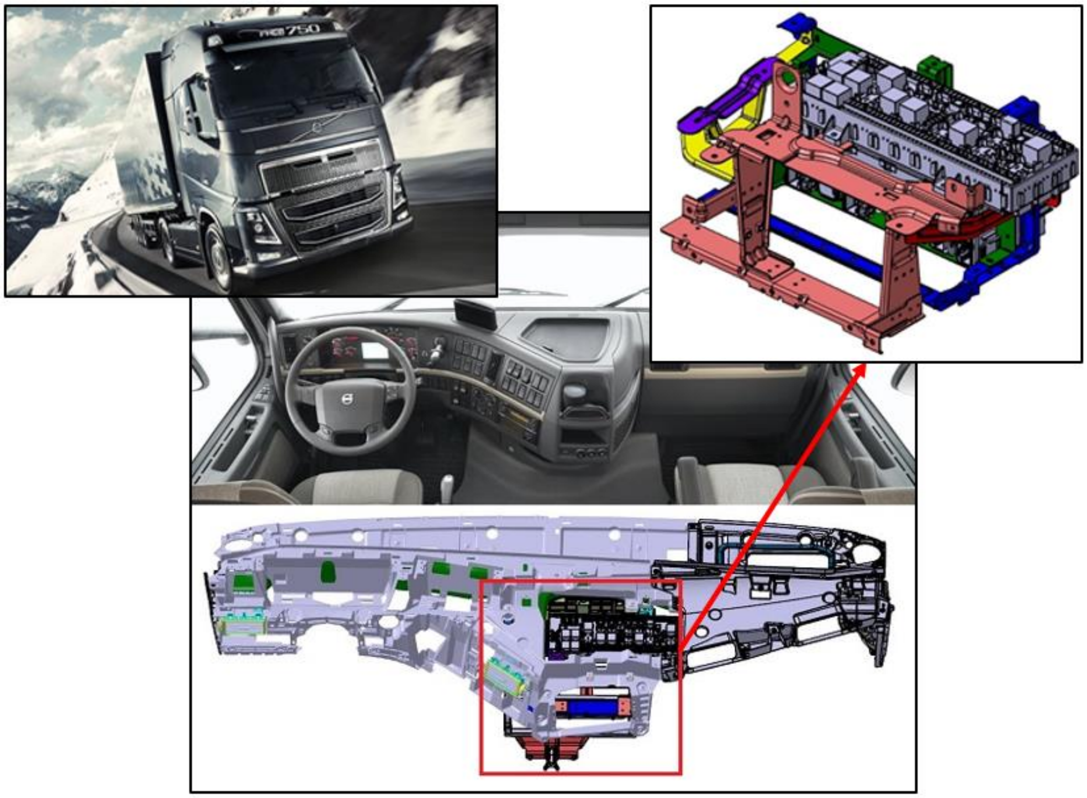

Development of a New Dashboard Framework

A product development study of using alternative materials to replace a steel sheet metal framework

Master Thesis

MARTIN LINDQVIST & ROBERT OSCARSSON

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

MASTER THESIS

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Abstract

The automotive industry always strives to reduce production costs, reduce weight and increase the performance of their products. This thesis work is mainly based on these factors regarding a specific solution that is used in the most common model of Volvo´s trucks. The object of study is a steel sheet metal framework located under the dashboard with the purpose of keeping electrical components in place and supporting the dashboard structure. The framework has many interfaces to surrounding parts and cables that were not to be changed. This generated many dimensional requirements. The thesis has the objectives to investigate the potential of utilizing new materials, and based on findings, propose a new solution that aims to reduce the weight, make the solution cheaper and reduce number of parts while keeping the current strength performance intact.

Understanding the current solution is essential in order to identify areas for improvements and to design a new solution. Because of this, the study of the current solution was an important part of this thesis. It includes identification of requirements and desires, cost analysis, strength analysis, function analysis and parts and interface mapping. As the focus of this thesis is the utilization of new materials, an extensive material study was conducted. The method used for this was largely based on the functionality of the software Cambridge Engineering Selector (CES) which uses limitations on basic material properties to reduce the number of material option in order to find the most suitable one. With the results gathered from the pre-study and the material option evaluation a concept generation and selection phase began. For selecting the most suitable design, a methodology often practiced at Chalmers University of Technology was used. This included elimination matrix, Pugh matrix and Kesselring matrix.

It was found that the most suitable material groups were polymer, mostly PPA, with 30% to 50% glass fiber reinforcements and the lightweight metals aluminum and magnesium alloy. Two design concepts remained after concept selection. These concepts were further developed in more detail using CAD software. Several material combinations were applied for each design and these material combinations went through several analyses. This included assembly analysis, cost analysis, strength analysis and environmental reflection. The results were compared with each other and with the current solution.

It was found that the most suitable solution was to utilize molded polymer with 50% glass fiber reinforcement. By doing this the number of parts could be reduced to 7 parts down from 23 and the weight could be reduced by up to 70%. The costs could be reduced with almost 50% over the course of a five-year-period. The potential weight reduction also supports the potential of decreasing the environmental impact. This could all be done while keeping the current strength and stiffness requirements by using a reinforced design.

This thesis shows the large potential in moving away from sheet metal components and into lighter materials such as glass fiber reinforced polymer and lightweight metals even for components that require a higher degree of strength and stiffness. The results are also transferrable to other projects within the automotive industry with similar goals.

Sammanfattning

Bilindustrin strävar alltid efter att minska produktionskostnaderna, minska vikten och öka prestandan i sina produkter. Detta examensarbete bygger till stor del på dessa faktorer när det gäller en specifik lösning som används i den vanligaste modellen av Volvo's lastbilar. Objektet som studeras är ett ramverk av plåt som sitter under instrumentbrädan med syftet att hålla elektriska komponenter på plats och bära instrumentbrädan. Ramverket har många gränssnitt mot omgivande delar och kablar som inte får ändras. Detta genererade många dimensionskrav. Detta examensarbete har syftet att undersöka möjligheterna att utnyttja nya material och baserat på analyser föreslå en ny lösning som har målet att minska vikten, göra lösningen billigare, minska antalet delar samtidigt som den nuvarande hållfastheten hålls intakt.

Att förstå den nuvarande lösningen är nödvändigt för att identifiera områden att förbättra och att designa en ny lösning. På grund av detta är förstudien av den nuvarande lösningen en viktig del i detta examensarbete. Det inkluderar identifiering av behov och önskemål, kostnadsanalys, hållfasthetsanalys, funktionsanalys och kartläggning av delar och gränssnitt. Eftersom fokus i detta examensarbete är användningen av nya material genomfördes en omfattande materialstudie. Den metod som använts för detta var till stor del baserat på funktionaliteten i programvaran Cambridge Engineering Selector (CES) som använder begränsningar om grundläggande materialegenskaper för att minska antalet material alternativ för att hitta den mest lämpliga. Med de resultat som samlats in från förstudier och materialutvärderingen inleddes en fas innehållande konceptgenerering och konceptval. För att välja det mest lämpliga konceptet utnyttjades metoder som ofta används vid Chalmers Tekniska Högskola. Detta innefattar elimineringsmatris, Pugh matris och Kesselring matris.

Det visade sig att de mest lämpliga materialgrupperna var polymer, mestadels PPA, med 30 % till 50 % glasfiber och lättviktsmetallerna aluminium- eller magnesiumlegering. Två designkoncept återstod efter konceptvalet. Dessa utvecklades vidare mer i detalj med hjälp av CAD-program. Flera materialkombinationer tillämpades för varje design och dessa materialkombinationer gick igenom flera analyser. Detta inkluderar monteringsanalys, kostnadsanalys, hållfasthetsanalys och miljöreflektion. Resultaten jämfördes med varandra och med den nuvarande lösningen.

Det visade sig att den bästa lösningen utnyttjade mestadels polymer med 50 % glasfiber. Genom att göra det kunde antalet delar minskas ned till 7 från 23 och vikten kunde minskas med upp till 70 %. Produktionskostnaderna kunna minskas med nästan 50 % under en femårsperiod. Den potentiella viktminskningen stöder också potential att minska miljöpåverkan. Allt detta kan göras samtidigt som de nuvarande kraven på styrka och styvhet hålls med hjälp av en förstärkt konstruktion.

Denna avhandling visar stor potential i att röra sig bort från plåtkomponenter till lättare material, såsom glasfiberförstärkta polymer och lättmetaller, även för komponenter som kräver högre styrka och styvhet. Resultaten kan också överföras till andra projekt inom fordonsindustrin med liknande mål.

Preface

This is a master thesis (30 credits) conducted by two students at Chalmers University of Technology at the end of a five-year engineering program. Both students have been studying the engineering program automation and mechatronics complemented with the master program product development. The thesis was chosen based on our interests in automotive engineering and material science combined with innovative concept design.

The thesis was conducted at Volvo Group Trucks Technology in the department of electrical packaging and installation and for the department of product and production development at Chalmers University of Technology.

We would like to thank everyone who has helped us at Volvo GTT. A special thanks to Zoher Bharmal, our supervisor at Volvo GTT and Carmen Boidache, group manager at Volvo GTT. We would also like to thank the polymer supplier Erteco for guidance in polymer materials. Finally we would also like to thank our supervisor and examiner at Chalmers, Lars Almefelt for academically support and feedback during the thesis work.

Thesis Supervisor and examiner: Dr. Lars Almefelt

Table of Contents

Terminology

CAD	Computer Aided Design
Catia V5	CAD software used in this study
CES	Cambridge Engineering Selector, material database and selection software
ECU	Electronic Control Unit
FCR	Fuse Relay Center
FEM	Finite Element Method
FH-16	The flagship model of the trucks developed by Volvo
LHD	Left Hand Drive, steering wheel on the left side
PA	Polyamide, plastic material
Pascal	Unit of pressure, megapascal (MPa) and gigapascal (GPa) are used
PPA	Polyphthalamide, high performance polyamide
PC	Polycarbonates
PET	Polyethylene terephthalate
Polymer	Plastic materials, chemical compounds
PP	Polypropylene, plastic material
RHD	Right Hand Drive, steering wheel on the right side
Tensile Strength	Material property, the stress value required in the material to break
Yield Strength	Material property, the stress value required for permanently deformation
Young’s Modulus	(E-modulus) Material property that corresponds to stiffness
Volvo GTT	Volvo Group Trucks Technology, a Volvo AB business unit

1 Introduction

This master thesis is a product development study within the automotive industry. Common factors that drive research and development in the automotive industry are weight reduction, cost savings and increased performance. These were also the main factors of this project and the overall view of the study was to develop an alternative design with an alternative material.

The purpose of this chapter is to describe why there was a reason for conducting this product development study by presenting the background, purpose, objectives and limitations.

1.1 Background

The background will inform the reader about what object was studied and the current solution as well as a description of the overall feature. Chapter 2 will go into even more details about the current solution and its functions.

1.1.1 Object of Study

The object of study is a structural framework currently used in trucks developed by Volvo Group Trucks Technology. The framework will be referred to as "Dashboard Framework". The current dashboard framework is a complex solution serving several purposes and have many interfaces towards surrounding parts.

1.1.2 Company Presentation

Volvo was founded in 1927 by Assar Gabrielsson and Gustaf Larson as an affiliated company of SKF (Svenska Kullagerfabriken). Volvo Group is today one of the world's leading supplier and developer of heavy duty trucks. The corporation is also a major actor in the areas of buses, construction equipment and marine and industrial engines. Volvo Group is a global company that employs about 115 000 people and in 2012 sales had amounted to about 304 billion SEK. The same year the truck industry represented 63 % of Volvo Group's total net turnover. Volvo's corporate vision is to become the world leader in sustainable transport solutions through their corporate values of quality, safety and environmental care (Volvo Annual Report, 2012).

Volvo Group Trucks Technology, also known as Volvo GTT, is a development unit at Volvo Group. Volvo GTT develop the truck brands Volvo Trucks, Mack Trucks, Renault Trucks, UD Trucks and Eicher Trucks all owned by Volvo Group. Volvo GTT employs about 10 000 people worldwide most of whom are engineers (Volvo Group, 2013).

Figure 1 A Volvo truck model FH-16.

1.1.3 Description of Current Solution

The dashboard framework is a feature that is located in the cab under the dashboard retainer, see figure 2. The feature has the objectives of keeping the fuse relay center (FRC) and electrical boxes, also known as ECUs, in place and handle the wiring to the units within. The dashboard framework also serve the purpose to support the whole dashboard structure.

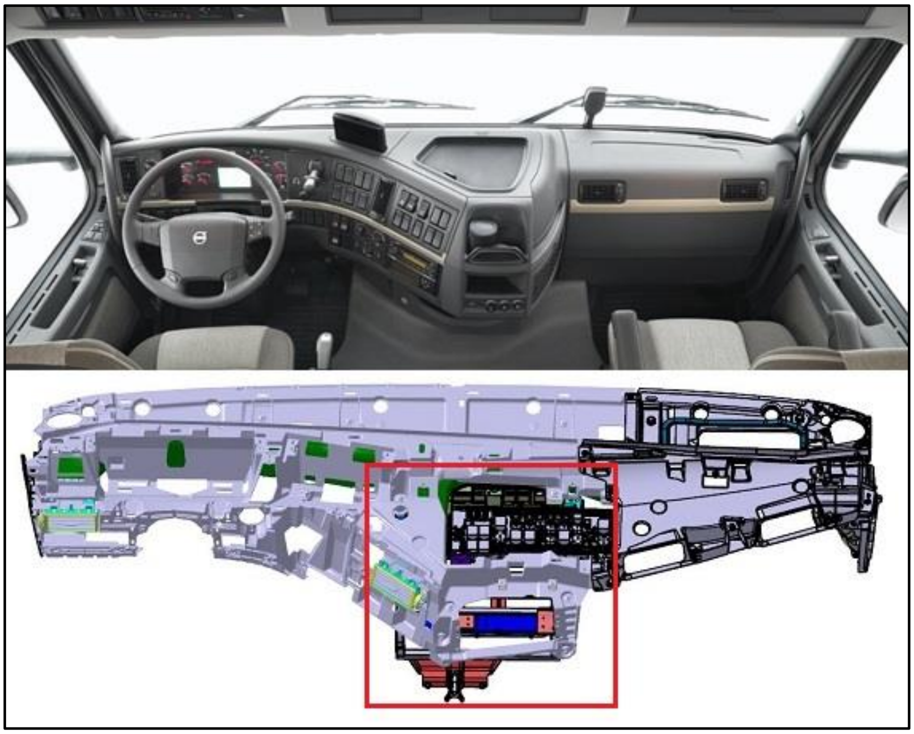


Figure 2. The top shows the interior of a truck and the bottom shows the same without panels.

The dashboard framework is located between the dashboard retainer and the subframe, see figure 3. This makes the dashboard framework an important connection to the dashboard and contribute with increased stability of the structure.

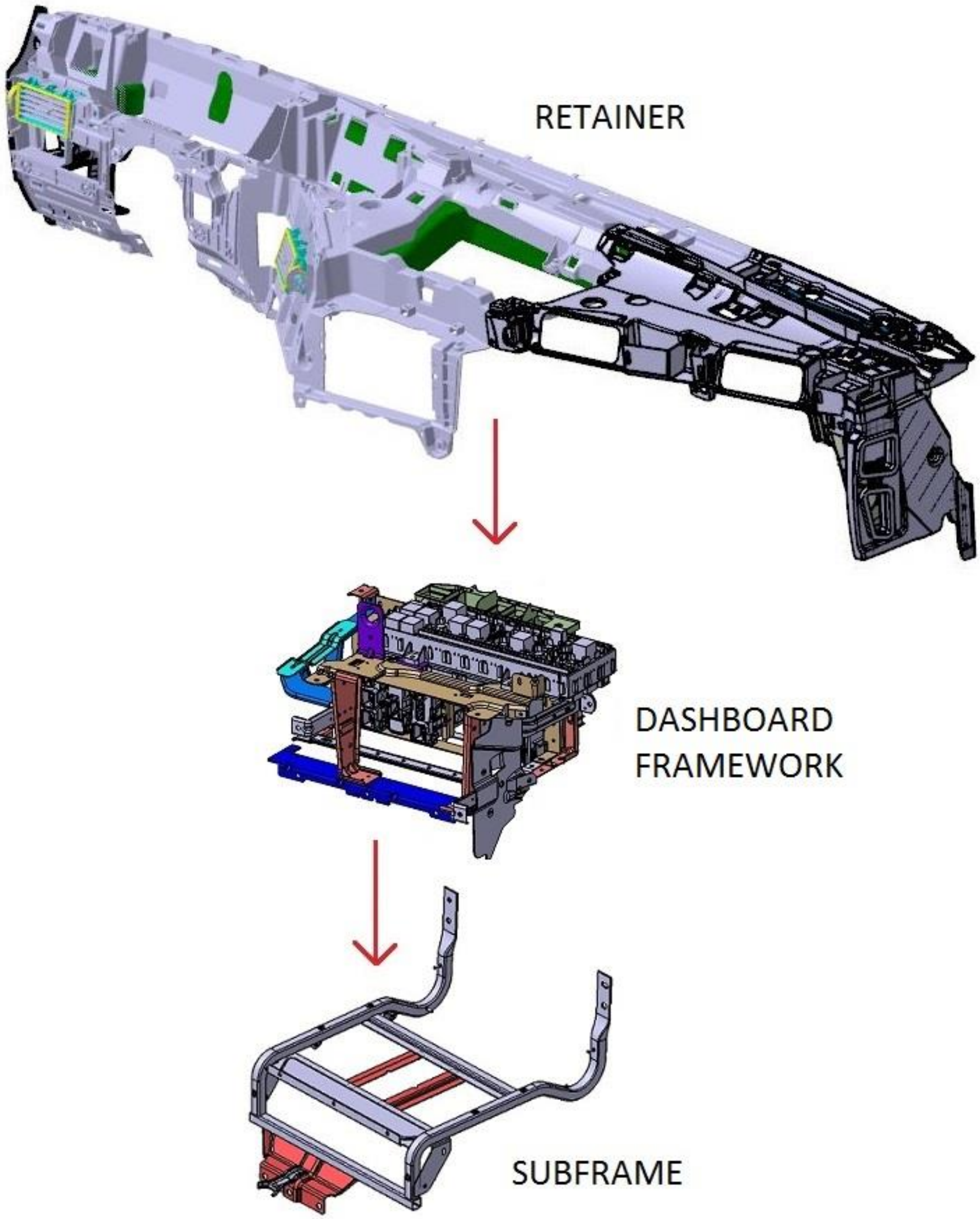


Figure 3. A simple explode view of the main parts of the dashboard structure showing the dashboard retainer, dashboard framework and subframe.

The specific ECUs in the dashboard framework can be seen in figure 4 and are the following.

FRC	(Fuse Relay Center)
CIOM	(CAB Input Output Module)
HMIIOM	(Human Machine Interface I/O Module)
VS	(Video Switch)
ALARM	(Anti-Theft Alarm)
DACU	(Driver Assistance Control Unit)
BBM	(Body Builder Module)

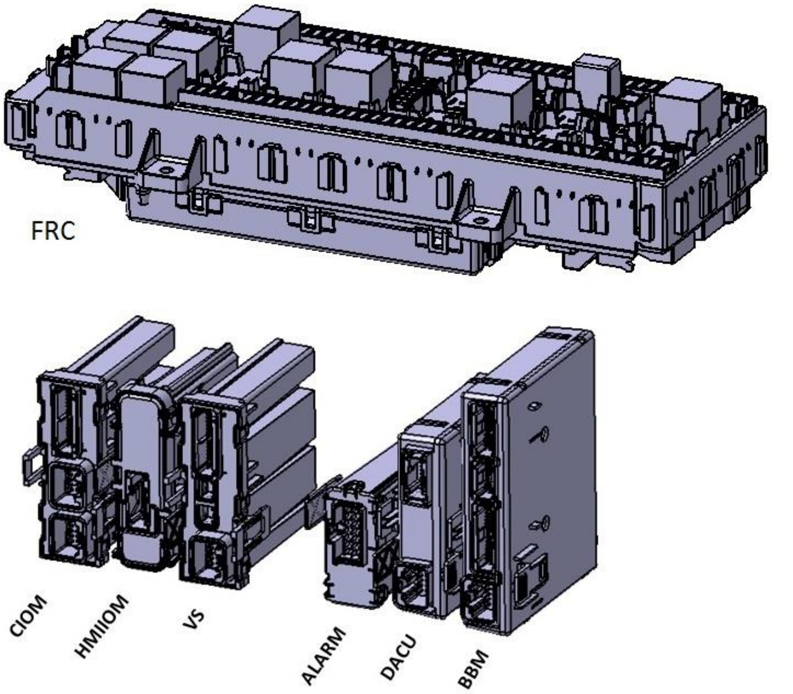


Figure 4. All ECUs and the FRC located in the dashboard framework.

This design of the dashboard framework is used in the latest series of Volvo trucks, the FH-series. The latest FH-series was released in 2012 and is considered to be the flagship product of Volvo Trucks, see figure 1 on page 2 (Volvo Group, 2013).

Current Solution

The current solution for the dashboard framework is a structure consisting of steel sheet metal brackets joined together. The sheet brackets are welded together by a subcontractor and delivered to Volvo as 6 delivery units. The whole current solution of the dashboard framework can be seen in figure 5.

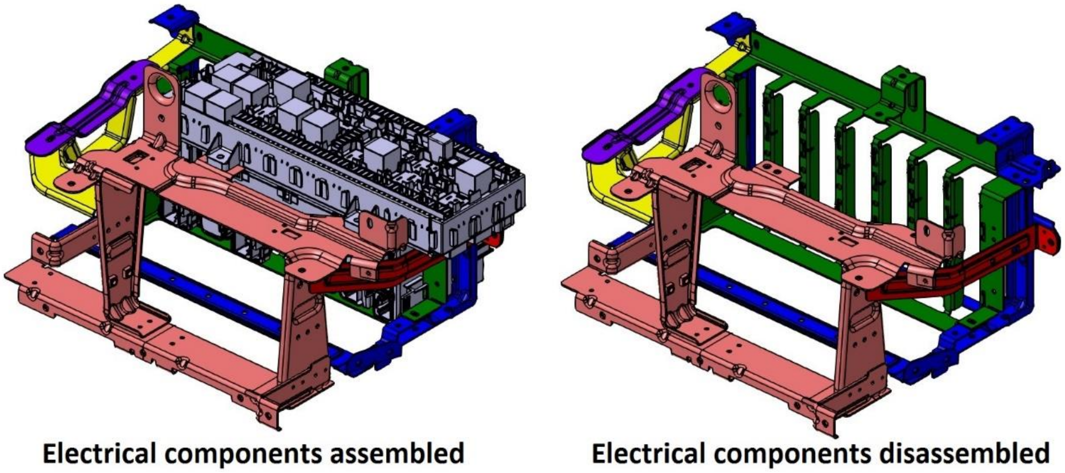


Figure 5. The current solution of the dashboard framework used in today's FH-series Volvo trucks.

The following is a description of each delivery unit of the dashboard framework and the order in which they are assembled together. The numbers correspond to the numbers in figure 6 and the colors correspond to the colors in figure 5.

1. Framework Rear (Blue)

- Consists of 8 different parts and a total of 9 parts.
- Serves the purpose of connecting the dashboard framework to both the retainer and the subframe and lies as a ground for additional delivery units of the dashboard framework and the FRC.

2. Framework Front (Pink)

- Consists of 6 different parts and a total of 8 parts.
- Serves the purpose of connecting the dashboard framework to both the retainer and the subframe and acts as a ground for additional delivery units of the dashboard framework and the FRC. Also include a lifting anchor that is used when assembling the dashboard in the cabin.

3. Framework ECU (Green)

- Consists of 2 different parts and a total of 2 parts.
- Serves the purpose of allowing attachment for the ECUs.

4. Support Bracket (Red)

- Consists of 1 part.
- Serves the purpose of increasing the stability and strength of the dashboard framework.

5. Support Bracket FRC (Yellow)

- Consists of 1 part.
- Serves the purpose of increasing the stability and strength of the dashboard framework and allow guiding for cables to ECUs.

6. FRC Harness Lock Bracket (Purple)

- Consists of 1 part.
- Serves the purpose of locking the cables resting on “Support bracket FRC”.

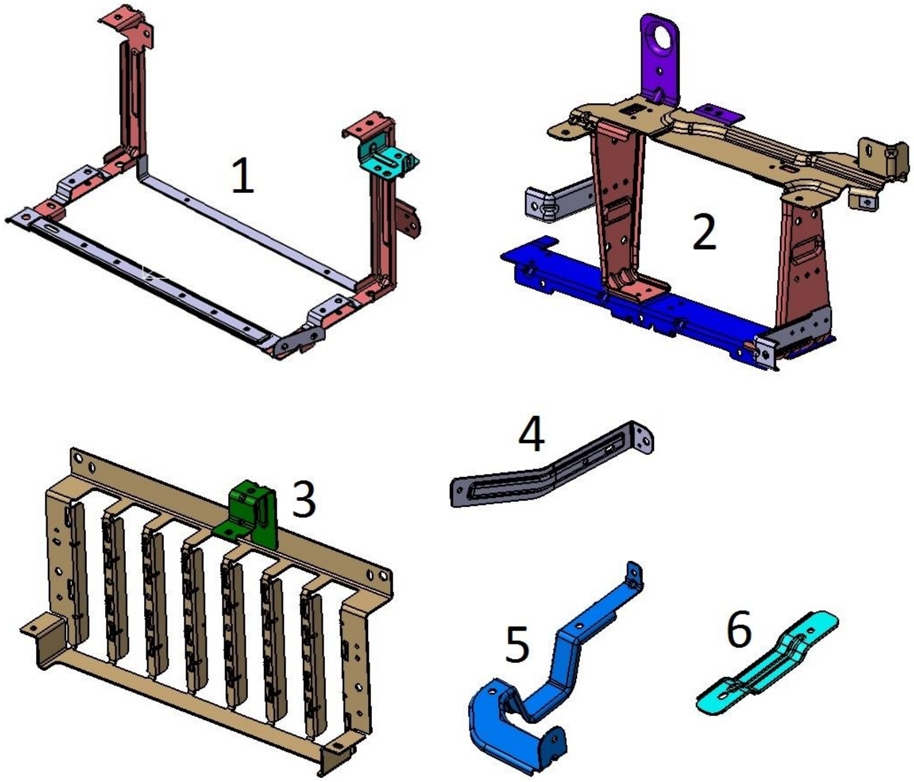


Figure 6. A montage of all delivery units of the dashboard framework. The number correspond to the previous list of descriptions.

All in all there are 19 different parts and a total of 22 parts. This contributes to a weight of about 5,5 kg, high tool cost and high assembly time. Also the design has fairly low flexibility and requires 3 parts to be mirrored for RHD (right hand drive) trucks that require additional tools. The low flexibility also limits possibilities for future changes in the electronic units. Because of this there are many aspects of this design that have room for improvements.

1.2 Purpose

This project is a design project with the goal to find an alternative solution to the current dashboard framework solution that is used in Volvo's FH-series trucks today. The focus of the project will be to develop concepts that utilizes alternative materials to steel. The concepts have to fulfill the strength, assembly and aftermarket demands that exists today. Another focus of the development will be on reducing the weight. This would also allow for the possibility of reducing the part price and tool costs.

The development of new concepts also have a focus on reducing the assembly and manufacturing time in comparison to the current solution. Another focus will be on making the concepts more flexible and modular. This in order to simplify the change between LHD (left hand drive) and RHD and also to be better prepared for future changes regarding wiring and ECU-boxes.

1.3 Objectives

The objectives of this project are to develop solutions that have:

- Alternative material evaluations
- Reduced weight
- Reduced number of parts
- Flexible design
- Reduced assembly time
- Reduced production cost
- Ensured quality and performance

1.4 Problem Formulation

The current solution has a large number of sheet metal parts and a large number of different parts with complex geometry. This causes high weight, high tool cost as well as a high manufacturing and assembly time in comparison to solutions that would utilize lighter materials and fewer number of parts. The design of the current solution also has low flexibility that limits electrical changes in the future and causes additional number of parts to be required for dual steering side compatibility.

Hypothesis:

Using materials that can be injection molded or die casted will allow for a lighter design and a cheaper overall part and tool cost.

Injection molded and die casted materials will also allow for a more flexible design with a lower number of parts and shorter assembly time.

Questions:

Could alternative materials be used that are not steel and still meet all requirements while being a cheaper solution?

Will it be possible to use one kind of alternative material for the whole solution or is a combination with different materials a valid solution?

What are the challenges when redesigning an existing solution in respect to alternative materials?

Can a cheaper solution be compatible with both LHD and RHD trucks while having no additional side specific parts and a large decrease of total parts?

1.5 Limitations

Design

Individual parts and delivery units of the new solution will not be designed to replace or upgrade trucks on the road today using the current solution. However, if a total dashboard replacement is needed of a truck using the current solution the new solution could be used instead. The new solution will not be designed to allow any kind of mechanical structure maintenance of the dashboard framework as there should not be any need of it. Individual parts or delivery units do not have to be designed to allow for individual replacement if certain parts of the dashboard framework breaks. Should an event occur where parts of the dashboard framework break, such as a high force collision, the whole dashboard framework will be replaced. No redesign of electrical components. The current electrical boxes and cables will be used as input for the design parameters. No B- and C-interfaces are to be changed (B-interface: Dashboard framework vs. subframe/retainer), (C-interface: dashboard framework vs. ECUs and FRC/VMCU). No repositioning of the lift anchor point on the dashboard framework (see delivery unit number 2 on page 7, purple part).

Analysis

Advanced strength calculations that take the whole dashboard into consideration will not be conducted by the thesis workers. This may be conducted by a calculation department at Volvo GTT after the final detailed design has been completed. Simple FEM analysis will be conducted on only a few concepts. Vibration and durability tests will not be conducted during the master thesis project as this require a working prototype.

Economical

Total detailed cost analysis was not conducted by the thesis workers. Instead manufacturing estimations were calculated with guidance from subcontractors and estimation services for specific materials and designs. Other costs such as assembly and transport were set to be the same as the current solution and therefore not calculated.

Outcome of the thesis

The outcome of the master thesis project is not a working prototype as the time length of the project did not permit it. The outcome of the project is a suggested design solution and material option based on a sequence of methodologies, both from literature and developed by the thesis workers. The readiness level of the outcome is a virtual design presented in a CAD environment. The new solution possesses competitive features supported by different kinds of analyses that was conducted by the thesis workers.

1.6 Outline of the Thesis

This thesis is presented in a chronological order. This means that the chapters and key assignments are presented in the order of when they were conducted. The purpose of having this outline was to give the reader a better flow when reading and avoiding the requirement to go back and forth through the pages in order to get a deeper understanding. This means there is no separate chapter for the theory of methods used. This is instead combined with the chapter describing the use and results of the method.

Chapter 2 will go through the studies that were conducted in the beginning to understand the current solution and generate data that was required for later analyses and design choices. This includes requirement specification for a new solution, understanding current parts, interfaces and surrounding parts as well as cost, FEM, assembly and function analysis of the current solution.

Chapter 3 consists mainly of material evaluation. The purpose of this chapter is to describe how suitable materials were identified. The chapter will chronologically describe the means of how this was achieved by starting with all materials and narrow it down to the most suitable through various requirements along the way.

Chapter 4 describes the concept generation and selection procedures. This chapter is linked to the requirement specification described in chapter 2 (and appendix A).

Chapter 5 starts with the outcome of chapter 4 (concept selection) and combines this with the outcome of chapter 3 (material option evaluation) and go through a series of analysis in order to find the best concept design and material combination.

Chapter 6 present the outcome of the previous chapter (the proposed concept solution). This is done by identifying the most cost effective high performing design and material combination.

Chapter 7 is the discussion where the thesis workers have taken some time to reflect on the methods used and how the study was conducted. This was done in order to establish weaknesses and strengths of the execution of this master thesis. The general applicability of the approach is also discussed.

Chapter 8 will conclude this thesis and suggest recommendations for future work.

1.7 Methodological Approach

This section describe the methodological approach that was applied to this study. The approach for applying methods was both based on literature and developed by the thesis workers. The combination between these two sources led to be a powerful methodology when the purpose is to find new materials and develop a new design for an existing solution.

The approach used for the pre-study of the current solution was mostly based on common methods used assessing an existing solution and assessing requirements and desires of a new solution. This includes requirement specification and functional analysis based on literature. Assessing the strength of current solution was also included here. The chosen strength analysis cases were based on Volvo data, these cases were also used in the concept analysis phase. Additional methods in the pre-study are part and interface mapping, cost analysis and simple assembly analysis. These methods were developed by the thesis workers based on what data was available and to make the results to fit the purpose better as these were inputs for later parts of the study.

Following the pre-study there are two major parts in the study that were running as parallel activities, meaning they were conducted more or less at the same time. These were the material option evaluation and the concept design generation, evaluation and selection. The approach for the material option evaluation was to start with having all kinds of materials as a possible material option and then narrowing it down to a short list of materials. This approach works well with the software used, Cambridge Engineering Selector (Granta Design 2013). Furthermore, strength analysis of a simple CAD was conducted by applying suitable materials and varying the thickness in order to narrow down the list even further and identify potential for improvements using the specified material. This approach was developed by the thesis workers to fit the purpose.

The approach for the concept design generation, evaluation and selection was largely based on literature. The process started with idea generation which in an overall sense was approached as described in literature (Ulrich & Eppinger, 2012). When examining the specific methods applied to the problem in the idea generation phase the methods were developed by the thesis workers to fit the purpose. Following the idea generation a more traditional methodology was applied following assessment of concepts based on requirements and comparing concepts to a reference as described by Ulrich & Eppinger (2012). Finally the concepts were scored individually following the method described by Johannesson et al (2004).

The reason for having the material option evaluation and the concept generation, evaluation and selection running at the same time was due to the fact that they complemented each other in several ways. This is most evident in the idea generation phase as initial concepts are created not knowing what kind of material they should have. This allowed the thesis workers to expand the initial limitation of the concept generation. As the concept screening and selection started the material option evaluation had matured as well contributing with information to the screening process. This was very useful when taking decision in the process that led to final design choices.

Following the design choices and material options was the concept refinement. The methodology used for concept refinement was defined by the thesis workers and in essence was an iterative process using CAD and FEM tools in order to meet desired results if possible. The methodology used to end up with a final recommendation was developed by the thesis workers and consist of several methods. The basis of the methodology is to be able to compare the chosen concept designs with the current solution. This was done by applying different materials on different parts that in turn created new concepts. These new concepts have, in addition to a design property, a material property stating the materials for each part. These materials was chosen based on the material option evaluation. By doing this, several analyses could be conducted and compared to the current solution. This includes strength analysis cases as defined by Volvo, simple assembly analysis, weight analysis and cost analysis. The cost analysis method was defined by the thesis workers and based on the available data of the current solution in order to be able to compare them. The costs was presented in several ways to fit the industry and timeline.

Finally, the approach used in order to find the best design choice and material option was chosen to be a cost vs performance graph. This plots all concepts based on their cost and their performance rating. This is a common method that is used to identify the most cost effective concept. The method for setting the performance rating was defined by the thesis workers and based on data from the analyses conducted in comparison to the current solution.

2 Study of Prerequisite for Design and Material Evaluation

This chapter will go through all the initial work and studies that were required in order to produce enough information that would enhance the concept generation. It includes methods for mapping the functions, parts and interfaces of the current solution and identification of requirements and desires for a new solution. Furthermore, additional assessments of the current solution such as cost analysis and strength analysis are included that are used as comparison data when conducting analyses on new solutions.

2.1 Stakeholders

The stakeholders in this project can be divided into two categories, direct and indirect. Direct stakeholders are groups that will notice a difference if a new solution is applied. Indirect stakeholders on the other hand will not notice a difference that can be linked to the feature but still interact with the surroundings of the feature. (Bonner, 2010)

Direct stakeholders:

- Manufacturing, subcontractors
- Assembly, Volvo and subcontractors
- Suppliers to subcontractors
- Product manager, Volvo GTT
- Product development, Volvo GTT
- Electrical installation
- Aftermarket service

Indirect Stakeholders:

- Truck owners
- Truck drivers

For this project the focus was on fulfilling the requirements from the direct stakeholders as the indirect stakeholders, truck owner and driver, don't have any specific customer needs regarding this feature.

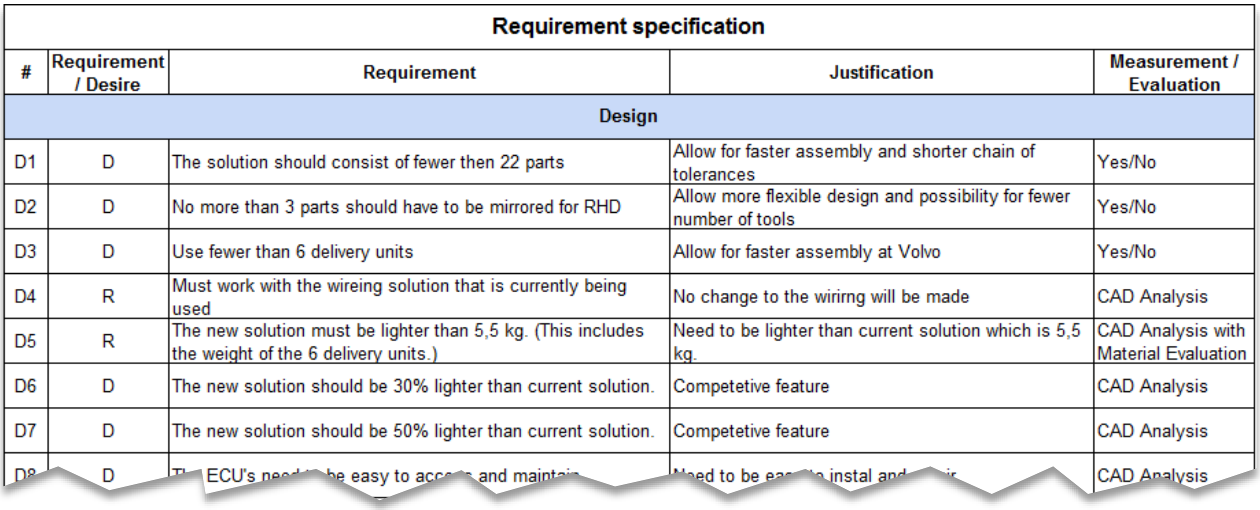
2.2 Requirement Specification

There are two main functions that a requirement specification contribute with. The first function is to give an input to the concept generation process. The second function is to provide information for the evaluation of concepts that leads up for final concept selection (Roozenburg and Eekels, 1995). The requirement specification describes the requirements a product need to fulfill and usually also include the desires that the product should fulfill. The specifications are normally established early in the process but are usually revised more than once in order to adjust for changes or increased knowledge about certain aspects (Ulrich and Eppinger, 2012).

For this project the work with requirement specification had two main phases. First phase was the initial creation of the requirement specification that set the direction and inputs for the concept generation process. The accuracy and depth of the requirements and desires at that point were low in order not to limit the concept generation too much as the knowledge of the product was still low at the time. The second work phase of the requirement specification was conducted after the concept selection had been completed. This phase had the main purpose to adjust and narrow down metrics for the requirements and desires based on chosen concepts and gained knowledge. In addition to these two main phases the requirement specification was updated along the way as needed.

The format used for the requirement specification was a spreadsheet layout with a new requirement or desire on each row. The columns represent different characteristics of the specification. The first column indicates what category the specification belongs to and its number. The second column specifies if it is a requirement "R" or a desire "D". The third column specifies justification for the requirement or the desire, why it is important and for whom. The fourth column specifies how the requirement or desire is evaluated and measured. For an excerpt of the requirement specification see table 1, see appendix A for the full requirement specification.

Table 1. A small part of the requirement specification, full specification can be seen in appendix 1.



Requirement specification

#	Requirement / Desire	Requirement	Justification	Measurement / Evaluation
Design				
D1	D	The solution should consist of fewer then 22 parts	Allow for faster assembly and shorter chain of tolerances	Yes/No
D2	D	No more than 3 parts should have to be mirrored for RHD	Allow more flexible design and possibility for fewer number of tools	Yes/No
D3	D	Use fewer than 6 delivery units	Allow for faster assembly at Volvo	Yes/No
D4	R	Must work with the wireing solution that is currently being used	No change to the wirirng will be made	CAD Analysis
D5	R	The new solution must be lighter than 5,5 kg. (This includes the weight of the 6 delivery units.)	Need to be lighter than current solution which is 5,5 kg.	CAD Analysis with Material Evaluation
D6	D	The new solution should be 30% lighter than current solution.	Competetive feature	CAD Analysis
D7	D	The new solution should be 50% lighter than current solution.	Competetive feature	CAD Analysis
D8	D	Th ECU's ne be easy to acc and maint	eed to be eas instal and ir	CAD Analysis

2.3 Assessment of Current Solution

2.3.1 Internal Parts

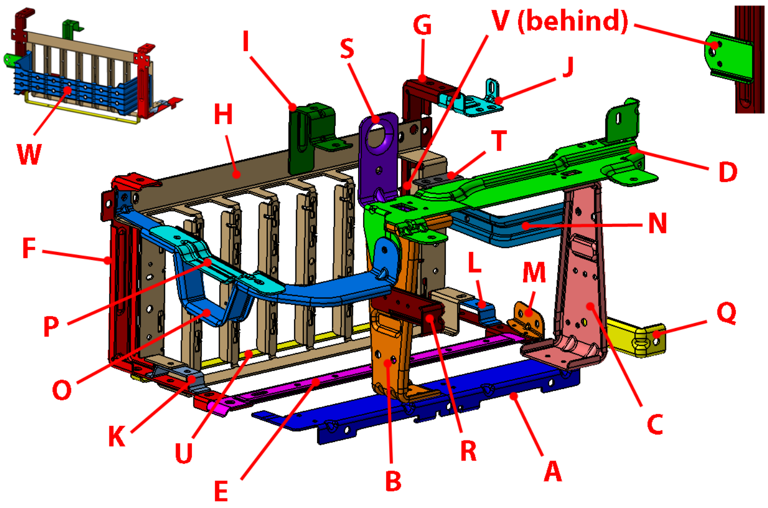


Figure 7. All parts of the current solution labeled with letters.

Understanding the current solution is essential in order to develop a new solution. One way of gathering information that increase the understanding is to identify and map all parts of the current solution. This approach is a part of the reversed engineering methodology where you disassemble a product in order to map all parts, their functions and abilities (Otto & Wood, 1996).

The current solution has 23 parts in total that is of concern for this project when developing a new solution. These parts are either welded or screwed together. 22 of these parts makes out the 6 delivery units that are assembled with screws directly on the dashboard. Three parts require to be mirrored for RHD trucks. Figure 7 illustrate all parts labeled with a letter and are explained in the list that follows.

A - Bottom Plate. Connects the front bracket to the subframe.
B and C - Left and Right Arm. Support the top plate and various other parts.
D - Top Plate. Connects the front bracket to the retainer.
E - Middle Bar. Guide cables for the ECUs.
F and G - Left and Right leg. Connects the retainer to the subframe and fasten the ECU frame.
H - ECU Frame. Hold all the ECUs in place.
I - Top Bracket. Connect the top support bracket and the FRC.
J - Rear FRC Extender. Connect the FRC and guide cables.
K and L - Left and Right Offset. Allow the ECU frame to be connected.
M - Angled Fix. Connect BBM and cable protection.
N - Right Support. Connect the front bracket with the rear bracket.
O - Left Support. Connect the front bracket with the rear bracket and harness cable for the FRC.
P - Harness Lock. Lock the cables for the FRC and strengthen the support.
Q and R - Left and Right Connector. Connect the retainer to the front bracket.
S – Lifting Anchor. The interface used when lifting the dashboard during assembly.
T - Front FRC Extender. Allow a fourth connection to the FRC by using a movable surface.
U - Rear Bar. Support ECU assembly.
V - Support Connector. Allow the left support to be assembled.

W - Support Bracket ECU. Support the ECUs and is the only plastic part.

2.3.2 Function Analysis

A function analysis is a decomposition of the functions of a system. The main purpose for conducting a function analysis is to be able to describe complex systems and identify problems on several levels of a system. There are several approaches for conducting a function analysis and also several ways of illustrating the function decomposition. Two typical methods of conducting a function analysis is using a process (flow) model or a function-means tree. The process (flow) model is a good model when there is a clear flow of certain factors in the system. These factors are usually energy, information and material. The function-means tree on the other hand is a hierarchy of subordinate functions and their means with the main function at the top. (Andreasen, 1980)

An approach that is shared among many methods is to begin with defining the system's main function and then decompose it to sub-functions. Each function is typically described using a verb and a noun such as "absorb energy". (Andreasen, 1980)

For this project the main reason for the function analysis was to analyze the system of the current solution in order to get a better understanding of it and assist in finding areas of improvement. A function analysis was conducted after the initial requirement specification and during the time of identifying parts and interfaces of the current solution, see figure 8. The approach used to do this was a function means tree diagram, see figure 8. This approach was chosen since it was hard to identify a flow that is required for a process flow model.

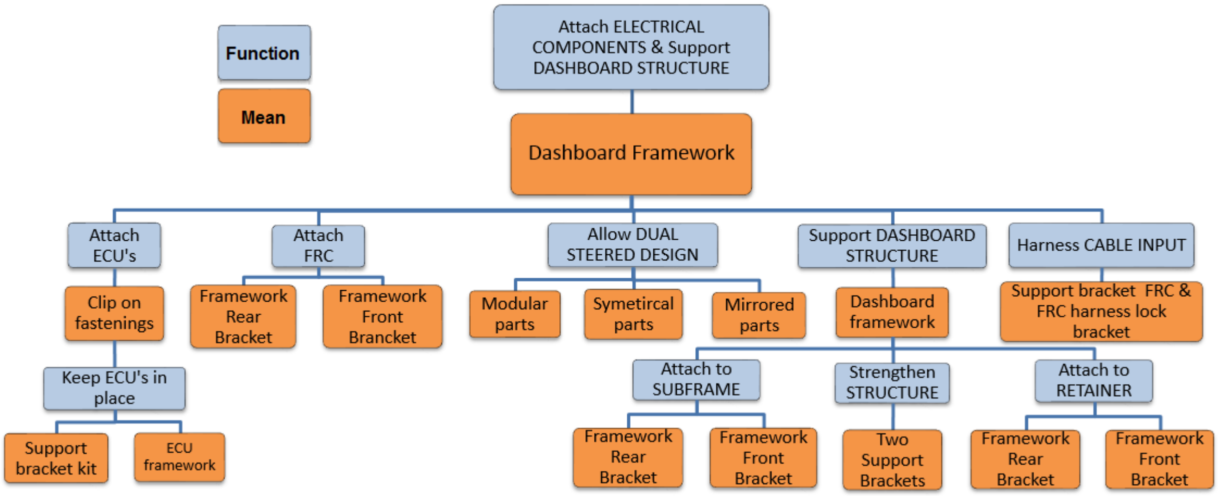


Figure 8. A function means tree diagram of the current solution.

2.3.3 Cost Analysis

An important factor when evaluating new concepts is the cost. As described earlier the framework consist of 22 parts which are put together to 6 delivery units plus an additional plastic bracket. The part and tool price for these units can be seen in table 2.

Table 2. A table showing part and tool prices of the current solution.

Part		Part Price (SEK)		Tool Price (SEK)	
		LHD	RHD	LHD	RHD
1	Bracket Framework Rear	75,15	91,50	2 227 600	307 000
2	Bracket Support FRC (Left)	11,93	15,00	790 000	790 000
3	Bracket FRC Harness Lock	3,99	3,99	200 000	-
4	Framework Front Bracket	100,49	110,00	1 440 000	870 000
5	ECU Framework Bracket	43,50	51,90	1 868 000	-
6	Support Bracket (Right)	4,95	6,90	310 700	310 700
7	Shafting Protection	3,91	3,91	No Info	No Info
8	Support Bracket Kit	7,10	7,10	No Info	No Info
Total Price		251,02	290,30	6 836 300	2 277 700

The prices are based on an annual production quantity of 55 059 parts for LHD trucks and 4 397 parts for RHD trucks. The part price consists of costs for material, labor and processes such as shaping, welding and painting. Differences in tool cost between LHD and RHD trucks comes from the fact that some of the parts are identical for both and only need one tool.

In order to better understand the costs within each part a so called “cost split up” was reviewed for one delivery unit. In table 3 a cost split up is shown for the delivery unit “Bracket Framework Rear” with its included parts and manufacturing processes.

Table 3. A table showing a cost split up of one of the delivery unit.

#	**Part Name**	**Part No.**	**Material Cost (SEK)**	**Production Cost (SEK)**	**Post Process Cost**	**Additional Elements (SEK)**	**Total Part Cost (SEK)**	**Tooling Cost (SEK)**
Product:	**Bracket Framework Rear**	**82249679**						
1	Bracket Harness Fixation	82249686	1,83	1,50			3,33	225000
2	Bracket Support Fixation	82269023	0,38	0,87	1,16	0,09	2,50	95000
3	Bracket Left Leg	82269040	2,91	2,44	3,57	0,36	9,28	455000
4	Bracket Right Leg	82269041	3,17	2,44	3,14	0,27	9,02	455000
5	Bracket ECU Fix 1	82299950	0,34	0,71	1,11	0,09	2,25	150000
6	Bracket ECU Fix 2	82299950	0,34	0,69	1,11	0,09	2,23	
7	Bracket X-steering	82334961	1,04	1,71			2,75	165000
8	Bracket	82425351	0,35	0,94	1,88	0,18	3,35	90000
9	Bracket	82425337	0,75	1,02	1,88	0,18	3,83	190000
	Welding 1				4,23		4,23	45000
	Welding 2				3,88		3,88	42000
	Welding 3				4,23		4,23	45000
	Welding Final				17,15		17,15	175000
	Painting				7,12		7,12	
	Total						**75,15**	**2132000**

Material and Shaping Cost (% of total part cost)	31,2
Welding and Painting Cost (% of total part cost)	68,8

Viewing the costs in the table it is possible to identify different cost categories. First of all the raw material price of the steel sheet metal used is 6,38 SEK/Kg. For this kind of delivery unit the cost of the welding and painting adds up to be almost 70 % of the part cost. This can be identified as an area for potential cost savings if an alternative material and design were to be utilized instead, which would not require this step in the manufacturing process. Welding 1 through 3 is the internal welding required between smaller parts and welding final is putting all parts together to the final delivery unit.

2.3.4 Strength Analysis

In order to test the dimensional stability and strength of the current solution and be able to compare it to the new concepts a number of FEM (Finite Element Method) cases were calculated. These calculations were implemented by the thesis workers and investigated how the current solution handled forces and vibrations during normal usage, misuse and while being assembled.

Analysis Cases

For the normal usage phase there were four tests conducted. Three different accelerations were applied in the vertical, longitudinal and lateral direction. This would simulate how the console would behave when the truck is braking, driving over a bump and turning left and right. The acceleration data that were used were the maximum values that had been gathered by Volvo during tests on a real track.

When testing for misuse the case was that a person with a weight of 100 kg was to sit on the dashboard. The load was divided on four points on the framework, two in the front with a force of 350N each and two in the back with 150N each.

An assembly test was conducted that simulated the forces applied on the framework when the whole dashboard is lifted into the truck during assembly. During the assembly the dashboard is lifted in three points, one of them being the lifting anchor on the dashboard framework. The lifting anchor is lifting 60kg and must be able to handle an acceleration of 2G. Since simulating this test on the whole dashboard would be too difficult, the simulation was done on the framework with a force of 1200N applied on the lifting point while treating the dashboard framework as fixed to its surroundings.

Finally a vibration test was conducted. The test was to find out at which frequencies the framework could start self-pulsation and to make sure these frequencies were not interfering with Volvo standards.

Results

The results of the analysis can be seen in table 4. These results will be used later in the thesis to compare with new solutions.

Table 4. FEM results of the analysis cases for the current solution.

	Current Solution				
Test	Stress (Mpa)				Displacement (mm)
	Max Spike	% of Yield	Max Estimate	% of Yield	
Acceleration Vertical	236	60%	145	37%	0,85
Acceleration Longitudinal	219	56%	180	46%	1,02
Acceleration Lateral	367	94%	270	69%	1,3
Lift	704	179%	210	54%	1,27
Sit on Dashboard 100kg	1260	321%	790	201%	4,81

The result of the frequency test showed that none of the oscillations interfered with the Volvo standards.

2.3.5 Final Assembly of Current Solution

While the current solution has many parts welded together by a subcontractor there are still seven delivery units, including the support for the ECUs, which are assembled on to the truck by Volvo. This assembly sequence is referred to as the final assembly. Table 4 shows the assembly relations between the delivery units and the means used for connecting them. This data was gathered in order to allow for a simple assembly comparison when evaluating new solutions.

Table 4. A table showing the assembly methods and relations of the current solution.

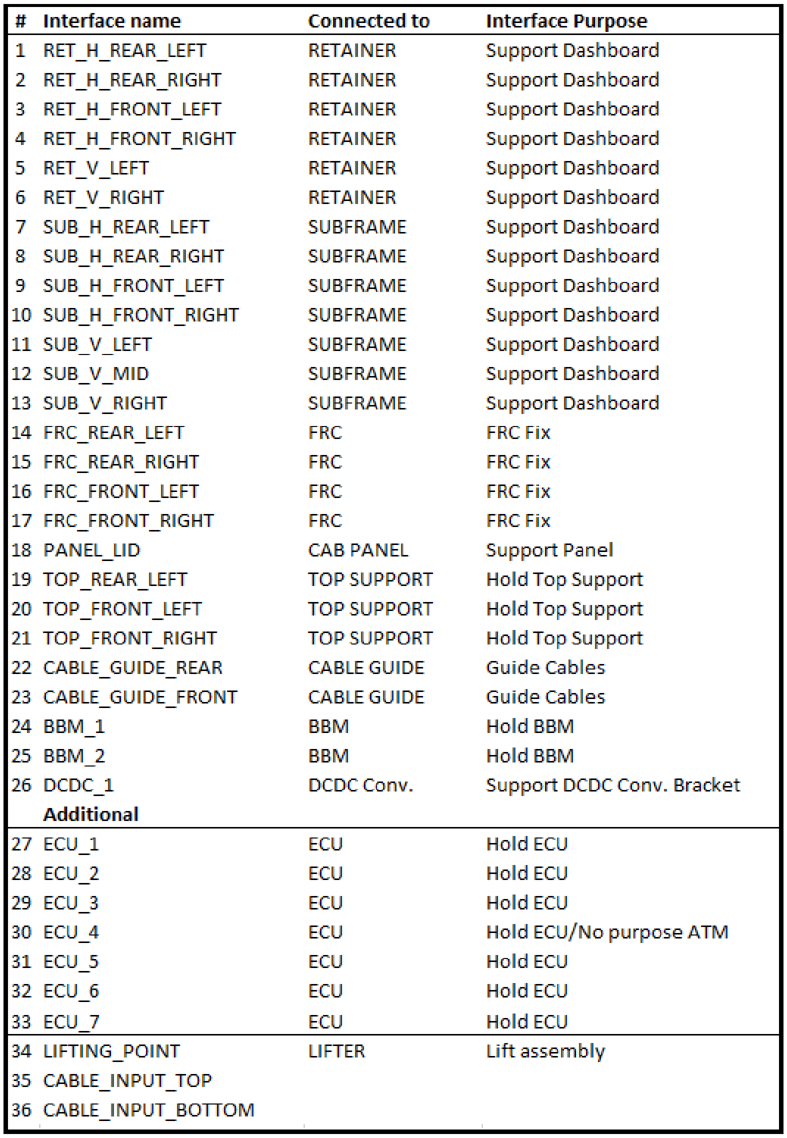
Assmebly Current Solution			
Part	**Assembled on to**	**Assembled with**	**Quantity**
Framework Rear	Subframe	M6 Screws	4
Framework Front	Subframe	M6 Screws	3
Framework ECU	Framework Rear	M6 Screws	4
Support Bracket ECU	Framework ECU	PF5x16	4
Support Bracket	Framework Front	M6 Screws	1
Support Bracket	Framework Rear	M6 Screws	1
Support Bracket FRC	Framework Front	M6 Screws	1
Support Bracket FRC	Framework Rear	M6 Screws	1
FRC Harness Lock Bracket	Support Bracket FRC	M6 Screws	2
Total		Screws	21

2.4 Interfaces and Surrounding Parts

The main challenge when developing a new solution is to meet all the surrounding interfaces in an efficient way. The dashboard framework is connected to many surrounding parts and is therefore required to meet many interfaces. These interfaces are important for the whole dashboard structure and have the functions of supporting the dashboard, holding electrical units, guide cables and making it possible to lift the whole dashboard during assembly.

To get a better understanding of what interfaces that need to be met with a new design, all interfaces were mapped using the current CAD models of all connecting parts of the dashboard. The interfaces were then labeled and can be seen in table 5. The dashboard framework has in total 26 surrounding interfaces and an additional 7 interfaces that can be used to snap on ECUs.

Table 5. A lists of all the interfaces to surrounding parts. These had to remain the same for the new solution



#	Interface name	Connected to	Interface Purpose
1	RET_H_REAR_LEFT	RETAINER	Support Dashboard
2	RET_H_REAR_RIGHT	RETAINER	Support Dashboard
3	RET_H_FRONT_LEFT	RETAINER	Support Dashboard
4	RET_H_FRONT_RIGHT	RETAINER	Support Dashboard
5	RET_V_LEFT	RETAINER	Support Dashboard
6	RET_V_RIGHT	RETAINER	Support Dashboard
7	SUB_H_REAR_LEFT	SUBFRAME	Support Dashboard
8	SUB_H_REAR_RIGHT	SUBFRAME	Support Dashboard
9	SUB_H_FRONT_LEFT	SUBFRAME	Support Dashboard
10	SUB_H_FRONT_RIGHT	SUBFRAME	Support Dashboard
11	SUB_V_LEFT	SUBFRAME	Support Dashboard
12	SUB_V_MID	SUBFRAME	Support Dashboard
13	SUB_V_RIGHT	SUBFRAME	Support Dashboard
14	FRC_REAR_LEFT	FRC	FRC Fix
15	FRC_REAR_RIGHT	FRC	FRC Fix
16	FRC_FRONT_LEFT	FRC	FRC Fix
17	FRC_FRONT_RIGHT	FRC	FRC Fix
18	PANEL_LID	CAB PANEL	Support Panel
19	TOP_REAR_LEFT	TOP SUPPORT	Hold Top Support
20	TOP_FRONT_LEFT	TOP SUPPORT	Hold Top Support
21	TOP_FRONT_RIGHT	TOP SUPPORT	Hold Top Support
22	CABLE_GUIDE_REAR	CABLE GUIDE	Guide Cables
23	CABLE_GUIDE_FRONT	CABLE GUIDE	Guide Cables
24	BBM_1	BBM	Hold BBM
25	BBM_2	BBM	Hold BBM
26	DCDC_1	DCDC Conv.	Support DCDC Conv. Bracket
	Additional		
27	ECU_1	ECU	Hold ECU
28	ECU_2	ECU	Hold ECU
29	ECU_3	ECU	Hold ECU
30	ECU_4	ECU	Hold ECU/No purpose ATM
31	ECU_5	ECU	Hold ECU
32	ECU_6	ECU	Hold ECU
33	ECU_7	ECU	Hold ECU
34	LIFTING_POINT	LIFTER	Lift assembly
35	CABLE_INPUT_TOP		
36	CABLE_INPUT_BOTTOM		

Example: RET_H_REAR_LEFT = RETAINER_HORIZONATAL_REAR_LEFT

This means the connection to the retainer in a horizontal alignment located in the rear to the left viewing from front to rear.

The table also lists the connecting part for each interface and its main purpose. The main parts connected to the dashboard framework are identified as the retainer and the subframe. These interfaces represent the function of supporting the dashboard structure. Apart from the electrical components the additional parts connected to the dashboard framework are identified as cab panel, body building module, top support, DC/DC converter bracket and cable guides. The corresponding interfaces are graphically illustrated in figure 9 and 10.

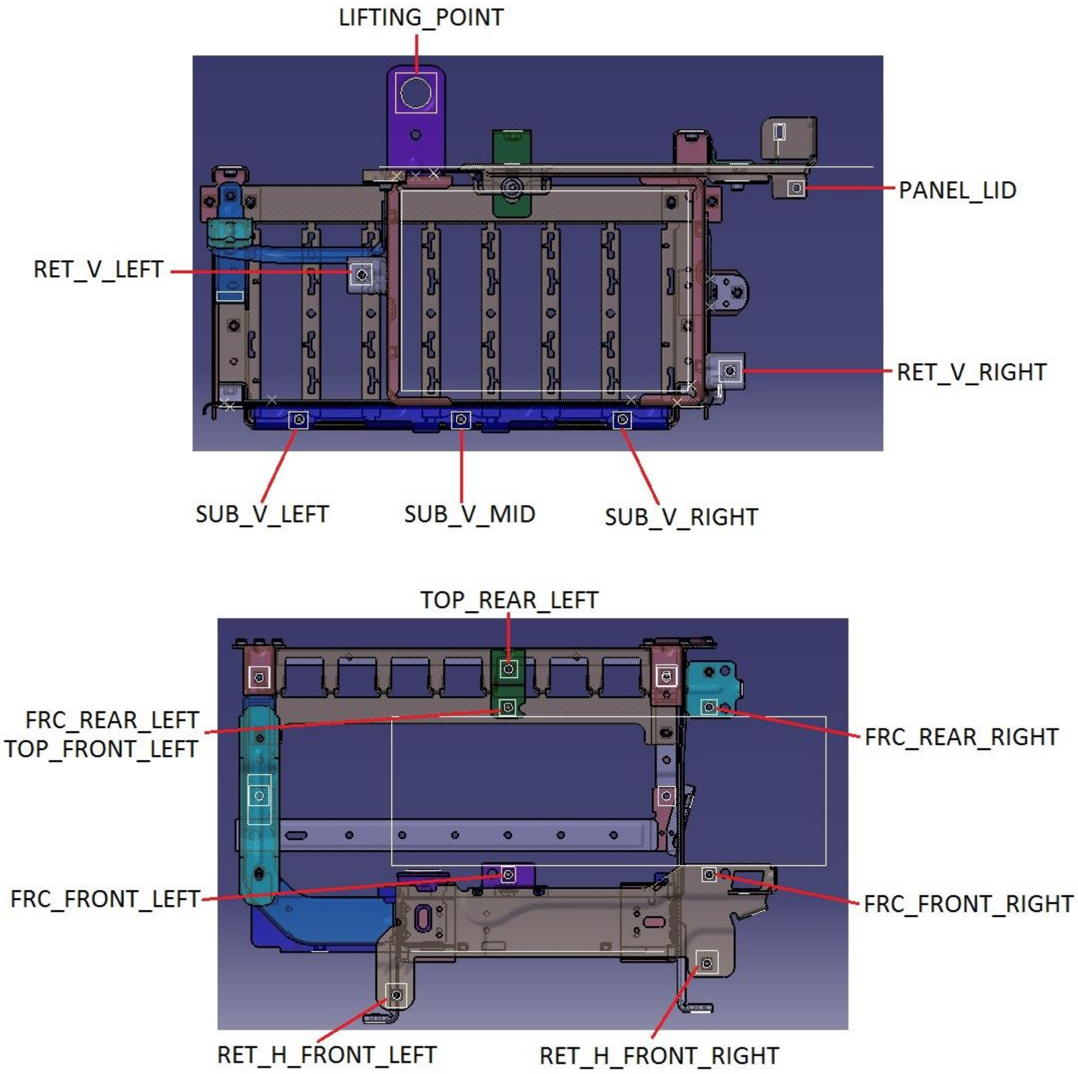


Figure 9. Interfaces corresponding to table 5.

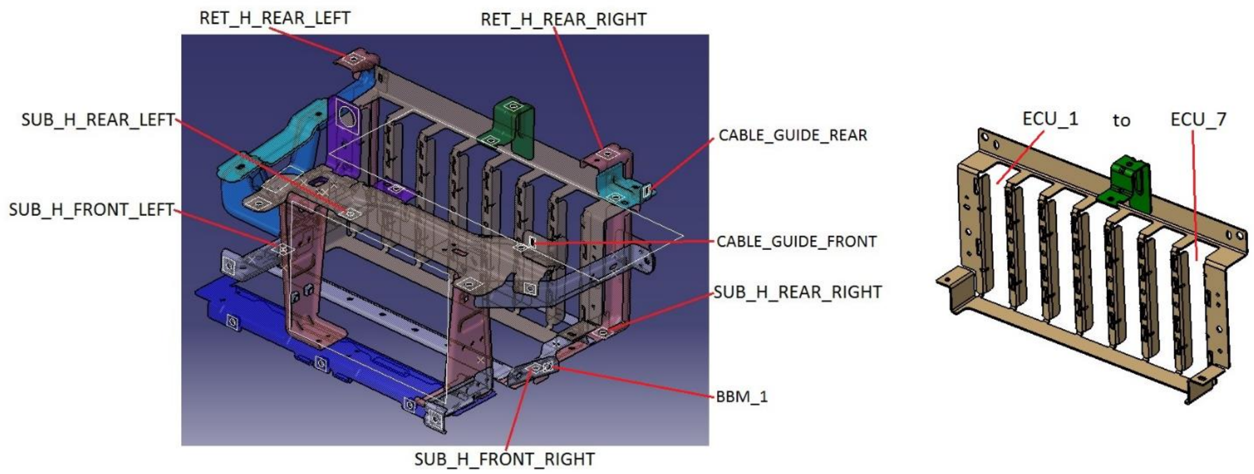


Figure 10. Interfaces corresponding to table 5.

In order to use the mapped interfaces practically for the concept design, a CAD part containing all interfaces was made by creating planes on the current CAD parts. This part could then easily be imported while designing the concept and be used to guarantee that the interfaces are met.

One connecting part that is not presented in table 5 or the corresponding figures is a cable protection. This is a part made out of plastics that has the purpose of protecting cables near the body builder module to the sharp sheet metal design of the current solution. The reason why this interface is excluded above is because a new design with an alternative material may make this part redundant, as a new solution may not cause any harm to the cables.

The standard screws used for assembly of the dashboard framework onto the retainer and surrounding parts onto the dashboard framework are illustrated in appendix B together with a corresponding list. The list shows the type of screws used for surrounding interfaces. These screws, or equivalent, were used for a new solution since the connecting holes and surfaces dimension are required to match. The most common screw for the internal assembly of the dashboard framework and the assembly of the dashboard framework onto the dashboard is flange screw M6x16. It is advisable to use this as a standard screw when dimensioning the internal and surrounding interfaces of a new solution to the largest extent possible. If the same screw type can be used for a new solution depends on material and design choices.

2.5 Prioritizing Objectives

When working with any kind of development project it is important to have a plan on how to distribute resources as well as set priorities early in the project. This is important in order to make decisions in a structured way throughout the project and keep an initial mindset of the objectives. Decisions are often causing certain trade-offs during the development. These trade-offs can be divided into three categories. The first category is cost and refer to the budget for the project. The second category is time and refer to the time schedule of the project. The third and last category is quality and refer to the functionality and quality of the project outcome. An illustration of this strategic method is called the iron triangle. Having the strategy and mindset of delivering a project which is the best for all three categories is a project owner's dream, but is likely not possible to implement and would most likely lead to a project failure. Therefore choosing a strategy that delivers a project that perform well for two aspects is much more desirable (Maylor, 2010).

For this project the strategy was to focus on the aspects of time and quality, see figure 11. Since this is a master thesis a time schedule was set early and a deadline had to be met. The quality of the outcome is considered to be more important than the cost of the project.

The aspect of cost, that is the project budget, should not be confused with the cost aspect of manufacturing the design of a new solution. Developing a cost competitive solution in this case fall under the quality aspect of the iron triangle.

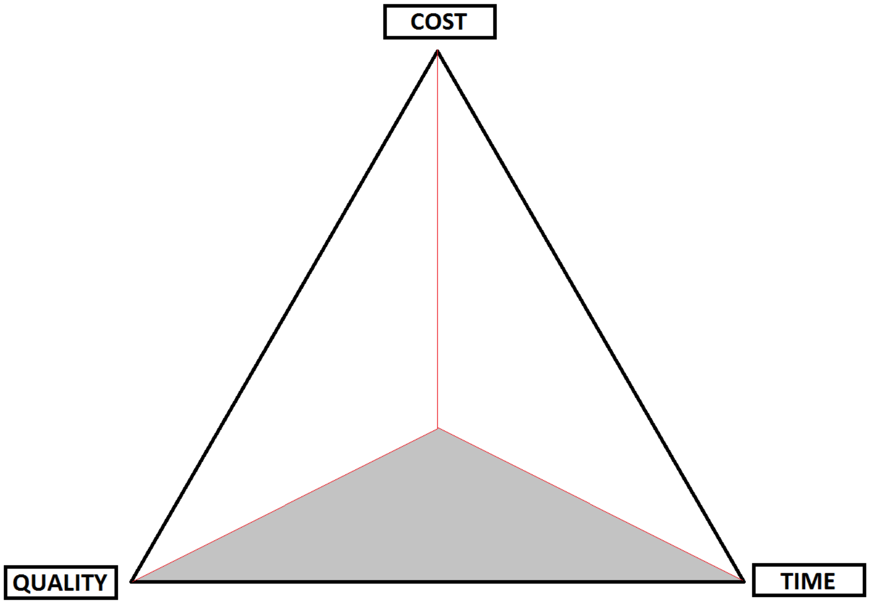


Figure 11: The "Iron Triangle" symbolizing the priority objectives. In this case the gray area mark the priorities being "Quality" and "Time".

3 Evaluating Material Option

A large part of this project was to find suitable materials for a new design. A concept design may be dependent of a specific material choice and it is therefore important to design based on the properties of the chosen material. Because of this condition the material evaluation and selection procedure started early on during the timeline of the project. It is also important to understand the design possibilities of each material and the capability of its manufacturing process. That together with mechanical properties was the most important factors when evaluating materials.

This chapter is presented in a chronological order with a large input of materials in the beginning and an elimination process of materials along the way. It ends up with describing manufacturing process, design guidelines and joining techniques for remaining suitable materials. The approach for the material gathering and evaluation processes was implemented by the thesis workers to suit this project.

3.1 Material Gathering and Screening

A good software tool to find suitable materials is Cambridge Engineering Selector, also known as CES (Granta Design, 2013). It is commonly used at Chalmers and is available for students at the university. This tool has access to a very large database of materials and will allow the user to type in various requirements for the material properties. It is then possible to screen out materials by various input in the software. CES also provides process information of each material such as shaping and joining processes.

For this project the CES software was used to find and map the capability of different material groups and differences within each material group. The screening process started with all available materials as possible materials as there were no requirements set at that point. The factors used in the initial screening process was the following:

- Yield strength (elastic limit), the stress limit the material can withstand before a constant deformation occurs. High yield strength is crucial to avoid that the product will break.

- Young's modulus (E-modulus), the base stiffness of the material. High stiffness causes the material to have lower displacement when a load is applied. This is important when having tolerances between interfaces across one or several parts.

- Density, the density of the material in kg per cubic meter. A lower density gives the capability of a lower total weight.

- Price, the price in SEK per kg material. This is an estimation by the CES software.

First thing to limit was the Young's modulus. A simple beam calculation was made to evaluate a possible lower limit of Young's modulus in comparison to the current solution. The current solution is a steel sheet metal design with a thickness of 2 mm. This can be compared by using formulas seen in formulas 1 to calculate the stiffness of a rectangular beam (Lund, 2000). See figure 12 for describing the data. C is a constant which is arbitrary for the purpose of comparison.

$$\text{Stiffness } k = C\,\frac{E\,I}{L^3} \qquad (1)$$

$$Rectagular\ beam:\ I = \frac{b\,h^3}{12} \qquad (2)$$

$$Arbitrary\ X = \frac{C\,b}{12\,L^3} \qquad (3)$$

$$\text{Stiffness } k = X * E\ *\ h^3 \qquad (4)$$

Formulas 1. Formulas for calculate stiffness of a beam.

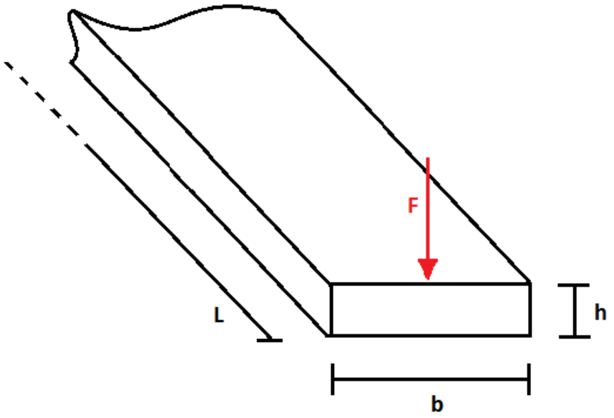


Figure 12. A simple beam for supporting the formulas 1.

The Young's modulus of steel sheet metal (the current solution) is 210 GPa (Gigapascal). Using the formulas to calculate a relative stiffness a reference could be calculated using the Young's modulus. The relative stiffness is a value that can only be used for comparison as the width (b) and length (L) of the beam is arbitrary. This study only deals with the thickness / height (h) of the beam and the applied force (F). In order to find a lower limit of Young's modulus the thickness varies from 1 mm to 7 mm for a set of Young's modulus values between 5 and 210. The following is a plot illustrating the stiffness comparison between different Young's modulus values and the reference from current solution (black line). See figure 13 for the results of the stiffness comparison.

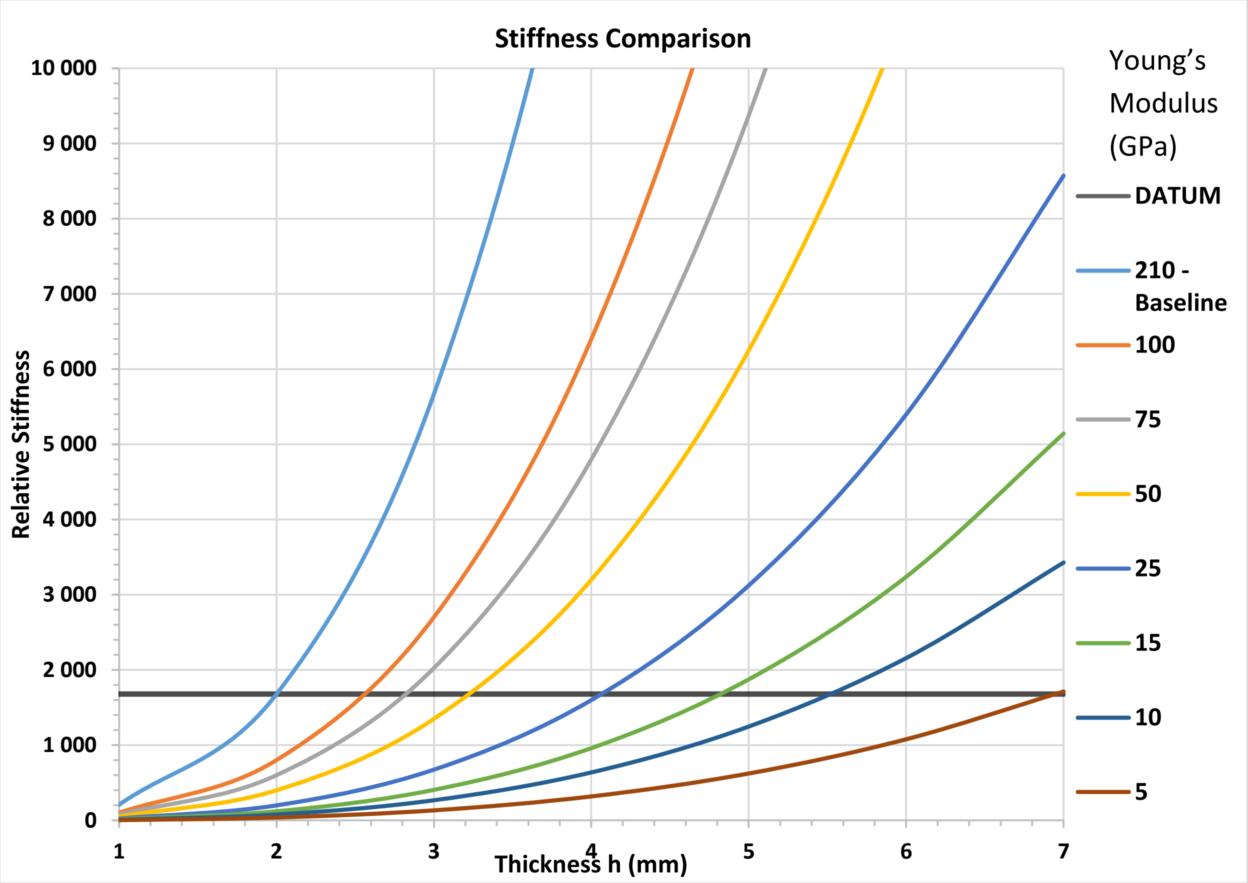


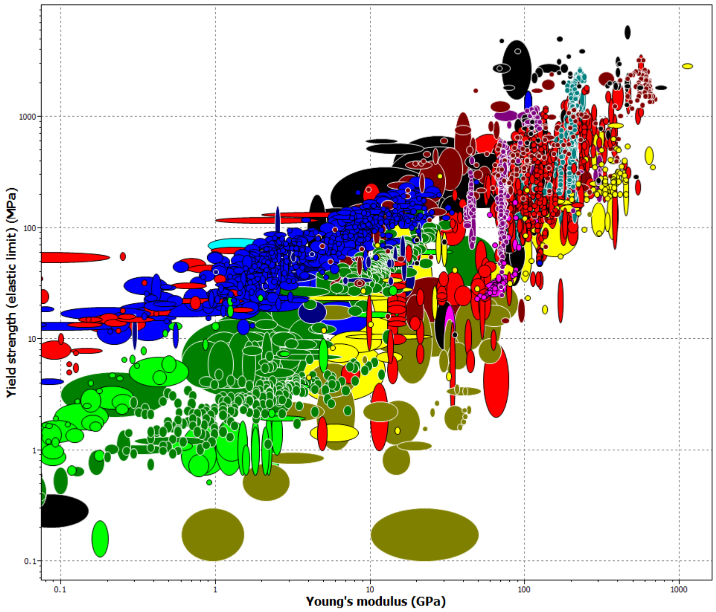
Figure 13. Stiffness comparison, each line is a specific value of Young's modulus. The plot shows how increasing material thickness changes the stiffness for a set number of Young's modulus values.

The conclusions that could be drawn from this was that the lower limit should not be lower than 10 GPa in order to have a competitive stiffness in comparison to the current solution. A Young's modulus of 10 GPa requires a material thickness of 5,6 mm which is considered to be the higher limit of possible thickness. A thicker material may cause problem in manufacturing depending on the method and contribute to a too high product weight depending on design and density of the material. The lower limit of Young's modulus was therefore set to 10 GPa.

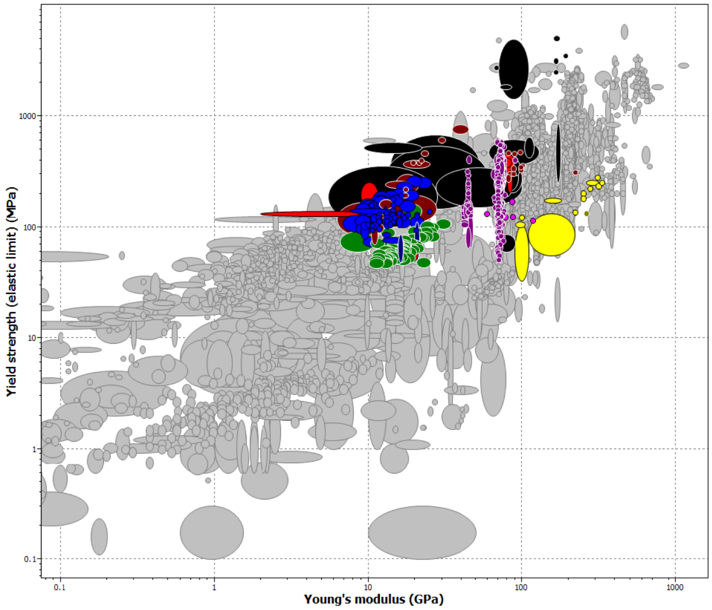
The limits for other screening factors, yield strength, density and price, were set by using a rough estimation based on current material (steel) and some general material knowledge. Because of this method the limits were set in order to not exclude suitable materials before more data were gathered.

The upper limit of the density was set to 6000 $\mathrm{kg/m^3}$. The upper limit of the price was set to 75 SEK/kg. The lower limit of the yield strength was set to 50 MPa and Young's modulus was previously set to 10 GPa. Using these limits in the limit function of the software CES, see figure 14, the following material groups were identified as possible materials: metals, polymers and ceramics.

Ceramics (yellow) have very low elongation and very low fracture toughness. This makes ceramics not a suitable material group as those materials may crack too easily during higher loads or vibrations. This leaves metals and polymers as possible material groups.



No Limitation - All Available Materials



Limitations - Material Groups Can Be Identified

Figure 14. In the top picture is the total database of materials presented on a logarithmic scale, Young's modulus vs yield strength. The bottom picture shows the remaining materials after the limits were set. Here for example blue are polymers, purple are metals and yellow are ceramics.

With metals and polymers as the remaining material groups there was still a huge amount of materials that lay within the set limits. In order to narrow down the number of materials, a number of subgroups were identified within each main material group. Just like with the previous representation, the materials are shown in a graphic view with yield strength on the y-axis Young's modulus on the x-axis.

In the metal material group the following subgroups could be identified (see figure 15):

- Aluminum
- Magnesium
- Zinc-Aluminum Alloy
- Duralcan

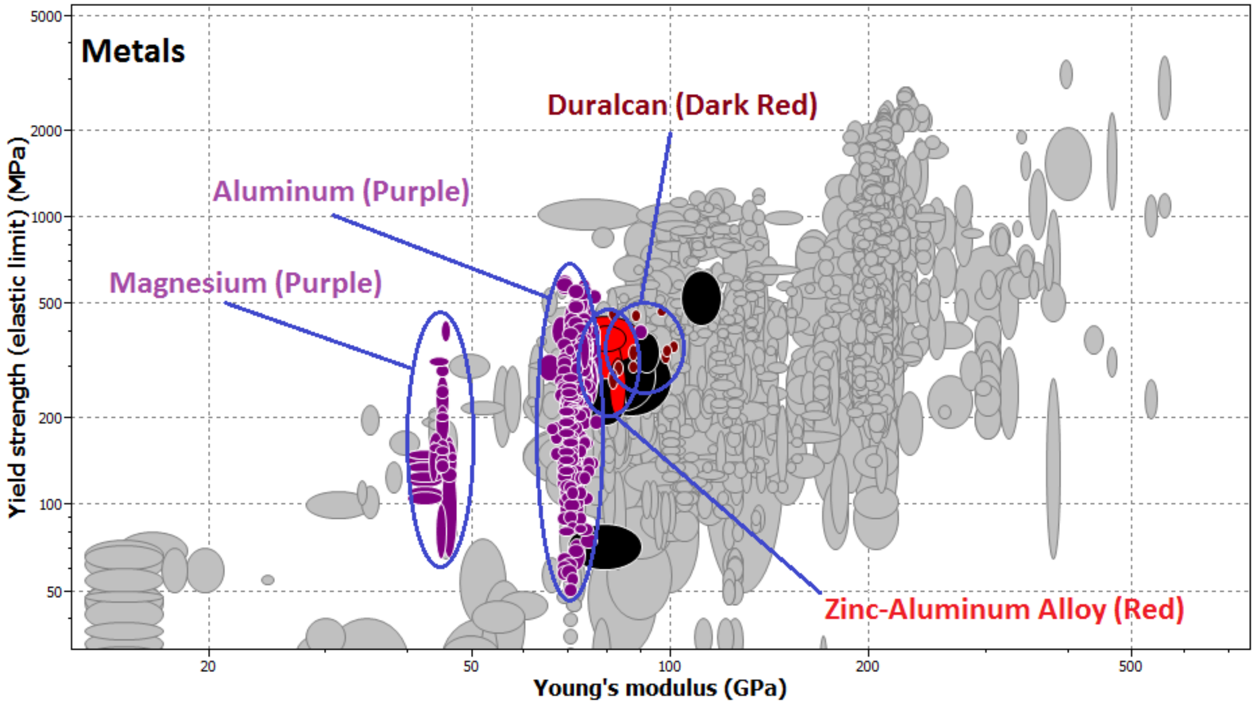


Figure 15. The material groups identified within the remaining metal materials.

In the polymer material group the following subgroups could be identified (see figure 16):

- PA (Polyamide)
- PC (Polycarbonate)
- PET (Polyethylene Terephthalate)
- Polyarylamide
- Polyester
- PP (Polypropylene)
- PPA (Polyphthalamide)
- PPS (Polyphenylene Sulfide)

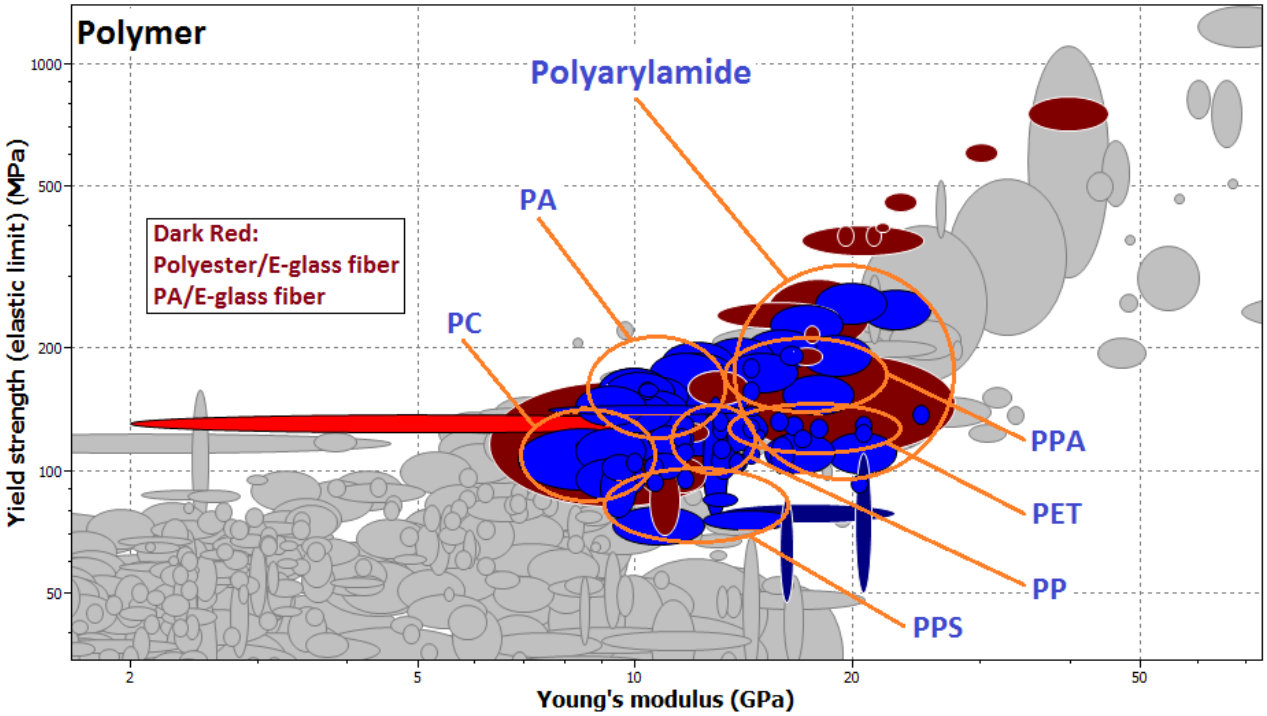


Figure 16. The material groups identified within the remaining polymer materials.

The next step was to identify the most suitable material or materials within each subgroup. This was done by graphically viewing the three most important material properties factors against the material price. Identifying the material with the highest Young's modulus, highest or adequate yield strength and lowest density. All these factors were viewed against the material price in order to determine the most suitable material. Figure 17 shows how this was done for the subgroup aluminum in the material group metals. The same analysis was made for all subgroups listed above for both metals and polymers.

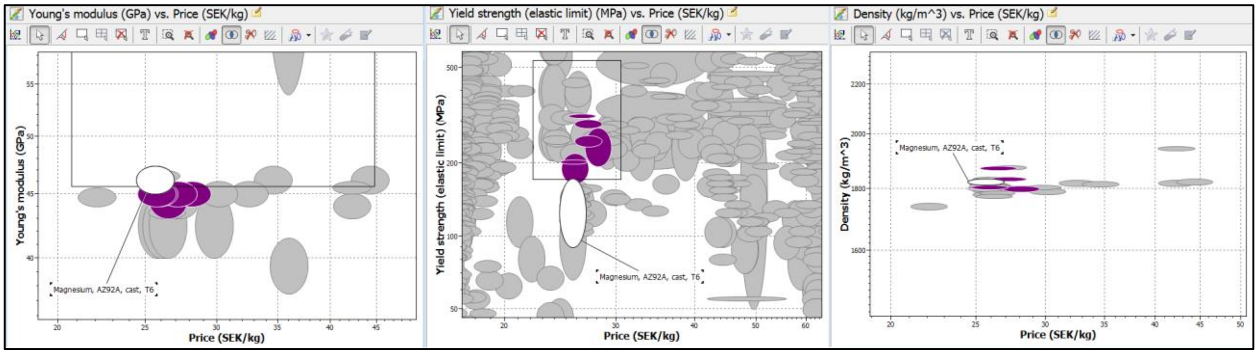


Figure 17. The left image plots Young's modulus vs price, middle plots yield strength vs price and right plots density vs price. This way the material with highest performance vs cost was identified.

After this was completed for all the subgroups the important data was gathered and listed in a spreadsheet. At this point 30 materials remained, see table 6. There were 8 materials from the metal group and 22 materials from the polymer group. The material data for these materials was compared in different ways to determine the suitability of all materials. All polymers had either a glass fiber filling or a carbon fiber filling. These seem to be the only viable options for polymers in order to maintain an acceptable stiffness. However this also contributes to a higher material price.

Table 6. Remaining 30 materials after most suitable material per subgroup was identified.

Current Materials

Material name	Material Group	Subgroup
Steel - VSCR 140 STD 311-0002 (Volvo)	Metal	Steel sheet metal
Steel - VSHR 350 STD 311-0003 (Volvo)	Metal	Steel sheet metal
Aluminum, 354.0, cast, T6	Metal	Aluminum
Aluminum, 7249, wrought, T76511	Metal	Aluminum
Magnesium, AZ92A, cast, T6	Metal	Magnesium
Magnesium, Elektron ZW3, wrought	Metal	Magnesium
Zinc-aluminum alloy, ZA-12, general casting	Metal	Zinc-aluminum alloy
Zinc-aluminum alloy, ZA-27, general casting	Metal	Zinc-aluminum alloy
Duralcan Al-20SiC (p) cast (F3K20S)	Metal	Duralcan
Duralcan Al-20Al2O3 (p) wrought (W2A20A-T6)	Metal	Duralcan
PA (type 66, 40% long glass fiber)	Polymer	Polyamide (Nylon)
PA (type 66, 50% long glass fiber)	Polymer	Polyamide (Nylon)
PA (type 66, 60% long glass fiber)	Polymer	Polyamide (Nylon)
PC (20% carbon fiber)	Polymer	Polycarbonate
PC (40% long glass fiber)	Polymer	Polycarbonate
PC (50% long glass fiber)	Polymer	Polycarbonate
PET (30% carbon fiber)	Polymer	Polyethylene Terephthalate
PET (30% long glass fiber)	Polymer	Polyethylene Terephthalate
PET (40% long glass fiber)	Polymer	Polyethylene Terephthalate
PET (45% long glass fiber, recycled content)	Polymer	Polyethylene Terephthalate
PET (60% long glass fiber)	Polymer	Polyethylene Terephthalate
Polyarylamide (30% glass fiber)	Polymer	Polyarylamide
Polyarylamide (50% glass fiber)	Polymer	Polyarylamide
Polyarylamide (60% glass fiber)	Polymer	Polyarylamide
Polyester SMC (40% glass fiber)	Polymer	Polyester
Polyester SMC (50% glass fiber)	Polymer	Polyester
PP (50% long glass fiber)	Polymer	Polypropylene
PPA (33% glass fiber)	Polymer	Polyphthalamide
PPA (45% glass fiber)	Polymer	Polyphthalamide
PPS (60% long glass fiber)	Polymer	Polyphenylene Sulfide
Grilon BG-30	Polymer	Polyamide (Nylon)
Grivory GV-4H	Polymer	Polyamide (Nylon)

The material list stated above is complemented with the most important material properties imported from CES data sheets, see appendix B. Apart from the previous stated material properties, Young’s modulus, yield strength, density and price per kilogram, this list also includes the tensile strength, price per square meter and service temperature range. The tensile strength limit describes the maximum stress allowed before a break or crack occurs in the material. Converting the price per kilogram to price per cubic meter by using the density gives a more fair way to compare the material costs as the difference in density of the materials varies a lot. Some polymers have half the density of aluminum and as low as ⅙ the density of steel.

In order to rank the suitability of all materials left a rating system was used. A few materials were screened out before using the rating system due to too low maximum service temperature. The minimum service temperature requirement is 100 degrees Celsius and the maximum service temperature of zinc-aluminum alloy and PA is 90 degrees Celsius. The rating systems was developed by taking the total range of one material property for all materials and then set the best value to 100 and the worst value to 1. The remaining materials were then calculated in order to obtain their respective value on the scale from 1 to 100. This rating system was applied to the material properties density, Young’s modulus, yield strength and price per cubic meter. The density and price per cubic meter got higher rating for lower values while Young’s modulus and yield strength were given higher ratings for higher values. By generating a definitive rating factor the rating from individual material properties were multiplied together as following:

$$Final\ Rating = Rating\ Density * Rating\ Young's * Rating\ Yield * Rating\ Price$$

The comparison was done for metals and polymers separately as there is a large difference between the two groups in terms of shaping and fastening methods. The final rating was used to determine most suitable materials and material groups.

The polymer ratings can be seen in table 7. The order of the materials is based on the final rating value, which is as stated above the rating from Young’s modulus, yield strength, density and price per cubic meter multiplied together. The materials are then given a green, yellow or red marking. The red materials represent the materials with low total rating and materials that did not meet the temperature requirements. The green materials represent the higher rated materials and should be considered as possible suitable materials. The yellow materials represent borderline materials that should not be ruled out at this point but may not be suitable materials based on their total rating value.

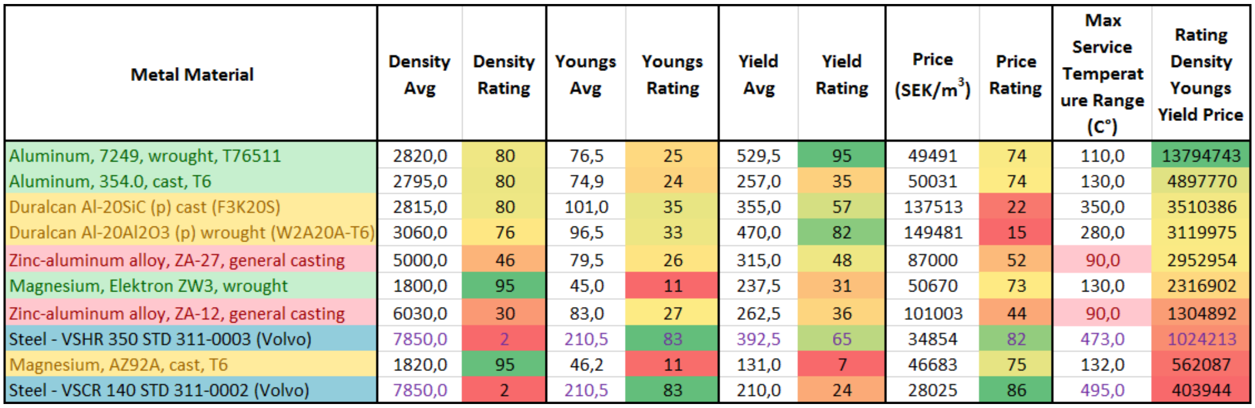
Table 7. Rating and comparison of the remaining polymer materials

Polymer Material	Density Avg	Density Rating	Youngs Avg	Youngs Rating	Yield Avg	Yield Rating	Price (SEK/m^3)	Price Rating	Max Service Temperature (C°)	Rating Density Youngs Yield Price
Polyarylamide (50% glass fiber)	1645,0	36	20,0	60	260,0	84	81428	45	193,0	8061378
Polyarylamide (60% glass fiber)	1790,0	21	23,0	72	250,5	80	77776	48	188,0	5804225
Grivory GV-4H	1470,0	53	13,5	34	220,0	68	78645	47	100,0	5783228
PA (type 66, 60% long glass fiber)	1670,0	33	14,0	36	190,0	56	52104	68	90,0	4498112
PET (30% carbon fiber)	1420,0	58	24,8	79	138,0	35	105364	27	177,0	4308045
PPA (45% glass fiber)	1645,0	36	17,4	49	230,5	72	96315	34	220,0	4254847
PA (type 66, 50% long glass fiber)	1565,0	44	11,8	27	175,0	50	51019	68	90,0	4049320
PET (45% long glass fiber)	1700,0	30	14,5	38	157,5	43	33915	82	183,0	3979167
PP (50% long glass fiber)	1330,0	67	11,1	24	119,5	28	32186	83	119,0	3738236
PC (50% long glass fiber)	1630,0	37	14,5	38	140,5	36	52405	67	133,0	3411462
PA (type 66, 40% long glass fiber)	1460,0	54	10,0	20	160,0	44	49567	70	90,0	3305674
PC (40% long glass fiber)	1520,0	48	11,7	27	130,0	32	50768	69	131,0	2825552
PPA (33% glass fiber)	1475,0	53	12,3	29	186,5	55	96908	33	215,0	2755550
PET (40% long glass fiber)	1700,0	30	14,5	38	128,0	31	41140	76	192,0	2690574
Grilon BG-30	1350,0	65	8,3	13	150,0	40	42188	75	100,0	2543125
PC (20% carbon fiber)	1280,0	72	13,8	35	104,6	22	88448	40	111,0	2194977
Polyarylamide (30% glass fiber)	1435,0	57	10,2	21	157,0	43	84019	43	186,0	2157632
PET (30% long glass fiber)	1610,0	39	11,7	27	111,5	25	38560	78	191,0	2006331
PET (60% long glass fiber)	1910,0	9	20,7	63	129,5	32	47177	71	194,0	1283339
Polyester SMC (50% glass fiber)	1910,0	9	13,1	32	160,5	44	66946	56	122,0	719821
Polyester SMC (40% glass fiber)	1825,0	18	11,6	26	98,6	19	57031	64	122,0	573204
PPS (60% long glass fiber)	1840,0	16	20,7	63	124,0	30	118312	17	270,0	496189

The materials with higher ratings are identified as materials with a higher percentage of glass fiber, between 40% and 60%. These materials are polyamides (PA) or a version of polyamides for example PPA. There are also a few PET materials and one PC with higher ratings.

The same comparison was conducted for the metal group and can be seen in table 8. The materials marked with blue represent the material of the current solution and is used for comparison.

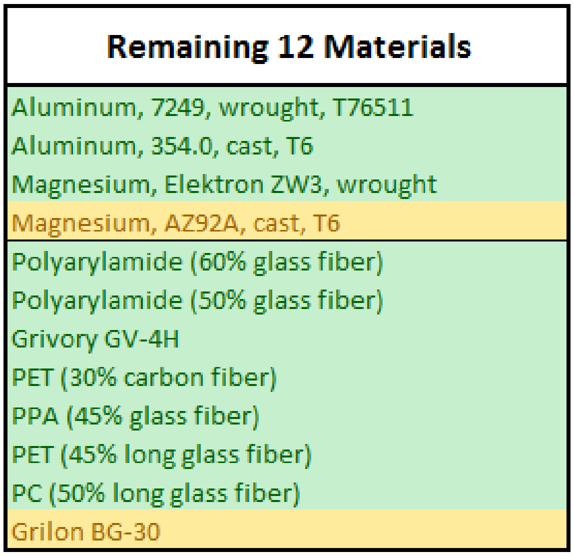
Table 8. Rating and comparison of the remaining metal materials



Metal Material	Density Avg	Density Rating	Youngs Avg	Youngs Rating	Yield Avg	Yield Rating	Price (SEK/m^3)	Price Rating	Max Service Temperature Range (C°)	Rating Density Youngs Yield Price
Aluminum, 7249, wrought, T76511	2820,0	80	76,5	25	529,5	95	49491	74	110,0	13794743
Aluminum, 354.0, cast, T6	2795,0	80	74,9	24	257,0	35	50031	74	130,0	4897770
Duralcan Al-20SiC (p) cast (F3K20S)	2815,0	80	101,0	35	355,0	57	137513	22	350,0	3510386
Duralcan Al-20Al2O3 (p) wrought (W2A20A-T6)	3060,0	76	96,5	33	470,0	82	149481	15	280,0	3119975
Zinc-aluminum alloy, ZA-27, general casting	5000,0	46	79,5	26	315,0	48	87000	52	90,0	2952954
Magnesium, Elektron ZW3, wrought	1800,0	95	45,0	11	237,5	31	50670	73	130,0	2316902
Zinc-aluminum alloy, ZA-12, general casting	6030,0	30	83,0	27	262,5	36	101003	44	90,0	1304892
Steel - VSHR 350 STD 311-0003 (Volvo)	7850,0	2	210,5	83	392,5	65	34854	82	473,0	1024213
Magnesium, AZ92A, cast, T6	1820,0	95	46,2	11	131,0	7	46683	75	132,0	562087
Steel - VSCR 140 STD 311-0002 (Volvo)	7850,0	2	210,5	83	210,0	24	28025	86	495,0	403944

After a selection of the higher rated materials had been made from both material groups and the lower rated materials had been screened out, 12 materials remained as suitable materials. Two of these were polymers that were suggested by a subcontractor that works with polymers. The remaining materials can be seen in table 9. These remaining materials were the outcome of the screening procedure and will be used as inputs for the next step, which is an analysis by conducting FEM calculations on simple CAD models.

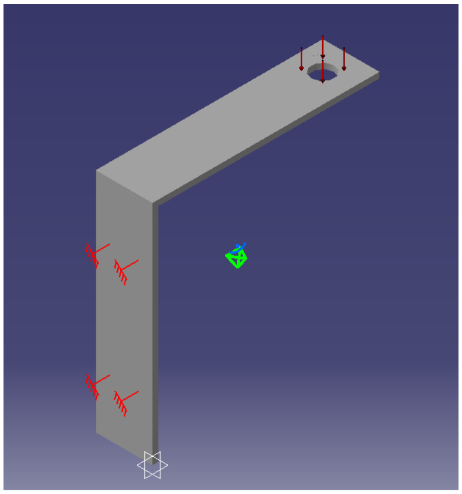
Table 9. A list of the materials that remained after the screening procedure



Remaining 12 Materials
Aluminum, 7249, wrought, T76511
Aluminum, 354.0, cast, T6
Magnesium, Elektron ZW3, wrought
Magnesium, AZ92A, cast, T6
Polyarylamide (60% glass fiber)
Polyarylamide (50% glass fiber)
Grivory GV-4H
PET (30% carbon fiber)
PPA (45% glass fiber)
PET (45% long glass fiber)
PC (50% long glass fiber)
Grilon BG-30

3.2 Material Analysis

In order to get a better understanding of the capabilities of the remaining materials an FEM analysis was used to evaluate displacement and Von Mises stress with a given load for various simple CAD models. The Von Mises stress is a measurement that can be compared with the yield strength. Hence if the Von Mises stress is higher than the yield strength of the material a constant deformation may occur (Lund, 2000). The approach of the analysis was implemented by the thesis workers and uses a model of a simple L-bracket as shown in figure 18. The main reason for this analysis was to evaluate the changes in stiffness when the bracket is reinforced by changes in the design rather than change of material. The software used for this analysis was Catia V5 (Dassault System) for both the CAD modeling and the FEM analysis.

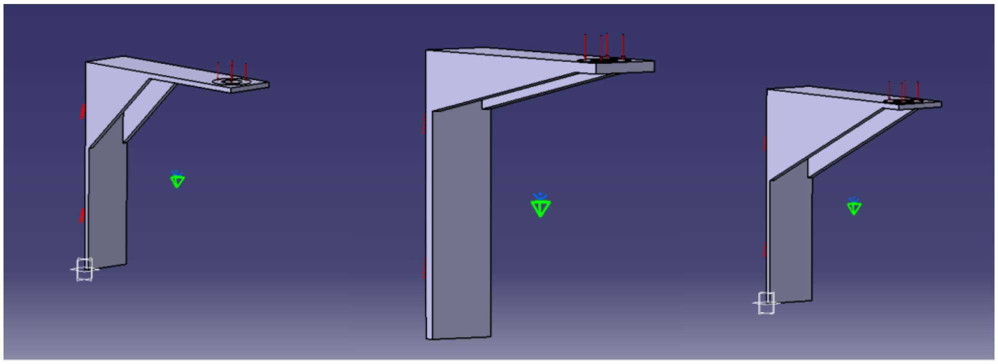


CASE 1

Figure 18. Case 1 L-bracket, undeformed.

The Young’s modulus, which represents the stiffness, is the material property that varies the most between the remaining materials. This is especially the case when comparing to steel which is used for the current solution. This analysis was very useful when comparing the capability of the remaining materials. While steel has a Young’s modulus of 210 GPa the remaining materials have a significant lower value. Aluminum has about 75 GPa, a third of steel, and magnesium has about 45 GPa. The remaining polymers however have even lower Young’s modulus value of between 10 and 20 GPa, which is lower than 1/10 compared to steel.

In addition to the stiffness analysis for different reinforcements the mass of the model, depending on the material, is calculated and compared. This to show the capability of the choice of material to maintain high stiffness and low mass. The different reinforcement cases used for this analysis are shown in figure 19.



CASE 2 **CASE 3** **CASE 4**

Figure 19. The alternative L-brackets with different reinforcements.

For the analysis the applied load was static and set to 100 N in a vertical direction facing downwards. The thickness of the part varied between the values 2 mm, 3 mm, 4 mm and 5 mm. The FEM analysis was conducted for all four thicknesses and for all twelve remaining materials and the material used in the current solution. This was done on all four design cases in order to gather comparative data.

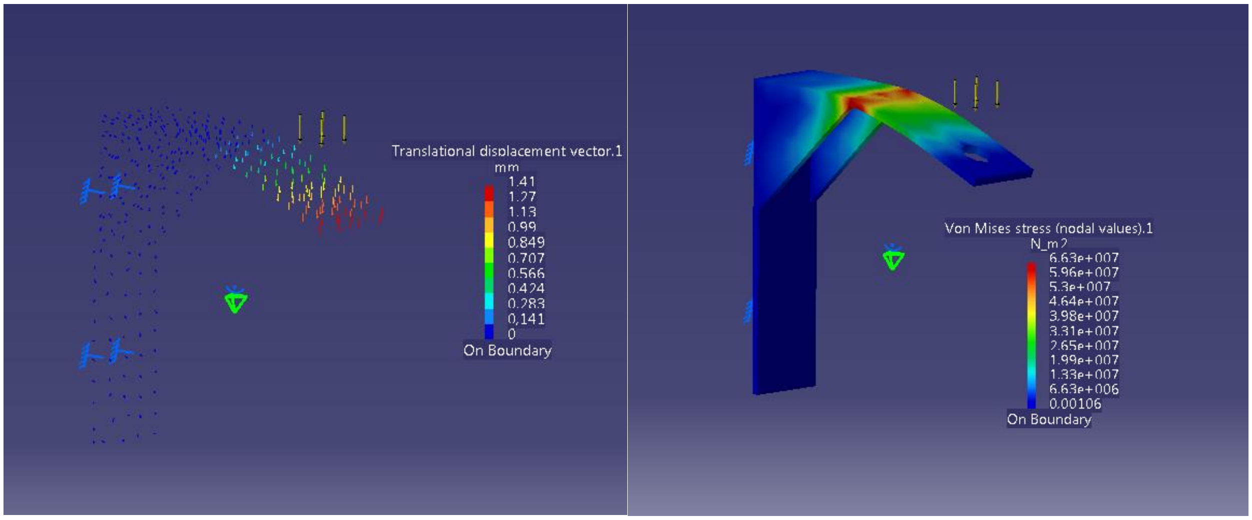


Figure 20. Left shows the displacement of case 2 and right show the Von Mises stress of case 2.

The maximum displacement from each calculation was noted, the Von Mises stress was noted for each case and the volume for each thickness and case, see figure 20. These values were then used to calculate the factors which were used for comparing. The comparing factors were stiffness (N/mm), mass (kg) and stiffness per kg (N/(mm*kg)).

The reference for rating the remaining twelve materials was set by calculating the comparative values for the steel used in the current solution. Case number one was used for the calculation with a thickness of 2 mm. This represents the design of the current solution utilizing steel sheet metal brackets. Table 10 and figure 21 shows the reference data for the current materials and the data from case number 3 for the remaining twelve materials. Case 3 proved to generate the best results when comparing suitable materials. The plots show the reference as a black straight line and how the stiffness and density change depending on the thickness. This design proved to be the best in terms of maintaining a high stiffness and low mass.

Table 10. Results from case 1 with current materials compared with the results of case 3 (reinforced design)

Case 1

Material / Thickness	Max Displacement (mm)				Max Von Mises Stress (MPa)				Density	Mass (kg)				Minimum Stiffness (N/mm)				Improvement Capability
	2	3	4	5	2	3	4	5	(kg/m3)	2	3	4	5	2	3	4	5	
Steel - VSHR 350 STD 311-0003 (Volvo)	**0,704**	0,312	0,153	0,0777	140	64,1	46,4	28,8	7850	**0,049**	0,073	0,096	0,120	**142**	321	654	1287	
Steel - VSCR 140 STD 311-0002 (Volvo)	**0,704**	0,312	0,153	0,0777	140	64,1	46,4	28,8	7850	**0,049**	0,073	0,096	0,120	**142**	321	654	1287	

Case 3

Material / Thickness	Max Displacement (mm)				Max Von Mises Stress (MPa)				Density	Mass (kg)				Minimum Stiffness (N/mm)				Large Improvement Capability
	2	3	4	5	2	3	4	5	(kg/m3)	2	3	4	5	2	3	4	5	
Aluminum, 7249, wrought, T76511	0,15	0,10	0,07	0,05	29,4	19,3	12,9	9,4	2820	0,023	0,034	0,044	0,054	662	1028	1531	2000	Yes
Aluminum, 354.0, cast, T6	0,15	0,10	0,07	0,05	29,4	19,3	12,9	9,4	2795	0,023	0,034	0,044	0,053	658	1012	1506	1965	Yes
Magnesium, Elektron ZW3, wrought	0,25	0,17	0,11	0,09	29,4	19,3	12,9	9,4	1800	0,015	0,022	0,028	0,034	394	599	885	1163	Yes
Magnesium, AZ92A, cast, T6	0,25	0,16	0,11	0,08	29,4	19,3	12,9	9,4	1820	0,015	0,022	0,028	0,035	403	629	943	1232	Yes
Polyarylamide (60% glass fiber)	0,50	0,32	0,22	0,17	29,4	19,3	12,9	9,4	1790	0,015	0,022	0,028	0,034	199	309	461	599	Yes
Polyarylamide (50% glass fiber)	0,57	0,37	0,25	0,19	29,4	19,3	12,9	9,4	1645	0,014	0,020	0,026	0,031	176	269	400	524	Yes
Grivory GV-4H	0,84	0,55	0,37	0,28	29,4	19,3	12,9	9,4	1470	0,012	0,018	0,023	0,028	119	182	271	352	Yes
PET (30% carbon fiber)	0,46	0,30	0,20	0,16	29,4	19,3	12,9	9,4	1420	0,012	0,017	0,022	0,027	218	330	495	645	Yes
PPA (45% glass fiber)	0,65	0,43	0,29	0,22	29,4	19,3	12,9	9,4	1645	0,014	0,020	0,026	0,031	153	233	351	455	Yes
PET (45% long glass fiber)	0,79	0,51	0,34	0,26	29,4	19,3	12,9	9,4	1700	0,014	0,021	0,027	0,032	127	195	292	379	Yes
PC (50% long glass fiber)	0,79	0,51	0,34	0,26	29,4	19,3	12,9	9,4	1630	0,013	0,020	0,025	0,031	127	195	292	380	Yes
Grilon BG-30	1,38	0,90	0,60	0,46	29,4	19,3	12,9	9,4	1350	0,011	0,016	0,021	0,026	72	111	166	216	Yes

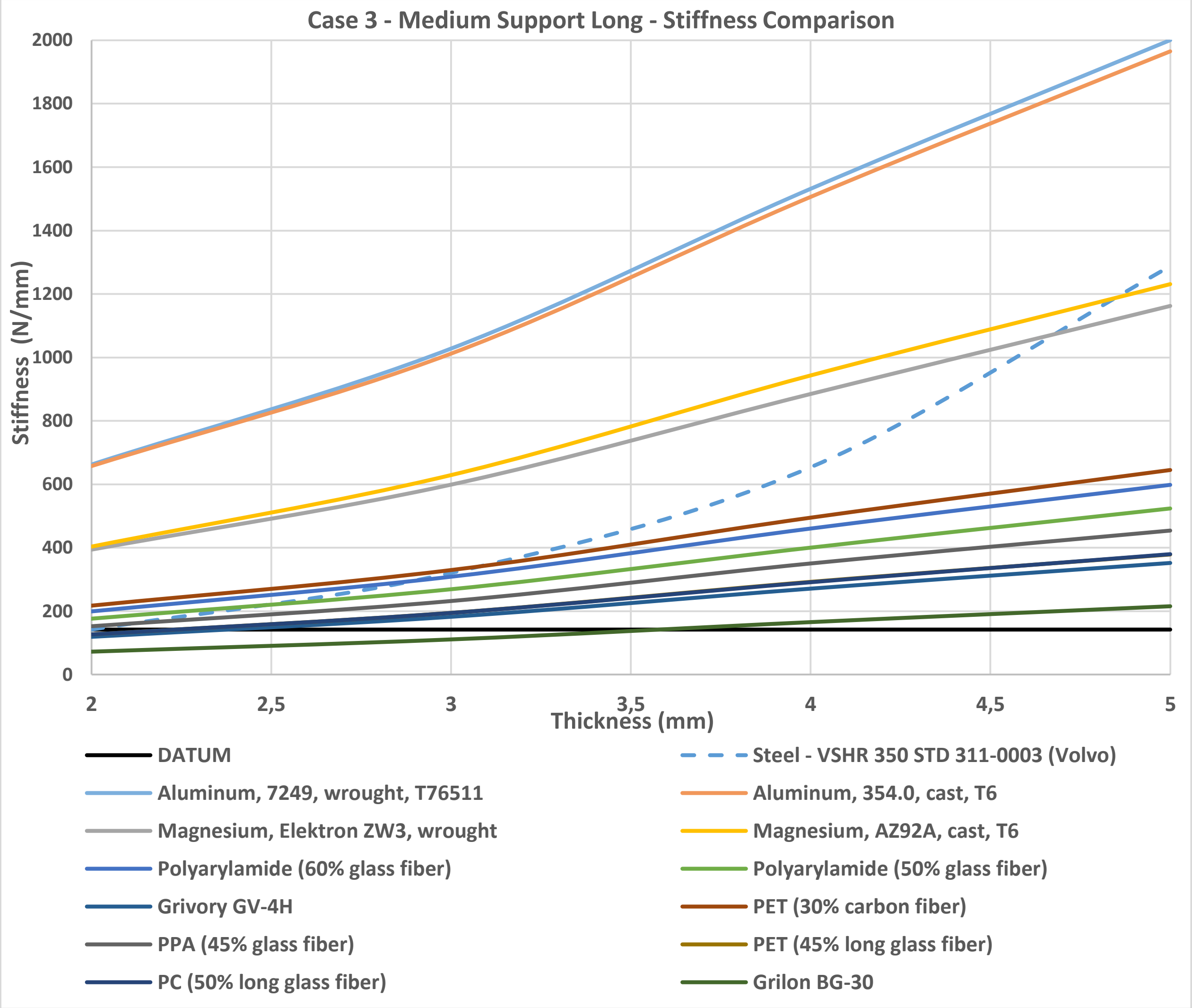


Figure 21. Stiffness of case 3 for all remaining materials. The black line (DATUM) is the current solution.

The fields marked with green in table 10 represents results that are competitive to current material. Since a main requirement for the new solution is to decrease the mass, the requirement for having a field marked as green in the mass columns is to have lower than half the mass of the reference material and design which results in 0,0245 kg. This shows which materials have high competitiveness in terms of total mass. If the material and thickness get a green marking on the mass they get a green marking on the stiffness, if it is higher than the reference stiffness of 142 N/mm. If the mass and the stiffness both have green markings on any of the thicknesses they are considered to have an improvement capability when comparing to the current solution.

Viewing the results from the analysis, especially of case number 3, it shows that all remaining materials have an improvement capability. All the metals have improvement capability with the thickness of 2 mm while nearly all the polymers have improvement capability with the thickness of 3 mm.

This analysis has shown that materials with a Young’s modulus value lower than 1/10 the value of steel can still be a competitive option and maintain the same or higher stiffness if utilizing a reinforced design and a larger thickness. Also while doing that, a mass lower than half of the steel reference can be achievable. This will give more freedom when choosing the definitive material for the final design and comparing other material property variables can then result in selection of the most suitable material.

Translating the reinforcements used in this analysis to the actual design of a new solution may not be possible in all or any features. In some cases a better reinforcement may be achieved when working with the detailed design and in other cases limited space may require a weaker reinforcement to be used. Also the shaping process has to be taken into consideration when designing reinforcements and tradeoffs may be necessary by comparing the additional tool and part cost versus the gain in stiffness. However this analysis still shows great capability from both the remaining polymer and metals in terms of stiffness and weight reduction.

3.3 Shaping Processes

Another important aspect of the material selection is the manufacturing and assembly processes. There are a number of shaping processes available for the remaining twelve materials stated in table 9.

3.3.1 Metals Shaping

For metals the available and suitable shaping methods are:

- High Pressure Die Casting
- Hot Metal Extrusion
- Metal Shape Drawing
- Hot Closed Die Forging
- Cold Closed Die Forging

The method with the highest degree of design freedom is high pressure die casting making this the most desirable method to use. However hot and cold closed die forging may be a valid option for simpler designs. The part and tooling costs are similar between these methods. When using the extrusion and drawing methods the design freedom is limited to design with constant cross sections. This makes these methods very undesirable due to the complexity of the feature (Granta Design, 2013).

The only remaining materials that can be processed by high pressure die casting are:

- Aluminum, 354.0, cast, T6
- Magnesium, AZ92A, cast, T6

High Pressure Die Casting

In order to create metal parts using high pressure die casting molten metal is injected into a metal die of two halves. The molten metals then solidify inside the die, see figure 22. The two halves then open up and the casting is ejected. This require high temperatures to create the molten metals and a high pressure for both the injection of the molten metal and to hold the two die halves together (Granta Design, 2013).

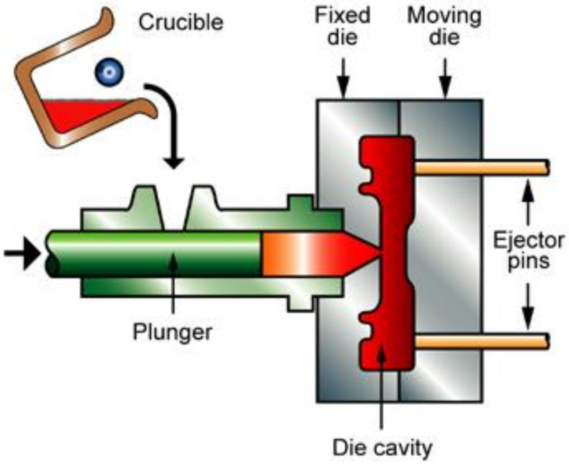


Figure 22. The process of high pressure die casting.

3.3.3 Polymers Shaping

For polymers the available and suitable shaping methods are:

- Injection molding
- Polymer Extrusion
- Polymer Casting
- Polymer Forging

The most desired shaping methods for polymer is injection molding as it allows for the highest design freedom. Injection molding is the method that is best compared with die casting for metals and has similar shaping costs. All the remaining polymers stated in the previous chapter can be injection molded (Granta Design, 2013).

Injection Molding

This method is in many ways similar to the high pressure die casting used for metal shaping. When using injection molding molten polymer is normally injected into a cold steel mold by a screw machine, see figure 23. The polymer solidifies under pressure and when finished the molding ejects. This requires lower temperature than high pressure die casting. The mold can have several entries for the molten polymer in order to get a better control of how the material flows in the mold (Granta Design, 2013).

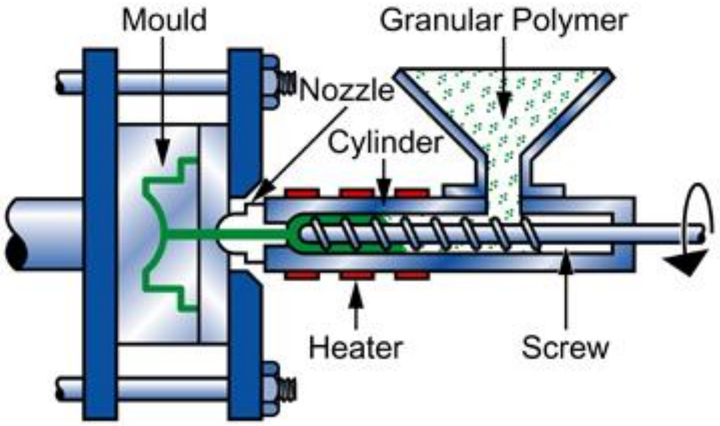


Figure 23. The process of injection molding.

3.4 Design Guidelines

The two shaping processes, die casting for lightweight metals and injection molding for glass-reinforced plastics, have very similar design requirements and requires a similar mindset when designing a feature. This is due to the open and close function of the tool also called die or mold. All the design guidelines presented in this chapter (3.4) are taken from the two guides distributed by Bayer (2000) and DuPont (2000).

There are several design choices that should be considered in order to minimize the tool and part cost. First of all holes, windows and large surfaces should be aligned so they are a part of the mating surfaces of the tool. This will allow the tool to utilize its regular geometry in order to create holes and windows. Also holes and windows should be avoided where possible as confluence in the material flow lowers the material performance of the final part.

The main aim when designing is to go for an overall geometry that allows the tool to produce the part without causing any undercuts in the design when molding. This is basically a tool that only has to close and open to produce the complete part, see figure 24. The figure shows a cross-section of a box-shaped part together with a 3D view of the same part. This simple design allows for a lower tool cost.

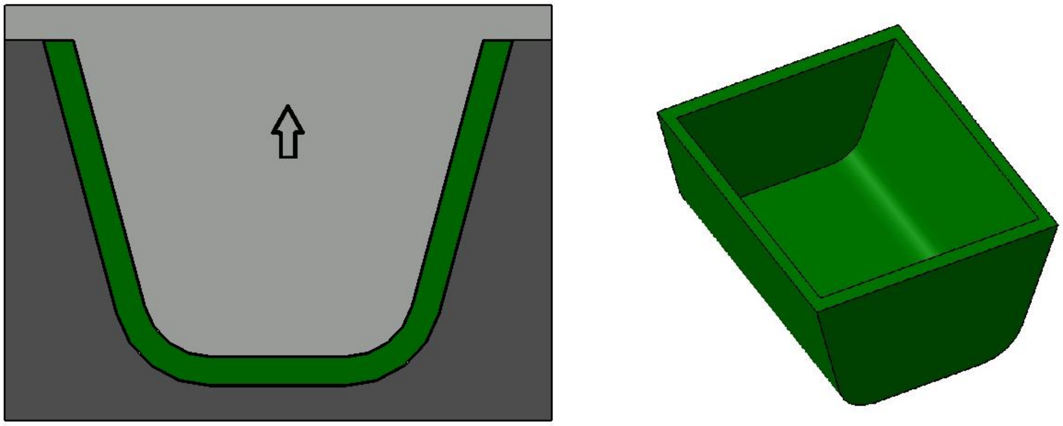


Figure 24. A simple open and close design with no undercuts.

Undercuts are divided into two types, internal and external. They are caused by design features which because of its orientation and position make it impossible or very hard to eject the part from the mold. An internal undercut feature is illustrated in figure 25 in the same box-shaped part but this time with a feature sticking out. This is an internal undercut as the feature is on the inside of the outer walls of the feature. There are often many ways to work around undercuts by redesigning the part to fit the injection molding process better. This could be both minor and major changes depending on the geometry. An example of a solution to the undercut using the same box-shaped part is shown in figure 26. This new design can be molded by a simple open and close tool.

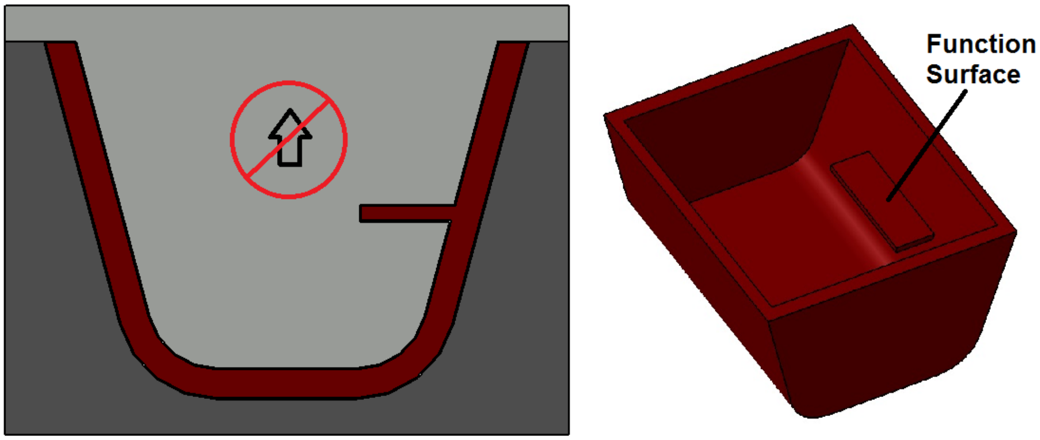


Figure 25. An internal undercut caused by a function surface that cannot be molded, the part will get stuck in the mold. A cross–section with the closed tool is displayed on the left.

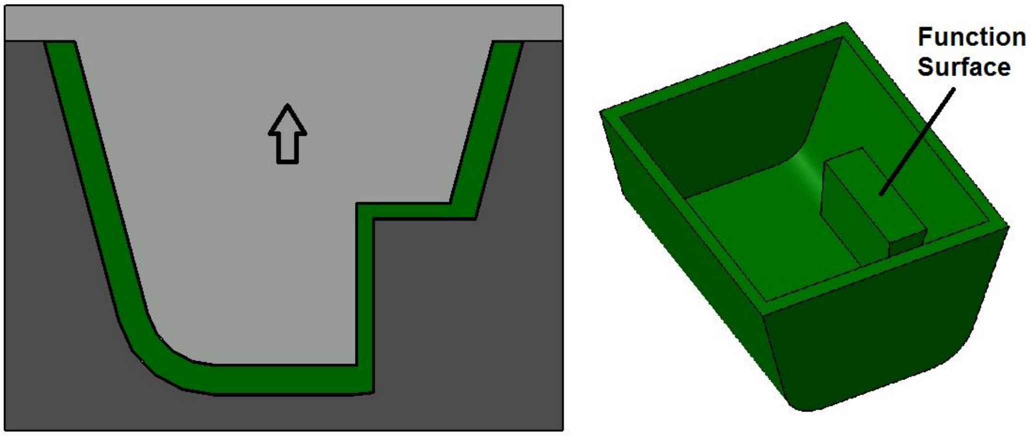


Figure 26. A solution to the internal undercut shown in figure 25 where the function surface is still available. A cross–section with the closed tool is displayed on the left.

If it is not possible to avoid undercuts in the geometry in order to create the required function, it may still be possible to create the part. External undercuts can be molded in two ways. The cheapest way is to adjust the parting line, the line where the two dies of the tool meet shown in figure 27.

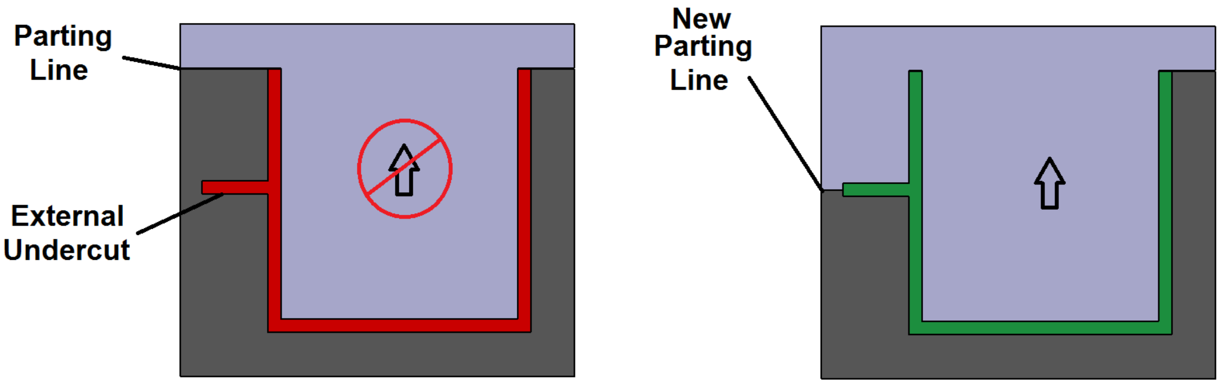


Figure 27. External undercut and a solution to an external undercut by adjusting the parting line of the tool.

If adjusting the parting line is not possible to solve the external undercut, the tool can be equipped with side cores, also known as side activities. These side cores will be in position when the tool closes and when the part is completed it will eject sideways allowing the tool to pen and eject the part properly. This is a more expensive solution but can also be used for creating holes and windows perpendicular to the tool direction. Figure 28 shows an example where using side cores may be required. This example shows a part with two undercut features parallel to each other leaving the space between them to require a side core in order to be molded.

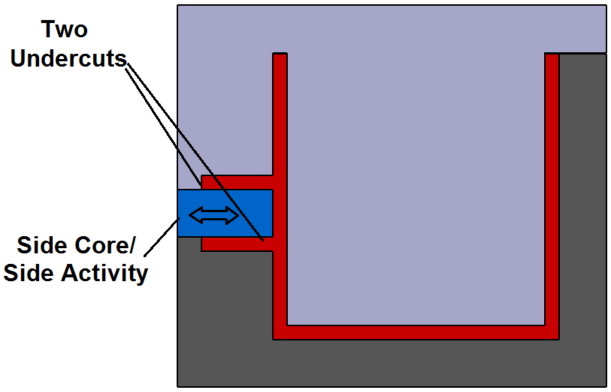


Figure 28. Description of the functionality of a side core.

Internal undercuts should generally be avoided and redesigned into a solution similar to the one shown before. However, if avoiding or redesigning the internal undercut is not a viable solution they may still be possible to mold by utilizing a lifter function in the tool. This is a more complex way of creating a part and can easily cause a jam if not designed properly.

Stiffness

Lightweight metals and polymers have a significantly lower Young's modulus than steel, especially polymer materials. However, there are ways to increase the stiffness for a certain design. Increasing the wall-thickness is a common way to increase the stiffness. By following the stiffness formula stated in formulas 1 from chapter 3.1 the stiffness has an exponential increase by the power of 3 relative to the wall-thickness. For example if the wall thickness is increased from 2 mm to 2,5 mm the stiffness will become twice as high and increasing the wall-thickness from 2 mm to 3 mm the stiffness will become 3,375 times as high. This is an easy way to increase stiffness and may be required when higher stiffness is desired. However, increasing the wall-thickness increases the cooling time in the manufacturing process and has a large impact on the overall volume and therefore the total weight. If low weight is desired, increasing the wall-thickness should be considered with care.

A more weight efficient way to increase stiffness is to utilize ribs in the design. Ribs will strengthen the design in the direction of the rib and is commonly used in polymer and lightweight metal parts. When designing ribs, especially for polymers, there are normally guidelines to follow in order to avoid sink marks in the polymer material. In this case the solution is not an aesthetic product and since sink marks have a low impact on the performance, ribs can be designed more freely based on results from strength analysis. However, some guidelines to follow, when designing ribs, are that the width of the ribs should be ⅔ of the wall-thickness to maximize strength and ⅓ of the wall-thickness to minimize sink marks from polymer materials. For this concept study the focus will be on ribs potential to increase strength. If the wall-thickness is 3 mm the width of ribs can be up to 2 mm. The height of the ribs also has a large impact on strength and stiffness. Increased rib height gives higher stiffness and strength but too high ribs can cause problems with material flow during manufacturing.

Corners

Sharp corners should be avoided. By rounding corners the stress concentration and fracture can be reduced. The inner radius should at least be equal to the thickness of the walls. Rounding edges also allows the design to be easier to handle and decreases the risk of having cables worn out against the framework.

Draft

In order to make the part easier to eject from the mold a draft angle is necessary on the part in the direction of the tool. This is required for both die casting and injection molding but the required angle differs between the methods and materials. The draft angle may also differ depending on if it is on walls or inside cores. The following is a list of suitable draft angles for a number of materials.

Polymer:	Draft angle between 1 and 2 degrees.
Aluminum:	Draft angle 1 degree for walls and 2 degrees for inside core.
Magnesium:	Draft angle 0,75 degrees for walls and 1,5 degrees for inside core.

In addition, rib reinforcements should have a draft angle of at least 0.25 degrees.

3.5 Joining Methods

An area where the two material groups, polymers and lightweight metal alloys, differ is the joining methods that can be utilized. This section will present and evaluate a number of methods.

3.5.1 Polymer Joining

Threads

Creating threads directly in the mold is one way to create screw joints. This requires a more advanced molding tool that allows for a screw motion in order to create the threads during molding. This can be very expensive especially if many threads are required. Another way is to create the threads by machine after the part has been molded. This adds an additional tool and manufacturing process that can be very costly.

An alternative to creating threads directly in the mold is to only create normal holes, preferably in the direction of the tool, which have a slightly smaller diameter than the diameter of the screw. By doing this, so called self-tapping screws can be used during the assembly to both create the threads and assemble the parts in one move. This will be a lot cheaper than molded threads without the need for a post process. Self-tapping threads can have equal or better stripping torque, the torque required to cause thread failure, than molded or machined threads while being a cheaper solution. It can therefore be considered to be a better method (Erteco 2012).

If a very high stripping torque is required, the use of metal inserts may be necessary. This will add labor and part costs and should be considered if the previous method cannot handle the stress.

Snap-fit

In order to lower assembly time for polymer parts it is possible to use the flexibility of the material. This is commonly done with so called snap-fit solutions. It should be noted that a snap-fit connection is not as stiff as a thread connection and should only be considered when the design allows for lower robustness of the part. There are different kinds of snap-fit designs. The most common snap-fit design is the cantilever design (BASF, 2007), see figure 29.

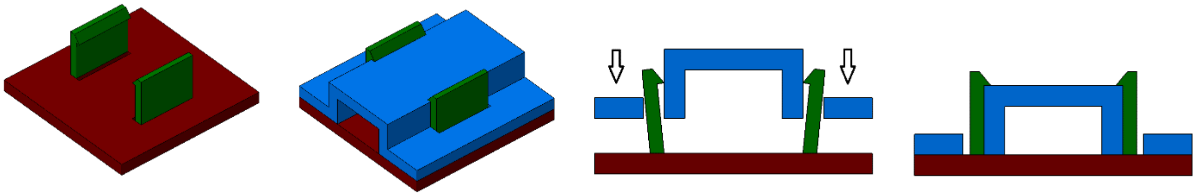


Figure 29. A part snaps onto another part by utilizing a cantilever snap-fit solution.

When designing a snap-fit it is important to choose dimensions that will give required force necessary for assembly and disassembly as well as keeping a desired force on mating surfaces that will maximize the stiffness of the connection (BASF, 2007).

The calculation varies depending on where the snap-fit is positioned in comparison to the rest of the part. In order to avoid undercuts the snap-fit cantilever can be placed on the side of the part facing outwards. Otherwise holes can be made under the cantilever part to avoid side activities in the tool as shown in the previous figure. More information about snap-fits and how to calculate dimensions can be found in appendix D.

3.5.2 Lightweight Metal Joining

Threads

Creating threads in an aluminum or magnesium part can be done in several ways. One way is to cut the threads separately from the shaping process. This will require additional post processes and may add tool or fixture costs (Granta Design, 2013).

Another option is to use thread inserts. These can be placed in the die casting tool directly. This may be a more cost effective option as it does not require any post process however it does increase the labor or automation cost.

Welding

Direct welding between two parts is also an option. This will increase production costs and require additional tools or fixtures in manufacturing. It will also remove the possibility of disassembly but will keep high strength between parts (Granta Design, 2013).

3.6 Conclusion - Material Options

The two material groups that were identified as suitable replacements for the current steel sheet solution were polymers and lightweight metals. The polymer materials were mostly reinforced polymer with about 30 % to 60 % glass fiber while the lightweight metals were aluminum and magnesium alloys. This was due to basic requirements for the material properties including density, Young's modulus, yield strength, service temperature and estimated price.

The most suitable shaping process for these materials was identified as injection molding for polymers and die casting for lightweight metals. The design guidelines for these two manufacturing processes are very similar. Without going into specific metrics for properties such as rounding and draft angle the same design will work with both processes. This will allow for concept design not to require a specific material set until strength analysis will be conducted followed by further improvements.

There are a number of benefits and drawbacks with both material groups. However some of these may differ depending on the specific material within its group but as a general guideline some of the benefits and drawbacks are stated in the following sections.

3.6.1 Glass Fiber Reinforced Polymers

Benefits

- Very low density, high potential for weight reduction.
- High potential to integrate several functions in the same part.
- Can use self-tapping screws during assembly to decrease manufacturing and part costs.
- May not require any post processes such as cutting or painting.
- Can create the complete unit in one step, fairly cheap manufacturing.
- Can keep a high yield strength that is competitive with metal and avoids deformation.
- Possible to use snap-fit connections for easier assembly.
- Require less energy during manufacturing.
- Warm touch.

Drawbacks

- Low Young's modulus in general, decrease base stiffness.
- Brittle material, may break rather than permanent deform during overloading.
- High raw material price per kg for stronger materials.

3.6.2 Lightweight Metals

Benefits

- Low density compared to steel, potential for weight reduction.
- Higher Young's modulus compared to reinforced polymers.
- In general high yield strength in aluminum alloys.
- In general a lower raw material price than polymer with higher Young’s modulus.
- Higher recycling potential than polymer materials.

Drawbacks

- Usually require post processes such as cutting, painting or other surface treatments.
- Require more energy during manufacturing, increases costs and environmental impact.
- Low yield strength in magnesium alloys compared to stronger polymer materials.

4 Concept Design Generation, Evaluation and Selection

This chapter will present how the concepts were created. It will go through all the steps from idea generation to how the concepts were evaluated and finally how the final concepts were chosen.

4.1 Idea Generation

The first step of a concept generation is to start generating ideas. For the idea generation the task is to come up with as many different ideas as possible. At this stage you shouldn't be afraid of thinking outside the box and let your imagination flow. Focus is on quantity rather than quality so all ideas are welcome in order to maximize the probability to find a suitable solution. To further encourage the creation of new ideas negative criticism in the idea generation process is often forbidden (Ulrich & Eppinger, 2012).

A common method in idea generation is brainstorming which can be done in many different ways. One way is the use of stimuli. Stimuli can be both related and unrelated to the product (Ulrich & Eppinger, 2012). For this project two different approaches utilizing related stimuli were used. This meant using the current solution and its environment as a mean of generating new ideas. The first approach was to examine the steel construction that is currently being used in today's solution. For this the assessment of the current solution from chapter 2.3.1 was used where all parts had been examined and labeled with letters as can be seen in figure 30. Using the labeled parts as a base the current solution was examined to find how different parts could be merged together. In this way existing parts were combined in different ways and new parts and sub-solutions were created.

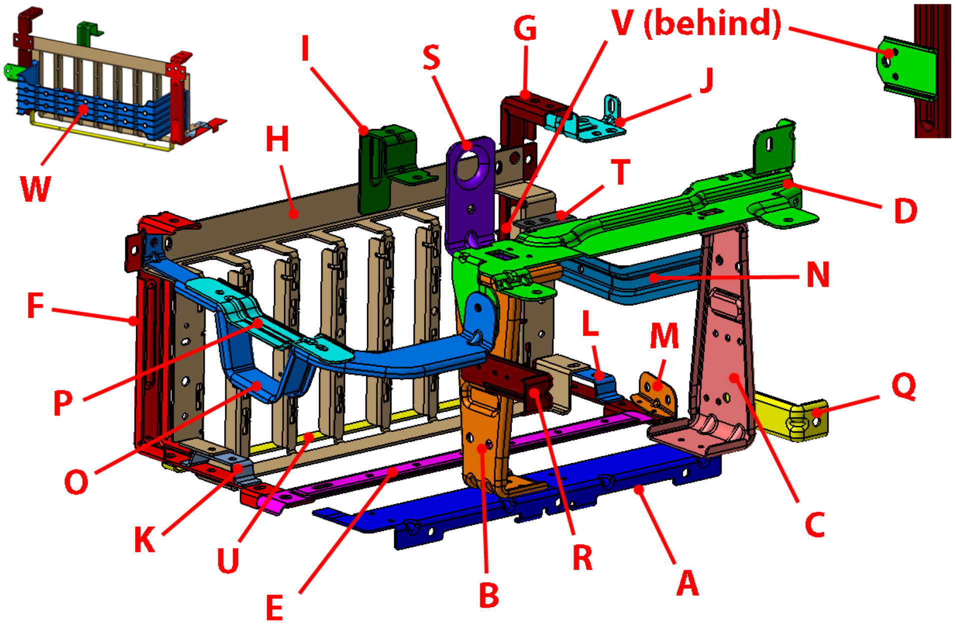


Figure 30. All parts labeled with letters. This was used to generate concepts by putting parts (letters) together.

The second brainstorming approach implemented was to use the interfaces from the current solution and using them as a base for new concepts, see figure 31. The mapping of the interfaces was gathered in the assessment of the current solution from chapter 2. By combining the interfaces in different ways new parts and ideas for concepts could be created. Using Catia for this greatly helped understanding how the interfaces were located in the 3D environment.

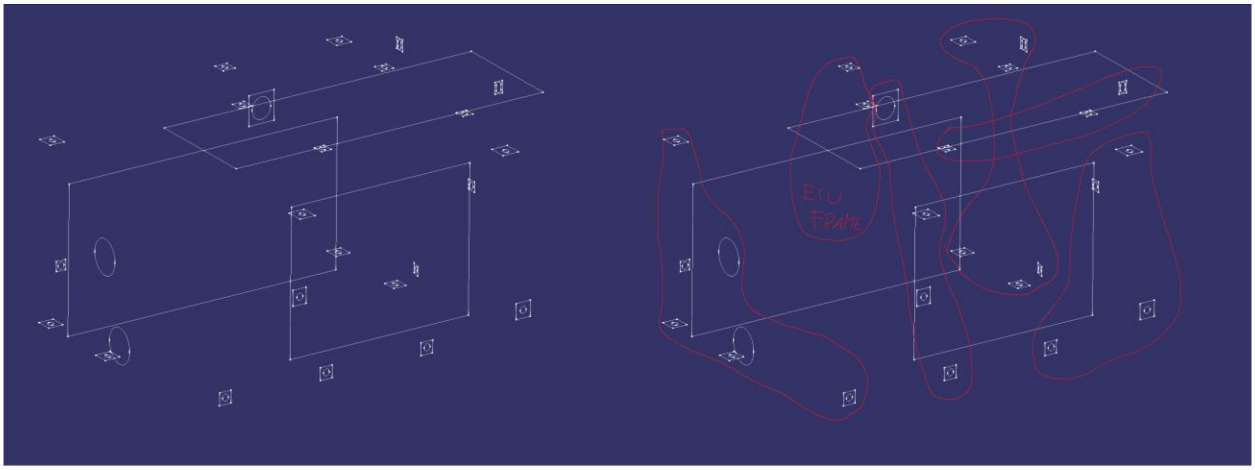


Figure 31. Interfaces to surrounding parts drawn. This was used to generate concepts by putting interfaces together. The right image shows one concept where each encirclement represents a part.

During both brainstorming methods the aim was to come up with solutions that would be able to compete with the current solution regarding a number of properties. The main ones of these being higher stability and robustness making the product more durable, fewer parts to speed up assembly and lower cost, higher reuse of parts to lower cost etc.

4.2 Concept Generation

When creating the basic concepts no regard was taken to the material choice. Instead focus was on coming up with function based solutions that would work with both metals and polymers. The aim with the concept generation phase is to realize the results from the idea generation. One approach when realizing concepts is to visualize them, either by hand or digitally, which will give a better understanding of the concept. Visualizing the concepts is also a good way to present the concepts to others in order to get feedback.

The approach implemented by the thesis workers were to visualized the concepts in the form of hand drawn sketches showing the basic outlines and functions of each design. The concepts were also given names that reflected the specific design of the concept. Some of the sketches can be seen in figure 32.

The concepts were created in three batches where the subsequent batch utilized the results and ideas from previous batches. All in all 21 concepts were made before moving on to the concept screening process.

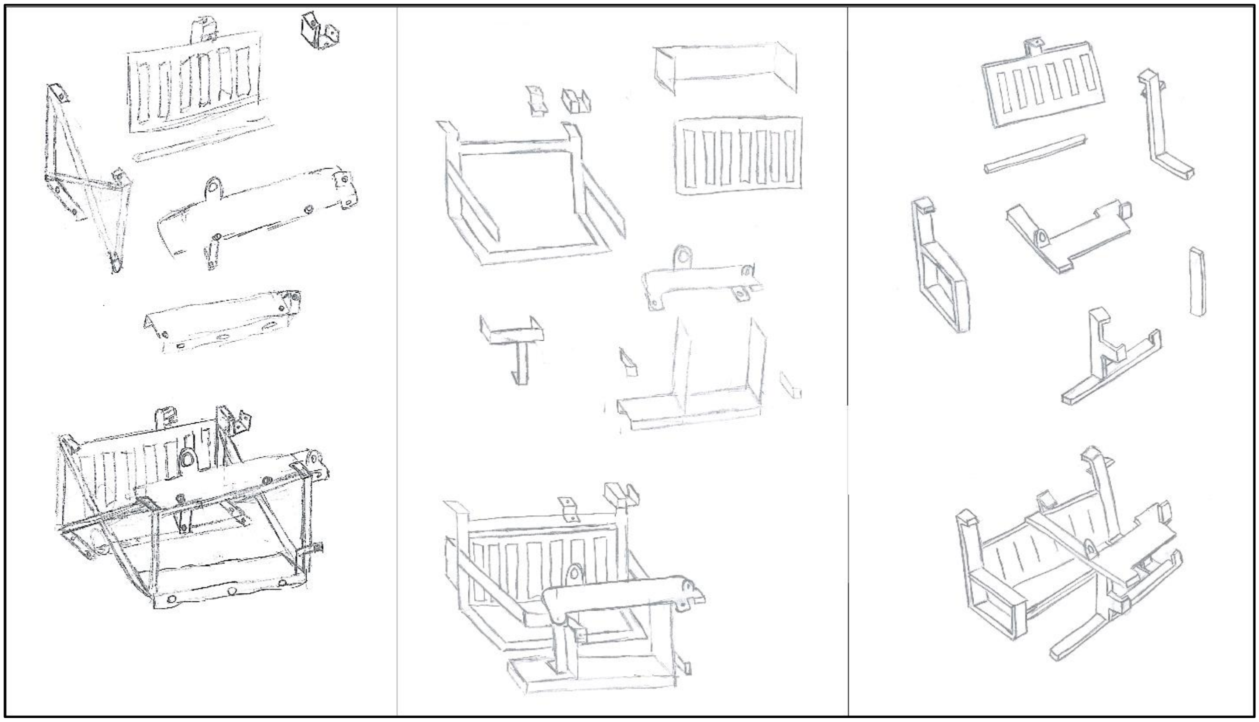


Figure 32. Sketches of three concepts out of the 21 concepts that was sketched. This demonstrate the procedure used during the concept generation.

4.3 Concept Screening and Scoring

After the concepts had been created it was time to start the evaluation process. Here all concepts were evaluated on their performance and how well they fulfilled the requirements and desires from the requirement list. Concept screening and scoring are processes which aim to lower the number of concepts by sorting out the ones that do not fulfill the requirements or have a poor performance.

4.3.1 Assessing Concepts Based on Requirements

The first phase of the concept evaluation process was to check if the concepts fulfilled the requirements. This was done by utilizing the elimination matrix and was a first step to screen out the concepts that did not fulfill the basic requirements of the product. This evaluation exists mostly to save time in a project by not keep on working with concepts that will never have a chance to make the final solution (Ulrich & Eppinger, 2012).

In the elimination matrix all concepts were examined to make sure they solve the overall task of the product and fulfilled the demands of the requirement specification. They also had to be compatible with the surrounding environment i.e. parts, interfaces and cables and fulfill their demands of the requirement specification. The estimated cost of the concepts was also checked to make sure it is not out of proportions.

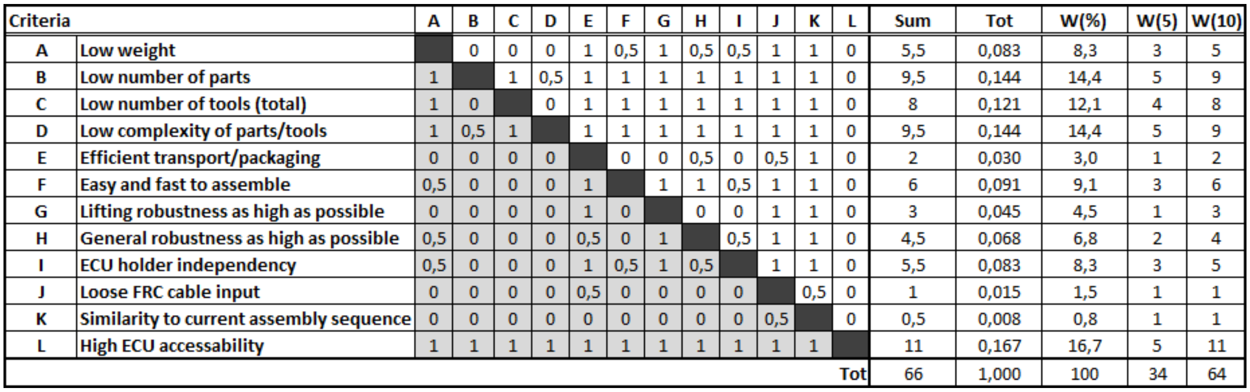
Although some concepts will not pass the elimination matrix, they still might have sub-solutions that are interesting to look into. Therefore it is important to not be too quick to dismiss a concept right off. During the elimination there were a few concepts that did not pass the elimination matrix at first. Some of these only had minor faults so instead of stopping them they were modified in order to pass.

In the end 5 of 21 concepts were dismissed during this phase. The concepts that did not pass were later on examined again to see if parts of them could be used to create new concepts. The full elimination matrix can be seen in appendix E.

4.3.2 Weighing the Importance of Desires and Development Factors

In the evaluation matrices that will be used in the following chapters, the concepts will be evaluated based on a list of criteria. In order to be able to use these matrices to their full potential the importance of each criterion must be decided. To do this a Weight Determination Matrix was used, see table 11.

Table 11. Weight Determination Matrix.



Criteria		A	B	C	D	E	F	G	H	I	J	K	L	Sum	Tot	W(%)	W(5)	W(10)
A	Low weight	■	0	0	0	1	0,5	1	0,5	0,5	1	1	0	5,5	0,083	8,3	3	5
B	Low number of parts	1	■	1	0,5	1	1	1	1	1	1	1	0	9,5	0,144	14,4	5	9
C	Low number of tools (total)	1	0	■	0	1	1	1	1	1	1	1	0	8	0,121	12,1	4	8
D	Low complexity of parts/tools	1	0,5	1	■	1	1	1	1	1	1	1	0	9,5	0,144	14,4	5	9
E	Efficient transport/packaging	0	0	0	0	■	0	0	0,5	0	0,5	1	0	2	0,030	3,0	1	2
F	Easy and fast to assemble	0,5	0	0	0	1	■	1	1	0,5	1	1	0	6	0,091	9,1	3	6
G	Lifting robustness as high as possible	0	0	0	0	1	0	■	0	0	1	1	0	3	0,045	4,5	1	3
H	General robustness as high as possible	0,5	0	0	0	0,5	0	1	■	0,5	1	1	0	4,5	0,068	6,8	2	4
I	ECU holder independency	0,5	0	0	0	1	0,5	1	0,5	■	1	1	0	5,5	0,083	8,3	3	5
J	Loose FRC cable input	0	0	0	0	0,5	0	0	0	0	■	0,5	0	1	0,015	1,5	1	1
K	Similarity to current assembly sequence	0	0	0	0	0	0	0	0	0	0,5	■	0	0,5	0,008	0,8	1	1
L	High ECU accessability	1	1	1	1	1	1	1	1	1	1	1	■	11	0,167	16,7	5	11
													Tot	66	1,000	100	34	64

In a Weight Determination Matrix all the criteria are put in the left column. The task is then to compare each criterion against each other. This is done in the upper right diagonal of the matrix. You then go row by row until the upper right diagonal of the matrix is full. If a criteria is more important you put in a “1”, equally important a “0,5” and less important a “0” The upper right half is mirrored and inverted to the bottom left half of the matrix. Each row is then summarized, the higher number the more important the criterion is. (Johannesson et al, 2004)

The criteria that were used in the Weight Determination Matrix were gathered from the requirement specification. These criteria were desired properties that the new concepts should have. As can be seen in table 11, high ECU accessibility together with a low number of parts a low complexity of parts and tools were found to be the most important criteria.

The sum for each criterion is usually converted into a percentage. However, in order to be able to apply the result to the evaluation matrices the sum for each criterion was also transformed to an integer. This was done by giving the highest percentage a “5” and the lowest a “1” and then mathematically calculate the remaining numbers in between. This was done for two scales, from one to five and from one to ten.

4.3.3 Comparing Concepts with a Reference Solution

The first matrix that was used to evaluate the concepts in regard to the chosen criterion was the Pugh matrix. The Pugh matrix is a decision making matrix whose goal is to quickly narrow down the number of concepts by comparing them to each other. The method choose one concept as datum which then all the other concepts are compared to. For each criterion the concepts either gets a “+”, “-” or “S” depending on if they are better, worse or equal in regard to the datum concept. The ratings are then summarized into a net value where “+”, “-” and “S” are worth +1,-1 and 0 respectively. (Ulrich & Eppinger, 2012)

The Pugh matrix was used in three steps. First two normal Pugh matrices were conducted and then two Pugh matrices with added weights. After the first two steps some concepts with bad ratings were removed and finally one normal and one weighted Pugh matrix were conducted on the remaining concepts.

For the weighted Pugh matrix each rating is multiplied by a weight. The weights used were taken from the determination matrix and for the Pugh matrix the weights were chosen to be represented by integers from one to five. Just like the normal Pugh the ratings are then summarized into a net value for each concept.

In order to get a more accurate result it is advised to perform the matrix a couple of times with different concepts as datum. This was done both for the normal and the weighted Pugh matrix. Table 12 shows the last Pugh matrix that was done before the next step. It is a weighted Pugh matrix where concept 19 “The Arm” was used as datum.

Table 12. The last weighted Pugh matrix.

Concept / Criteria	W	The Perpendicular	The Crown	The Top Frame	The Republican	The U	The Bend	The Frame	The Box	The Double Bar	The Arm	The Large Frame
	W	**1**	**2**	**3**	**9**	**10**	**14**	**16**	**17**	**18**	**19**	**20**
Low weight	**3**	-3	-3	-3	0	0	0	0	-3	0	DATUM	0
Low number of parts (One side)	**5**	-5	5	5	-5	-5	5	5	-5	-5		5
Low number of tools (Both Sides)	**4**	-4	-4	-4	-4	-4	0	0	-4	-4		4
Low complexity of parts/tools	**5**	5	5	-5	5	5	-5	-5	5	5		-5
Efficient transport and packaging	**1**	1	1	-1	1	1	0	-1	1	1		-1
Easy and fast to assemble	**3**	-3	0	3	-3	0	0	3	-3	-3		3
Lifting robustness as high as possible	**1**	0	0	-1	0	-1	1	0	0	0		0
General robustness as high as possible	**2**	-2	-2	0	-2	-2	-2	2	0	0		2
ECU holder independency	**3**	-3	-3	-3	-3	-3	-3	-3	0	0		-3
Loose FRC cable input	**1**	1	-1	0	-1	-1	0	-1	-1	-1		0
Similarity to current assembly sequence	**1**	-1	0	-1	-1	-1	-1	0	-1	-1		-1
High ECU accessability	**5**	0	0	0	0	0	0	0	0	0		0
Σ+		7	11	8	6	6	6	10	6	6	0	14
ΣS		0	0	0	0	0	0	0	0	0	0	0
Σ-		21	13	18	19	17	11	10	17	14	0	10
Net value		-14	-2	-10	-13	-11	-5	0	-11	-8	0	4
Ranking		11	4	7	10	8	5	2	8	6	2	1
Further development		NO	YES	NO	NO	NO	YES	YES	NO	?	YES	YES

In order to make it easier to compare the results from all the matrices the concepts in each matrix were given a rank depending on its net value. The results gathered from matrices were fairly similar. The performance did not vary a lot but enough that 9 concepts could be removed. All Pugh matrices can be found in appendix F.

4.3.4 Scoring Concepts Individually

The last method conducted was the Kesselring matrix. The Kesselring matrix is similar to the Pugh matrix but instead of choosing a datum concept all concepts are compared to an ideal solution. For each criteria the concepts are individually given a value on the scale from one to ten. The ratings are then multiplied by a weight. All the weighted ratings are then summarized for each concept and saved as a result in percentage. This is a more in-depth concept evaluation and requires more understanding of the concept solutions (Johannesson et al, 2004).

In order to get accurate weighted values the weights used in the Kesselring matrix were in the form of percentage. For comparison the Current solution was included in the matrix as well. The result of the Kesselring matrix can be seen in table 13.

Table 13. Kesselring matrix

Criteria			Ideal		Original 0		The Crown 2		The Bend 14	
		w	v	t	v	t	v	t	v	t
A	Low weight	8,3	10	83,3	4	33,3	7	58,3	6	50,0
B	Low number of parts	14,4	10	143,9	1	14,4	7	100,8	9	129,5
C	Low number of tools (total)	12,1	10	121,2	1	12,1	7	84,8	7	84,8
D	Low complexity of parts/tools	14,4	10	143,9	3	43,2	8	115,2	4	57,6
E	Efficient transport/packaging	3,0	10	30,3	3	9,1	6	18,2	4	12,1
F	Easy and fast to assemble	9,1	10	90,9	8	72,7	8	72,7	6	54,5
G	Lifting robustness as high as possible	4,5	10	45,5	10	45,5	6	27,3	8	36,4
H	General robustness as high as possible	6,8	10	68,2	8	54,5	7	47,7	7	47,7
I	ECU holder independency	8,3	10	83,3	3	25,0	3	25,0	4	33,3
J	Loose FRC cable input	1,5	10	15,2	9	13,6	3	4,5	7	10,6
K	Similarity to current assembly sequence	0,8	10	7,6	10	7,6	8	6,1	5	3,8
L	High ECU accessability	16,7	10	166,7	5	83,3	5	83,3	5	83,3
T = ∑t			1000,00		414,39		643,94		603,79	
T / Tmax			1,00		0,41		0,64		0,60	
Ranking					7		3		6	

Criteria			The Frame 16		The Double 18		The Arm 19		The Large Frame 20	
		w	v	t	v	t	v	t	v	t
A	Low weight	8,3	7	58,3	7	58,3	7	58,3	6	50,0
B	Low number of parts	14,4	8	115,2	6	86,4	7	100,8	8	115,2
C	Low number of tools (total)	12,1	7	84,8	7	84,8	7	84,8	8	97,0
D	Low complexity of parts/tools	14,4	5	72,0	8	115,2	5	72,0	4	57,6
E	Efficient transport/packaging	3,0	3	9,1	9	27,3	5	15,2	3	9,1
F	Easy and fast to assemble	9,1	9	81,8	6	54,5	7	63,6	7	63,6
G	Lifting robustness as high as possible	4,5	6	27,3	6	27,3	6	27,3	6	27,3
H	General robustness as high as possible	6,8	7	47,7	6	40,9	6	40,9	8	54,5
I	ECU holder independency	8,3	9	75,0	8	66,7	9	75,0	9	75,0
J	Loose FRC cable input	1,5	3	4,5	3	4,5	6	9,1	3	4,5
K	Similarity to current assembly sequence	0,8	7	5,3	6	4,5	7	5,3	6	4,5
L	High ECU accessability	16,7	5	83,3	5	83,3	5	83,3	5	83,3
T = ∑t			664,39		653,79		635,61		641,67	
T / Tmax			0,66		0,65		0,64		0,64	
Ranking			1		2		5		4	

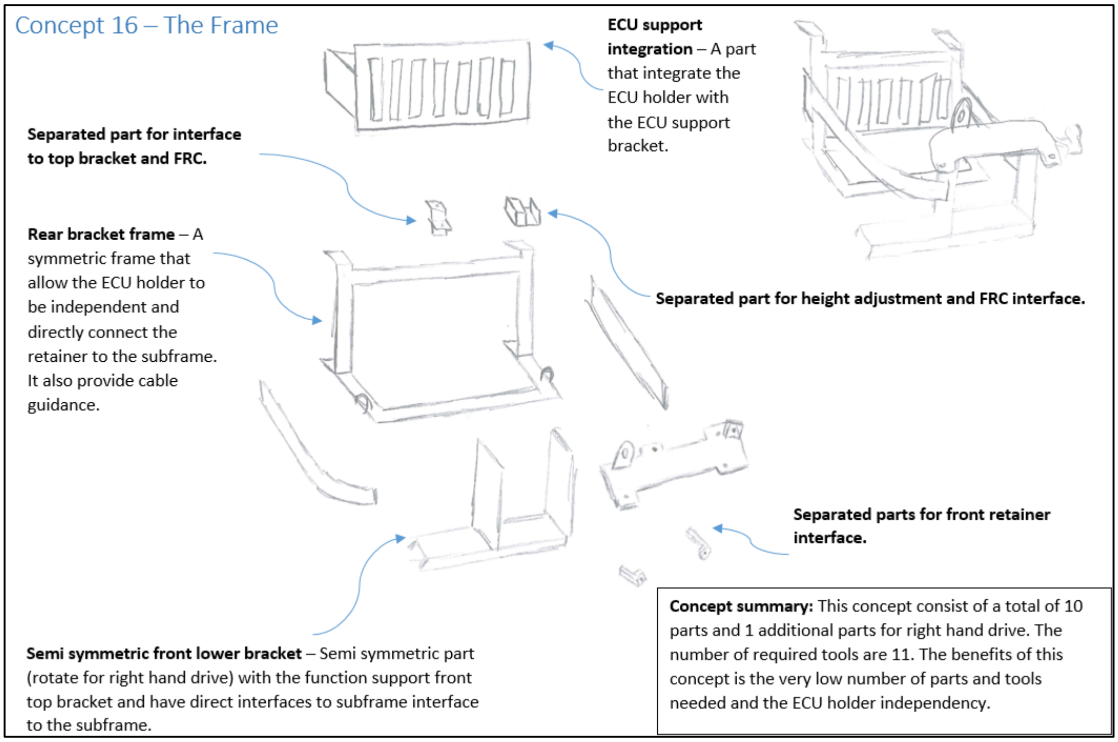
In order to decide which concepts to dismiss an average result value was calculated from all the concepts result values. Each concept was then given a range of plus/minus four percent from their result. If a concepts highest value then still was under the average result value it was dismissed. Only one concept was dismissed and the rest went on to the concept selection phase.

4.4 Selection of Concepts for Further Development

Since the remaining concepts all got similar scores in the Kesselring matrix it was decided more information was needed in order to only choose one or two concepts to continue with to the detailed concept design phase.

To begin with, all concepts were modeled in Catia V5 in order to get a better perspective on their designs and abilities. Making CAD-models can be very helpful when trying to realize a concept. Being able to work with the concept in 3D can give better inputs on what solutions work and what do not.

All concepts were also examined and summarized on a paper where all their abilities were explained. This gave a better overview of the concepts and their strengths making it easier to compare the concepts. Figure 33 describes one of the concepts, all remaining concept descriptions can be found in appendix G.



Concept 16 – The Frame

ECU support integration – A part that integrate the ECU holder with the ECU support bracket.

Separated part for interface to top bracket and FRC.

Rear bracket frame – A symmetric frame that allow the ECU holder to be independent and directly connect the retainer to the subframe. It also provide cable guidance.

Separated part for height adjustment and FRC interface.

Separated parts for front retainer interface.

Semi symmetric front lower bracket – Semi symmetric part (rotate for right hand drive) with the function support front top bracket and have direct interfaces to subframe interface to the subframe.

Concept summary: This concept consist of a total of 10 parts and 1 additional parts for right hand drive. The number of required tools are 11. The benefits of this concept is the very low number of parts and tools needed and the ECU holder independency.

Figure 33. A description sheet of the concept 16 "The Frame".

In addition to the CAD-models discussions were also held with a plastic supplier in order to get better input on manufacturability versus cost of the concepts.

With the information gathered it was decided to continue working on two concepts: "The Double Bar" and "The Frame". "The Double Bar" was chosen mainly because it had a good mix of number of tools and manufacturability whereas "The Frame" was a chosen as a test to see if it could be profitable to have fewer but more complex parts that would be more expensive to produce but easier to assemble.

5 Detailed Concept Refinement and Analysis

This chapter is based on the outcome of the concept generation, screening and scoring in chapter 4 as well as the outcome of the material evaluation in chapter 3. The two remaining concepts were developed in detail using the CAD software CATIA V5. Creating detailed design concepts will allow for conducting several analysis such as strength analysis (FEM), cost analysis and assembly analysis. It will also show the potential manufacturability, support material selections and be a tool for communicating concepts and design choices. The approaches of these analyses were implemented by the thesis workers.

The two concepts are similar in many ways and are designed to utilize the same architecture. A few parts are the same for both concepts. The main difference of the concepts are the parts creating the rear framework. The design of "The Double Bar" is intended to be the solution with a higher number of parts but with a lower complexity. The design of "The Frame" on the other hand has only one part where the other solution have five parts. This results with "The Frame" having lower number of parts but with higher complexity.

5.1 Part Design Description

There are six parts that are shared between the two concepts. There may however be some minor changes depending on material choice such as selection of connection method. These parts are the colored parts shown in figure 34 and are referred to as following:

Front Bottom Bracket - Green
Front Top Bracket - Orange
Right Support - Yellow
Left Support - Purple
ECU Holder - Light Blue
ECU Support - Blue

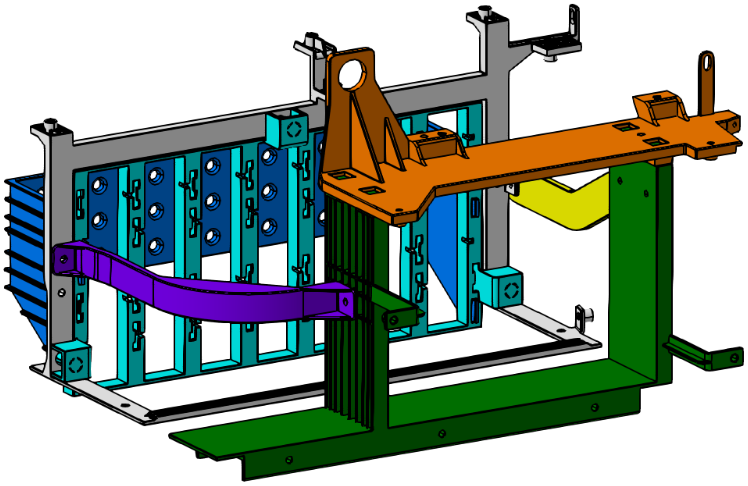


Figure 34. The parts that are colored are shared between the two design concepts.

All parts were designed in several iterations utilizing FEM analysis on single parts with a few of the cheaper and weaker materials applied, mostly from the material group of glass reinforced polymers. The reason for this was to maximize the individual stiffness of the parts as much as possible, decrease the maximum stress and avoid stress concentrations while keeping a low part volume. Another iterative design factor was the manufacturability. As the design became more detailed problems with manufacturability occurred that required several changes in the design.

These changes were mostly issues with undercuts in the design and were mostly avoided by changing the direction of complex design to meet the tool parts in a better way. In some cases undercuts could not be avoided and would require a side activity in the tool.

The concepts were designed using a 3 mm wall thickness. This is an increase of 1 mm compared to the current solution. As shown in chapter 3 increasing wall thickness will greatly increase the stiffness but also the volume. The selection of 3 mm was set as a trade-off between increased stiffness and a maintained low part volume. Thicker than 3 mm may also create problems with manufacturing in some cases and increase cooling time. Rib reinforcements were used to increase stiffness in addition to increased wall thickness. Guidelines presented in chapter 3 were used when designing rib reinforcements. These two methods together were optimized to find a desired stiffness and strength that could compete with the current solution.

Front Bottom Bracket

This part is fastened directly to the subframe. The part include arms that are connected to the retainer in the front. The bottom bracket is intended to be able to be used in both LHD and RHD trucks. The part can be rotated to fit both sides apart from the arm. This would require additional cavity volume in the tool on the opposite side for additional arms. To switch between LHD and RHD in manufacturing inserts would be required in the tool blocking off undesired arms and allowing desired arms. Figure 36 shows the part in detail.

Front Top Bracket

This part connects to the front bottom bracket by a wedge connection and a screw to lock the slide direction. The main purpose of this part is to meet interfaces and provide the lifting function. The part is designed to be able to be manufactured with a simple open and close tool but will still require side activities for holes perpendicular to the tool direction. A separate tool with a mirrored design have to be made for RHD trucks. Figure 35 shows the part in detail.

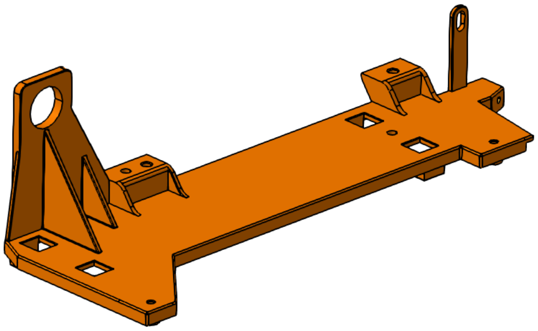


Figure 35. The shared part top bracket.

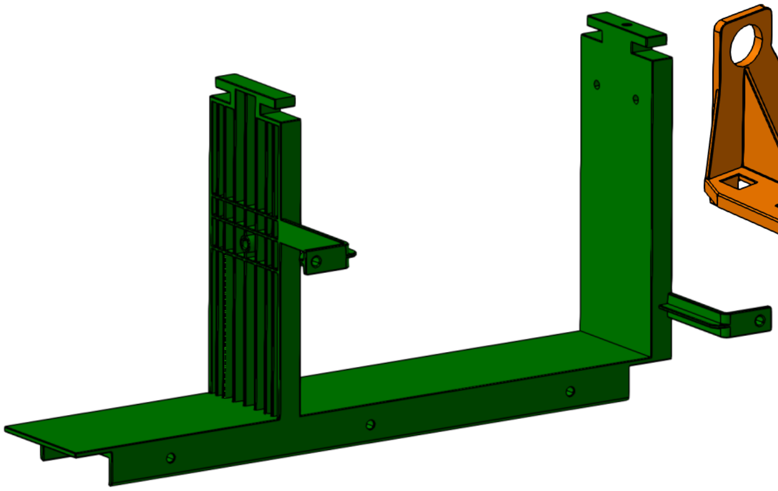


Figure 36. The shared part front bottom bracket.

Right Support

The purpose of this part is to keep the front parts together with the rear parts and increase robustness in the construction. The design can be used on both LHD and RHD trucks due to symmetry. A secondary purpose of the part is to provide fastening for a cable guide and an electric unit. The part is connected by screws. Figure 37 shows the part in detail.

Left Support

This part has the similar purpose as “Right Support” with the addition that it will harness the cable input for the FRC. The part is symmetric in vertical direction making it possible to flip in order to fit both LHD and RHD trucks. The part is connected by screws. Depending on material group the design varies. For polymer materials the function of harnessing the FRC cables is integrated in the design as a flexible arm while for lightweight metals there has to be an additional clip assembled on to the part. However the harness for the cable input is not designed for these concepts and will have to be considered for future work. Figure 38 shows the part in detail.

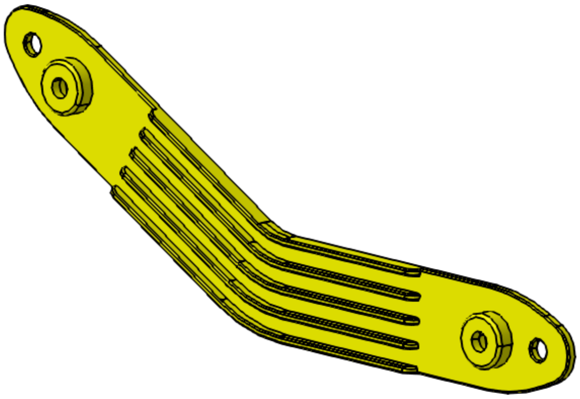


Figure 38. The shared part ”right support”.

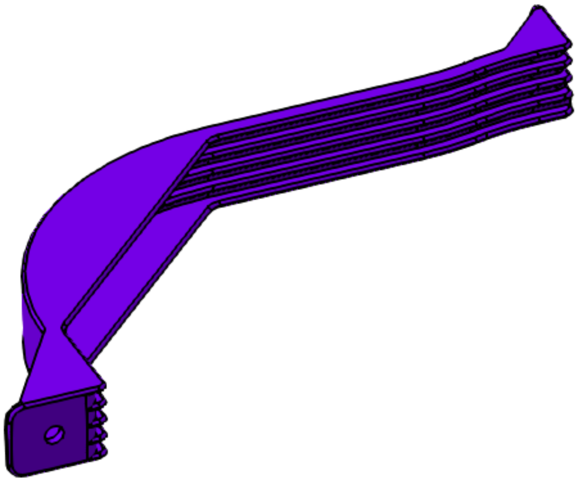


Figure 37. The shared part ”left support”

ECU Holder

This part has the main function of holding the ECUs in place. In comparison to the current solution this part is not a main part of the structural framework as the purpose was to separate the functions making the ECU Holder independent from supporting the dashboard. This would allow for this type of solution to be used in other truck models or applications as a standard solution. However the new solution may still indirectly provide support to some extent. The fastening method depends on material selection. The intended material is a polymer that would allow for snap-fit joints for faster assembly. A lightweight metal part would require screws as fastener. The part is symmetric allowing it to be used in both LHD and RHD trucks. The part can be seen in figure 39.

ECU Support

This part serves the purpose of supporting the back of the ECUs in a similar way as the current solution. The part is intended to be using polymer material and the main difference compared to the current solution is that it will be fastened with a snap-fit joint on to the ECU Holder. This will make the two parts into an independent solution for holding the ECUs in place. The part can be seen in figure 40.

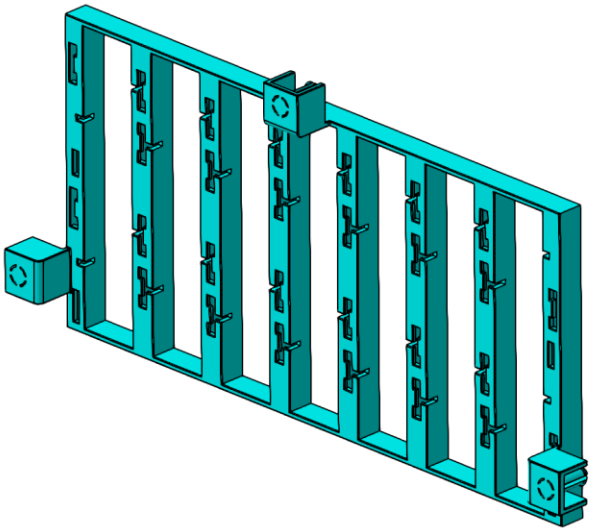


Figure 39. The shared part ”ECU Holder”.

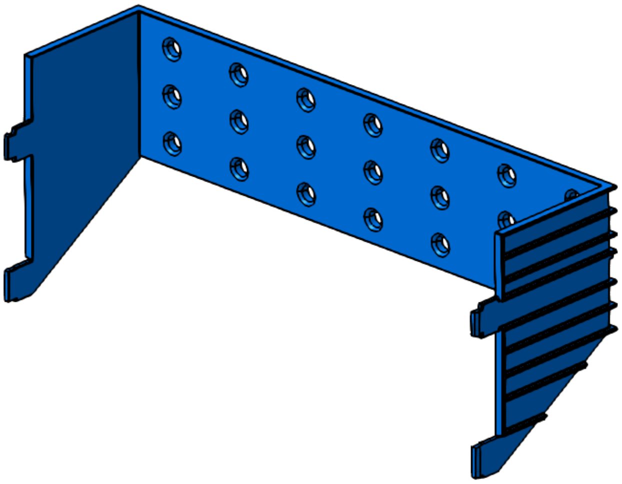


Figure 40. The shared part ”ECU Support”.

5.1.1 Concept Design A - Based on “The Double Bar”

The main focus with this design was to have a simple part design. The purpose of this was to have smaller and possibly cheaper tools. However this also contributes to an increased number of parts in comparison to concept design B which creates a longer assembly sequence and tolerance chain. The total number of parts of the framework using this design is nine with one part that requires an additional tool for RHD trucks.

L-Part

This part is the main part of the left side of the rear and is attached to the subframe. It is a symmetric part that can be used for both LHD and RHD trucks. The top interface is towards the retainer. Figure 42 shows the part in more detail.

L-Part Extended

This part is the right side equivalent of the L-Part. This part can be used for both RHD and LHD by using inserts in the tool. This part serves the same purpose as the "L-Part" with the addition of having an interface towards the FRC and a cable guidance. Figure 41 shows the part more in detail.

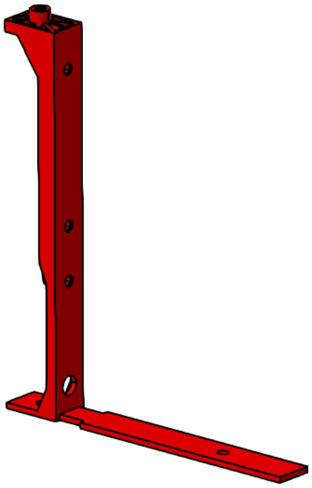


Figure. 41 L- Part.

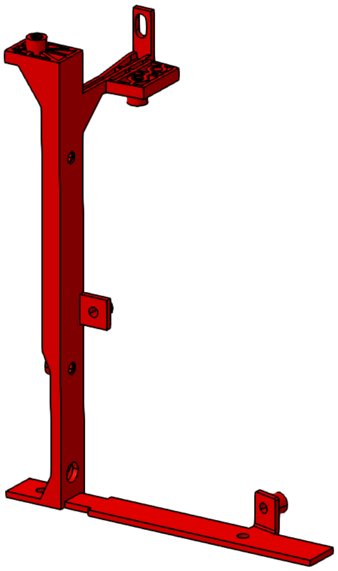


Figure 42. L-Part Extended

Bar

This part is symmetrical and can be used for both RHD and LHD trucks and is used twice in the same assembly. It serves the purpose of connecting the two L-Parts creating a more stable structure. The part can be seen in figure 43.

Middle Part

This is a symmetric part that is attached to the top "Bar" in order to create an interface towards the FRC and a plastic bracket next to the FRC. Figure 44 shows the part in detail.

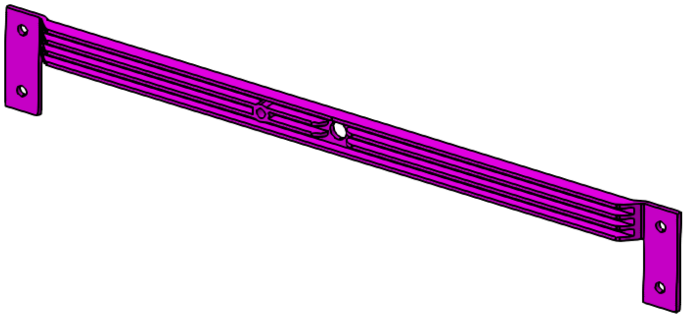


Figure 43. The part "Bar"

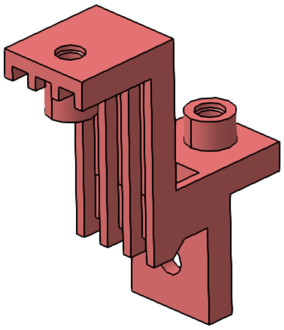


Figure 44. The part "Middle Bar"

5.1.2 Concept Design B - Based on “The Frame”

In comparison to concept design A this design aims to minimize the number of parts reducing the assembly time and the tolerance chains.

L-Frame

In comparison to concept design A this part replaces all the four parts making this a large part with complex design, see figure 45. An additional tool is required for RHD trucks unless inserts are used for blocking and releasing material flow in the cavities of the tool. This would however require further investigations that lies beyond the scope of this thesis.

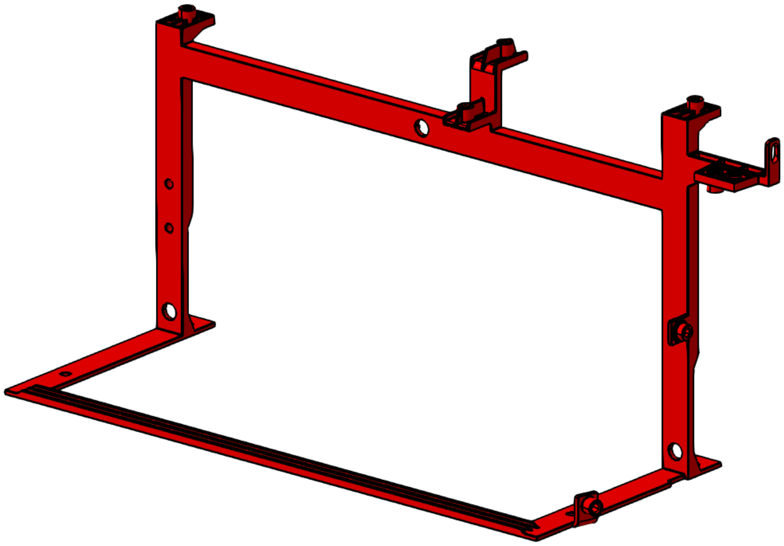


Figure 45. The part ”L-Frame”

5.2 Concept Analysis and Comparison

Conducting analyses of different areas of the concept solutions is a crucial process in order to determine the most suitable solution and material choice. The base of these analyses lie in a strength and stiffness analysis of the assembly, an analysis of the assembly sequence and a cost analysis. The main purpose of each analysis was to gather data similar to the data that was gathered for the current solution in chapter 2. The results of the benchmarking were used as comparative data when adjusting the concepts and presenting comparative results.

Before conducting the analysis and concept comparisons the specific materials had to be set for each part. This was done in several combinations with the main focus on having the same or similar material across as many parts as possible for each combination, for example having all or most parts as polymer material or having most parts in same lightweight metal material. Table 14 shows a list of the specific materials used in the analysis process. The materials are based on the material option conclusion from chapter 3 and consultation from a supplier in polymer materials.

Table 14. The materials used for analysis with respective properties (Granta Design, 2013), (Erteco, 2014).

Material		Density (kg/m^3)	Young's Modulus (Gpa)	Yield Strength (MPa)	Esitmated Price (SEK/kg)
PP + 40% GF	Sabic Stamax 40YM240	1220	8,3	121	26,60
PPA + 40% GF	Grivory GV-4H	1470	13	210	48,76
PPA + 50% GF	Grivory GV-5H	1560	17	220	53,19
PPA + 60% GF	Grivory GV-6H	1690	21	240	62,06
Magnesium	AZ92A, cast, T6	1830	45	140	27,00
Aluminum	354.0, cast, T6	2810	73	244	18,80

Material combinations were synthesized based on initial testing to get an understanding of basic strength theory of the material and design as well as a basic understanding for cost limitations and weight reduction. Table 15 shows the different material combinations for concept design A and B that were analyzed in the following sub-chapters.

Table 15. The material and design combinations used for analysis.

Concept Design A	**Material Combinations**				
Part Name	**A1**	**A2**	**A3**	**A4**	**A5**
Front Bottom Bracket	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
Front Top Bracket	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
Right Support	Sabic Stamax	Grivory GV-4H	Grivory GV-5H	Aluminum	Magnesium
Left Support	Sabic Stamax	Grivory GV-4H	Grivory GV-5H	Aluminum	Magnesium
ECU Holder	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax
ECU Support	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax
L-Part	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
L-Part Extended	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
Bar (x2)	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
Middle Part	Sabic Stamax	Grivory GV-4H	Grivory GV-4H	Aluminum	Magnesium
Concept Design B	**Material Combinations**				
Part Name	**B1**	**B2**	**B3**	**B4**	**B5**
Front Bottom Bracket	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
Front Top Bracket	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium
Right Support	Sabic Stamax	Grivory GV-4H	Grivory GV-5H	Aluminum	Magnesium
Left Support	Sabic Stamax	Grivory GV-4H	Grivory GV-5H	Aluminum	Magnesium
ECU Holder	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax
ECU Support	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax	Sabic Stamax
L-Frame	Grivory GV-4H	Grivory GV-5H	Grivory GV-6H	Aluminum	Magnesium

5.2.1 Strength Analysis of Assembly

During the concept design phase simple strength and stiffness analyses was conducted on single parts to find obvious weaknesses in the design and strengthen the parts. Conducting a strength analysis of the whole assembly, with parts connected as intended, was the final step to identify and improve weak areas of the concept solution. This was done in an iterative process with FEM where different materials were applied to the design. After each calculation minor adjustments to the geometry was made until the desired results had been reached.

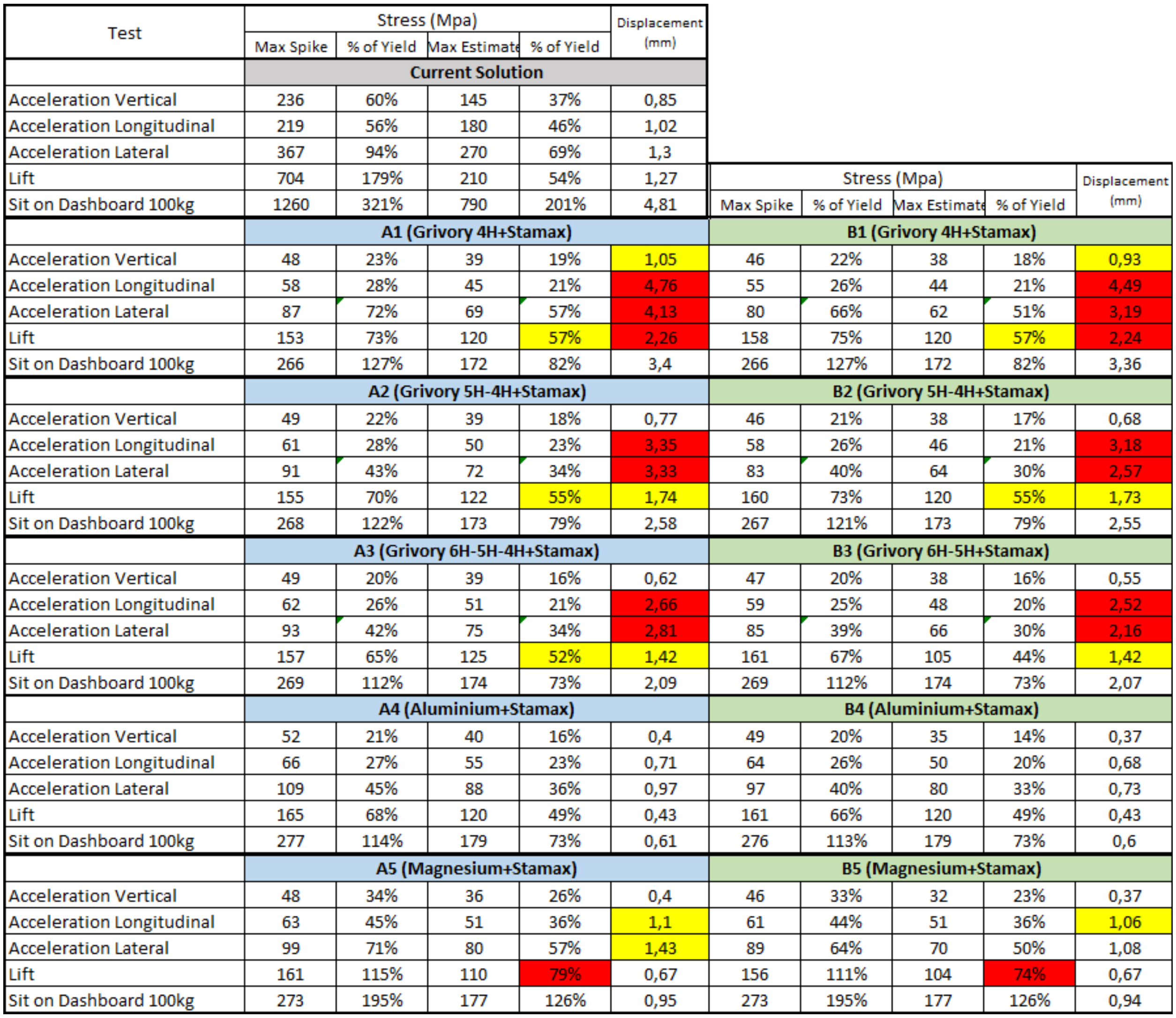
The different static load cases that were used are the same that were used during the assessment of the current solution in chapter 2. The load cases tested are the lift during the assembly of the dashboard, different G-forces that would occur during driving, frequency of the self-pulsation and misuse i.e. a person would lean against or sit on the dashboard.

Before going into the results a few notes regarding the FEM analysis should be made. The primary goal with the FEM-analysis has been to obtain results that can be used for comparison with the current solution rather than getting 100 % accurate results. Getting very accurate results would require an analysis on the whole dashboard which in turn would require a lot of computer power.

The result from the FEM-analysis for all the different material combinations for design A and B respectively can be seen in table 16. The result shows the maximum stress value, an estimated maximum stress value, a yield ratio for the stress and maximum displacement value measured in each case. The estimated stress value is an attempt to find a more accurate maximum since the maximum stress acquired from the software usually is a result of bad meshing, which often occurs around holes and sharp edges.

Looking at the results it can be seen that the concepts fare well regarding estimated stress levels. All concepts except A5 and B5 have better or similar yield stress ratio than the current solution. Regarding the displacement the polymer concepts A1-A3 and B1-B3 have little harder time to perform as well as the current solution while the metal concepts, A4-A5 and B4-B5, perform just as well as the current solution.

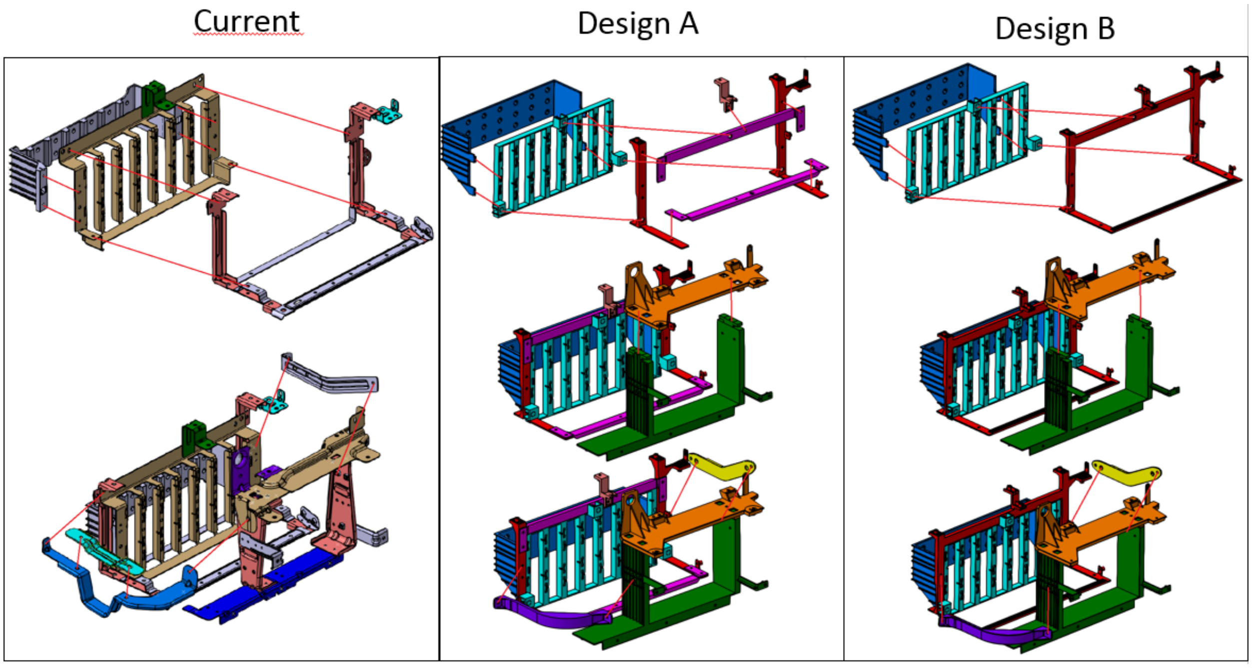
Table 16. The results from FEM analysis conducted for all 10 concepts and the current solution for all load cases.



Test	Stress (Mpa)				Displacement (mm)					
	Max Spike	% of Yield	Max Estimate	% of Yield						
	Current Solution									
Acceleration Vertical	236	60%	145	37%	0,85					
Acceleration Longitudinal	219	56%	180	46%	1,02					
Acceleration Lateral	367	94%	270	69%	1,3					
Lift	704	179%	210	54%	1,27	Stress (Mpa)				Displacement (mm)
Sit on Dashboard 100kg	1260	321%	790	201%	4,81	Max Spike	% of Yield	Max Estimate	% of Yield	
	A1 (Grivory 4H+Stamax)					**B1 (Grivory 4H+Stamax)**				
Acceleration Vertical	48	23%	39	19%	1,05	46	22%	38	18%	0,93
Acceleration Longitudinal	58	28%	45	21%	4,76	55	26%	44	21%	4,49
Acceleration Lateral	87	72%	69	57%	4,13	80	66%	62	51%	3,19
Lift	153	73%	120	57%	2,26	158	75%	120	57%	2,24
Sit on Dashboard 100kg	266	127%	172	82%	3,4	266	127%	172	82%	3,36
	A2 (Grivory 5H-4H+Stamax)					**B2 (Grivory 5H-4H+Stamax)**				
Acceleration Vertical	49	22%	39	18%	0,77	46	21%	38	17%	0,68
Acceleration Longitudinal	61	28%	50	23%	3,35	58	26%	46	21%	3,18
Acceleration Lateral	91	43%	72	34%	3,33	83	40%	64	30%	2,57
Lift	155	70%	122	55%	1,74	160	73%	120	55%	1,73
Sit on Dashboard 100kg	268	122%	173	79%	2,58	267	121%	173	79%	2,55
	A3 (Grivory 6H-5H-4H+Stamax)					**B3 (Grivory 6H-5H+Stamax)**				
Acceleration Vertical	49	20%	39	16%	0,62	47	20%	38	16%	0,55
Acceleration Longitudinal	62	26%	51	21%	2,66	59	25%	48	20%	2,52
Acceleration Lateral	93	42%	75	34%	2,81	85	39%	66	30%	2,16
Lift	157	65%	125	52%	1,42	161	67%	105	44%	1,42
Sit on Dashboard 100kg	269	112%	174	73%	2,09	269	112%	174	73%	2,07
	A4 (Aluminium+Stamax)					**B4 (Aluminium+Stamax)**				
Acceleration Vertical	52	21%	40	16%	0,4	49	20%	35	14%	0,37
Acceleration Longitudinal	66	27%	55	23%	0,71	64	26%	50	20%	0,68
Acceleration Lateral	109	45%	88	36%	0,97	97	40%	80	33%	0,73
Lift	165	68%	120	49%	0,43	161	66%	120	49%	0,43
Sit on Dashboard 100kg	277	114%	179	73%	0,61	276	113%	179	73%	0,6
	A5 (Magnesium+Stamax)					**B5 (Magnesium+Stamax)**				
Acceleration Vertical	48	34%	36	26%	0,4	46	33%	32	23%	0,37
Acceleration Longitudinal	63	45%	51	36%	1,1	61	44%	51	36%	1,06
Acceleration Lateral	99	71%	80	57%	1,43	89	64%	70	50%	1,08
Lift	161	115%	110	79%	0,67	156	111%	104	74%	0,67
Sit on Dashboard 100kg	273	195%	177	126%	0,95	273	195%	177	126%	0,94

5.2.2 Assembly Comparison

The assembly order of the parts was one thing that needed to be kept similar to the current solution in order to minimize implementation changes for a new solution. The goal was however also to make the procedure faster and more efficient. One way to achieve this was to minimize the number of screws needed and instead use snap fits. The same snap fits solutions are used in both Design A and B. An exploded view of the current solution and both new designs can be seen figure 46.



	Screws	Snap-Fit
Current Solution	21	0
Concept Design A	18	7
Concept Desing B	12	7

Figure 46. Exploded views showing the assembly of the current solution and the two new design options.

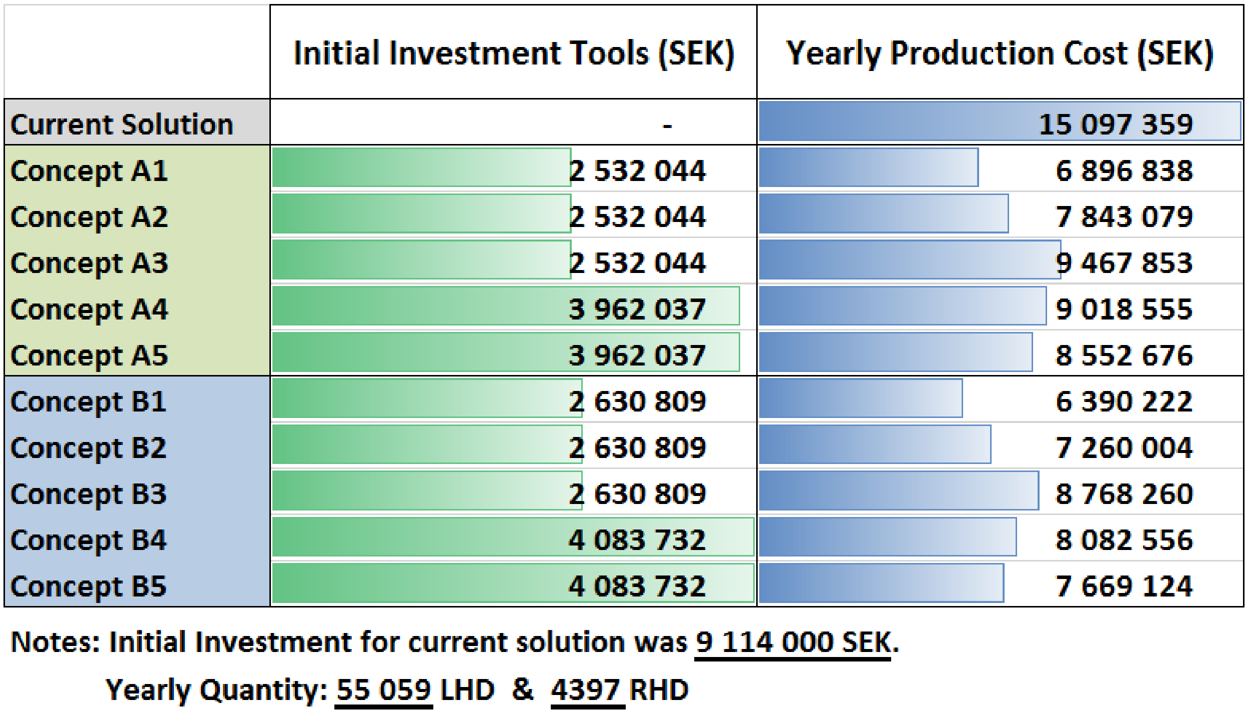
As can be seen both new designs are similar in their assembly procedure. Design A will however have more assembly steps than design B because it consist of more parts. This also means it will use more screws than design B. Thanks to the snap fit and wedge solutions both of the new designs require fewer screws than the current solution. Both designs have 7 snap fits. In addition to that design A uses 18 screws while design B only needs 12 screws. This can be compared to the current solution's 21 screws.

5.2.3 Cost Analysis

When calculating the cost for the concepts the site CustomPartNet (2014) was used in order to get part and tool cost. The part price for some of the parts was also checked with a subcontractor in order to validate the values. However, not knowing exactly how the tool costs are calculated and since they could not be validated the tools cost should be seen as rough estimates.

When calculating the part cost the material costs were gathered from subcontractors and the software CES (Granta Design, 2013). Except for the process cost the metal parts also had some post process costs in the form of painting which were added to the total production cost received from CustomPartNet (2014). The Polymer parts had no post process cost.

The estimated tool cost and a yearly production cost for all new concepts as well as the yearly production cost of the current solution can be seen in figure 47. The calculations are made for a yearly quantity of 55 059 RHD trucks and 4 397 LHD trucks. For comparison the investment of the tools for the current solution is 9 114 000 SEK but is not stated because it has already been invested.



	Initial Investment Tools (SEK)	Yearly Production Cost (SEK)
Current Solution	-	15 097 359
Concept A1	2 532 044	6 896 838
Concept A2	2 532 044	7 843 079
Concept A3	2 532 044	9 467 853
Concept A4	3 962 037	9 018 555
Concept A5	3 962 037	8 552 676
Concept B1	2 630 809	6 390 222
Concept B2	2 630 809	7 260 004
Concept B3	2 630 809	8 768 260
Concept B4	4 083 732	8 082 556
Concept B5	4 083 732	7 669 124

Notes: Initial Investment for current solution was 9 114 000 SEK.
Yearly Quantity: 55 059 LHD & 4397 RHD

Figure 47. The estimated tool costs and yearly production costs.

In figure 48 the production cost of the first 5 years can be seen. As shown the concepts are around 25-40 MSEK cheaper than the current solution with the tool cost of new concepts included. Viewing the potential cost savings in relation to new tool cost it can be seen that the tool cost is a small part of the total cost. This would allow for even more expensive tools to still be a viable option economically, such as tools that allow for even higher tolerances.

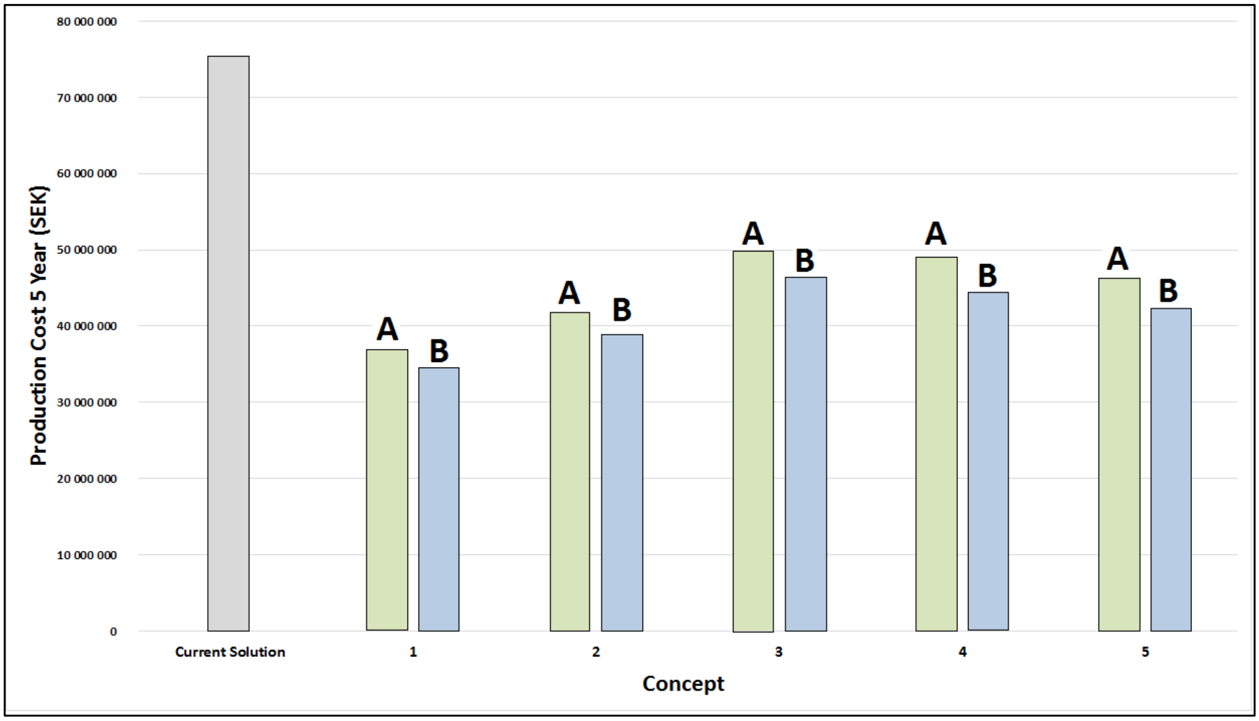
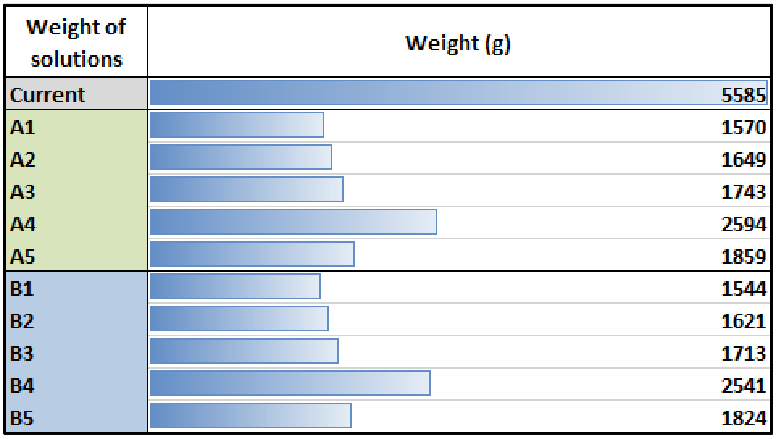


Figure 48. 5-year production costs of all concepts and the current solution. The tool cost is included in the concepts.

5.2.4 Weight Reduction

Weight reduction was one of the main objectives for this study. The final weight correlates directly from the density of chosen materials and the volume of design A and B. Figure 49 shows the weights in grams for all concepts and the current solution. The new solutions ranges from 70% to 50% weight reduction where the weaker polymer materials have the highest reduction rate.



Weight of solutions	Weight (g)
Current	5585
A1	1570
A2	1649
A3	1743
A4	2594
A5	1859
B1	1544
B2	1621
B3	1713
B4	2541
B5	1824

Figure 49. The weight of all concepts and the current solution for comparison.

5.2.5 Environmental Reflection

When doing an environmental evaluation of the concepts the software CES (Granta Design 2013) was used again in order to get an eco-audit report. An eco-audit report is a simple life cycle analysis that shows how big the energy usage and CO_2 footprint is in every part of the life of the product. Looking at the CO_2 footprint it could be seen that all concepts performed well having half or less than half of the CO_2 footprint of the current solution.

From the eco audit report it could also be seen that the use phase of the life cycle of the product was the absolute most important factor regarding the CO_2 footprint, about 95%. Usage in this sense means how much CO_2 is emitted when driving around with the weight of the product for 2 000 000 km (estimated lifetime distance for a truck). This would explain the results since the most important factor would be the material weight of the concepts which correlate to the results in figure 50.

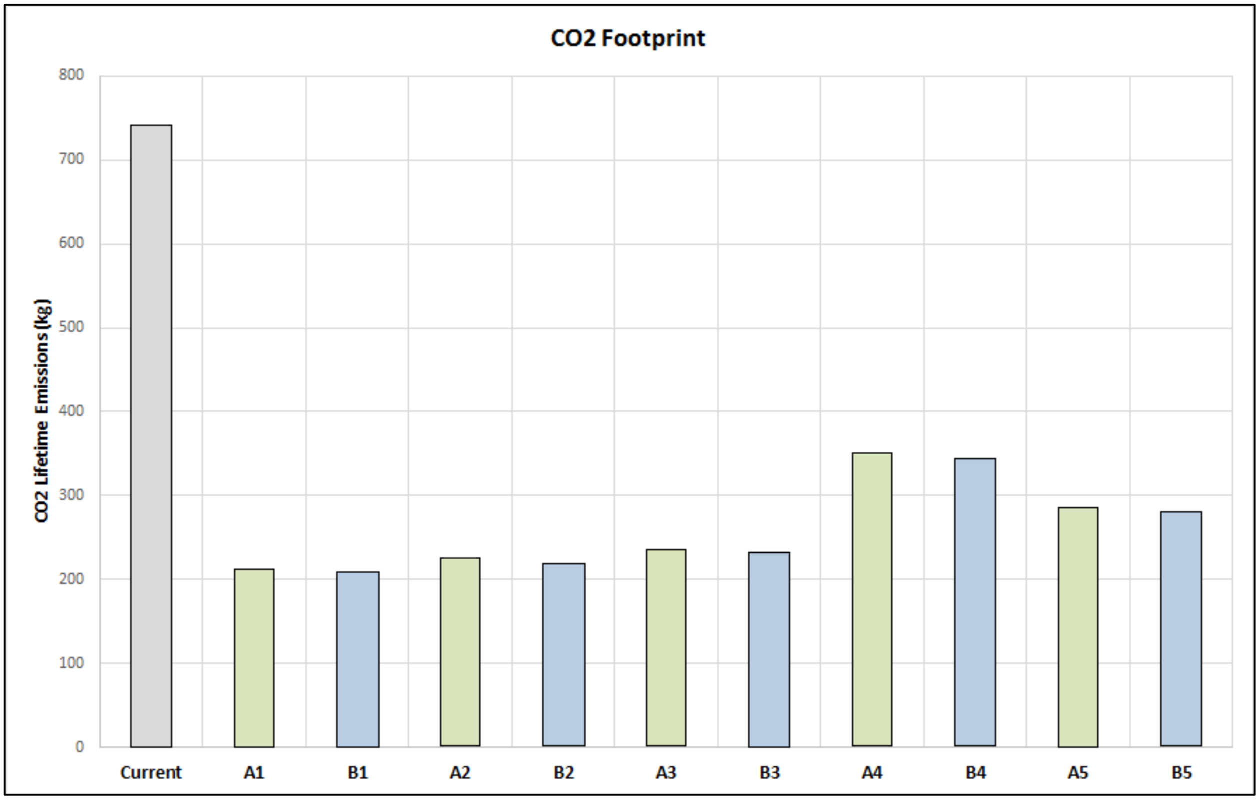


Figure 50. The CO_2 footprint presented for each concept and the current solution.

Except working with CES eco audit reports Volvo Group´s own blacklist of materials has also been consulted. This list contains materials that Volvo Group are not allowed to use because of various health and environmental reasons.

5.3 Concept Comparison Conclusion

To make a final comparison of the concepts their total performance needed to be calculated. To do this all the data from the analysis were evaluated and each concept was given a rating ranging from one to ten for each performance property. The properties being how well they performed regarding stiffness, stress, weight, environmental impact and assembly. The properties were then also weighed in order of importance. The results can be seen in table 17.

Table 17. Weighted ratings for each task and concept as well as the current solution.

	Weight	Stiffness	Stress	Eco	Assembly	Summary	
Weight	4	3	3	1	3		
Current	4,0	30,0	3,0	2,6	27,6	67	Current
A1	28,4	15,9	20,4	7,9	27,9	101	A1
A2	28,0	21,3	24,0	7,8	27,9	109	A2
A3	27,2	24,0	25,2	7,6	27,9	112	A3
A4	21,2	30,0	25,2	6,5	27,9	111	A4
A5	26,4	29,4	9,6	7,1	27,9	100	A5
B1	28,8	18,3	21,0	7,9	24,3	100	B1
B2	28,0	22,8	24,6	7,8	24,3	108	B2
B3	27,6	25,2	27,0	7,7	24,3	112	B3
B4	21,6	30,0	25,8	6,5	24,3	108	B4
B5	26,8	29,7	11,4	7,2	24,3	99	B5

Having the performance rating for each concept the performance could now be plotted against the cost showing concepts performance/cost ratio of each concept. Since a high performance and a low cost is desired the optimal result would be found in the upper left corner. The result can be seen in picture 51.

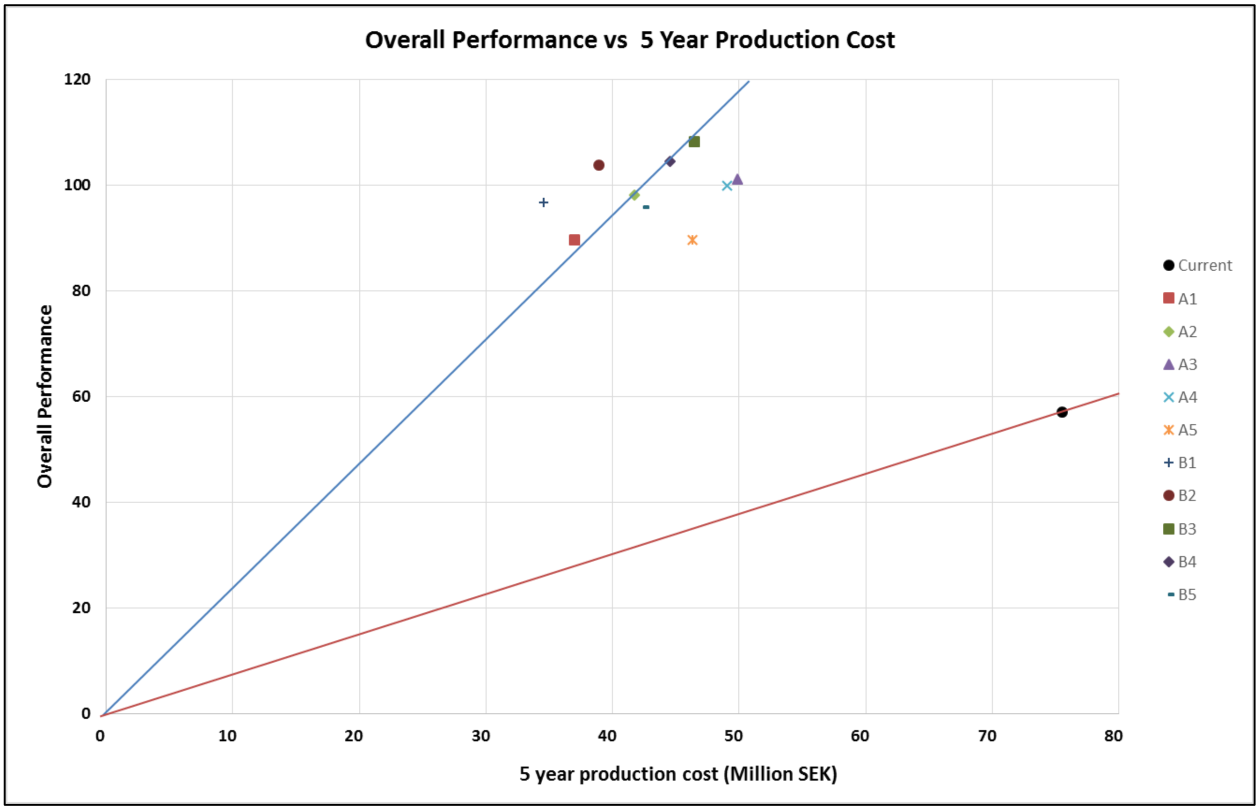


Figure 51. Performance vs Cost comparison that was used to identify the most cost effective high performing concept.

6 Presentation of Final Concept Solution

This chapter will present the chosen concept solution based on the concept analysis and comparison in chapter 5.

6.1 Suggested Concept Solution

With the concept comparison as base it was time to choose the most suitable concept. To do this the performance/cost plot from chapter 5.3 was used again. A zoomed in picture of the plot can be seen in figure 52.

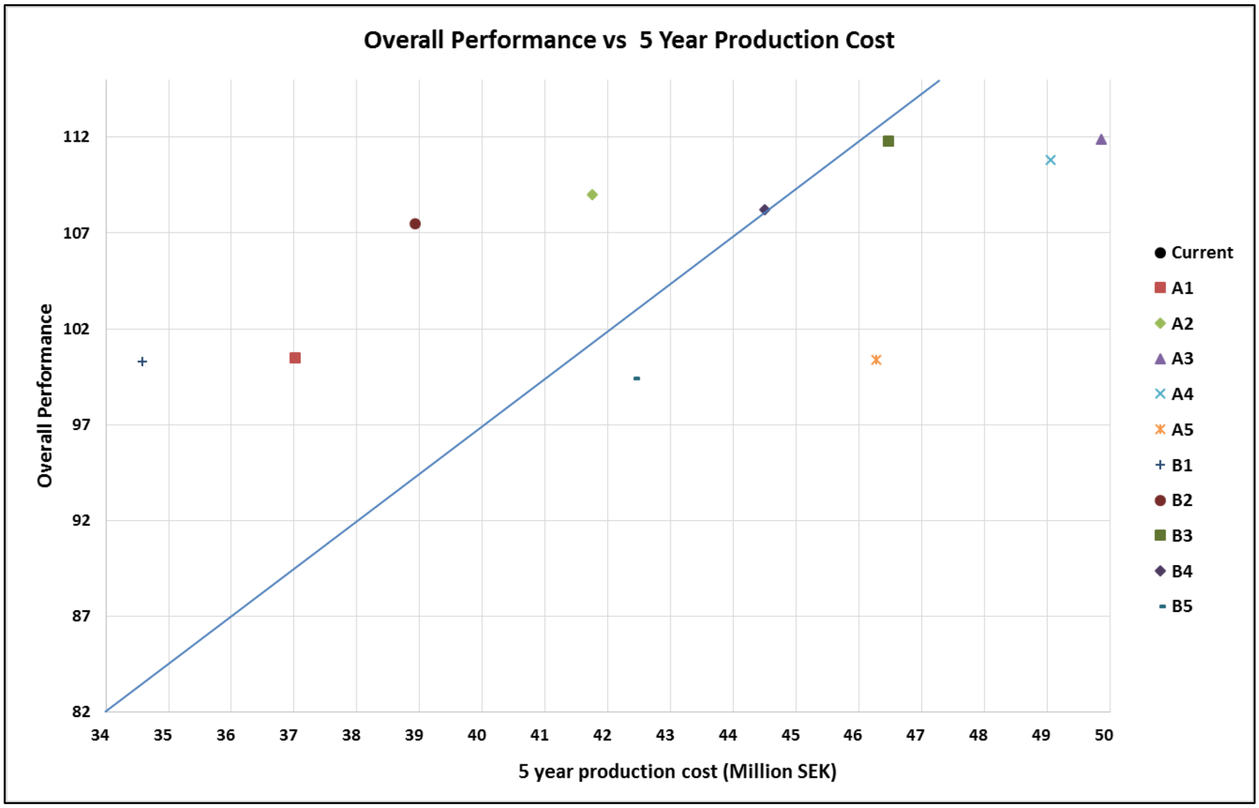


Figure 52. A zoomed in version of figure 51 in order to easier identify the most suitable concept.

As a first step to find the best concept a line was drawn from origin ([0,0] coordinate) to concept B4 which was the best performing metal concept. This should be interpreted as all the concepts which lie above this line have a better cost/performance ratio than concept B4. As can be seen in figure 52 there are a couple of concepts that achieve this.

Looking at the remaining concepts in the plot it can be seen that the best performing concepts can be found in the 107-112 interval. It can also be seen that concept B2 is the cheapest of the concepts in that interval. Going any cheaper will result in concept A1 which in regard to concept B2 is around 5 % cheaper but also lose 6,5 % in performance. This gives A1 the best performance/cost ratio, however the loss in overall performance is considered too high when comparing to the higher performance concepts. Therefore concept B2 is chosen as the suggested concept solution being the cheapest concept within the high performance interval.

6.2 Business Case

This chapter will present a summary of the most competitive properties of the suggested solution, concept B2. The concept B2 consist of mostly PPA with 50% glass fiber, see table 14 and 15 for more details about the materials. Figure 53 shows the concept assembled as intended. See appendix H in order to view the solution in its intended surroundings.

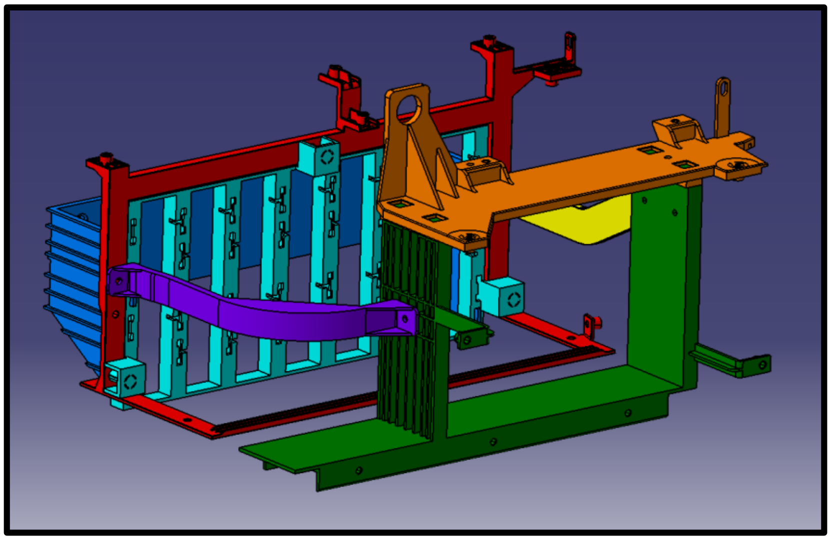


Figure 53. Final concept solution B2.

- A design that utilizes few parts which will reduce tolerance chains as well as simplify and speeding up the assembly process.
- Utilizing injection molding for polymers that opens up for more flexible design choices.
- Potential to reduce a 5-year production cost with up to 35 MSEK which is equal to 48% of the cost for the current solution.
- A lighter solution with a weight reduction of 3964g which equals to a 70% weight reduction compared to the current solution.
- Reduce assembly time thanks to snap fits and only 12 screws instead of 21 that are used today.
- A high performing stress safety factor and a solution that will not break.
- Potential for decreased environmental impact due to weight reduction.

7 Discussion

In this chapter we will discuss some aspects of the project that felt important to highlight. We will try to explain some of the challenges encountered and how they were dealt with.

Work structure

The approach of the project follows a fairly normal product development process that has been taught at Chalmers University of Technology. Since material option evaluation was an important part of the project we decided to keep the material and concept generation separate. This turned out well since all materials had similar manufacturing processes and adjustments between concepts with different materials could be made individually in the detailed concept generation phase.

Early on in the project we got in touch with a supplier working with polymers who wanted to assist during the study. While this of course was of great help it also made us focus more on polymers than other materials in the beginning of the project. Even though other materials were researched it was easier to get more feedback from the supplier regarding polymers and how to use them for our project. Putting this in relation to the fact that a polymer concept was chosen as the best solution, it could raise the question if the metal concepts could have been better if we had the opportunity to get the same feedback from a metal supplier. This is difficult to say of course, but it certainly would have been interesting to have had the opportunity.

Also, while working with a supplier gave us deeper knowledge about polymers it also meant we had to deal with influence from the supplier. Getting help and feedback while keeping the project our own was a balance during the project.

Design phase

A big problem during the whole design phase was the fact that it was difficult to estimate how much a design change would affect the cost and maybe primarily the tool cost. Even the suppliers we talked to had problems estimating the tool cost and essentially you would need to work close with the tool manufacturer to get an accurate cost estimate. The only real way to try and tackle this problem was by acquiring as much knowledge we could and using common sense when making design changes.

Analysis phase

A large part of the evaluating phase was the FEM-analysis of the concepts. Since we did not have access to expensive FEM-software we used Catia V5 instead which works well when you only want to compare results rather than getting very accurate results. Besides that, FEM-results are also very dependent on how fine the mesh is and how connections and loads are defined. In other words, very good accuracy of the results from our FEM-analysis cannot be guaranteed and the results should only be used to compare the concepts with the current solution. One example of this is the Von Mises stress values from one test being so high that the current solution would have broken which is not the case for the real current solution.

Another aspect of the analysis, especially for the polymer concepts, is the changes in performance during higher temperatures still within the range of service for the material. It is well known that for some materials the performance is reduced quite a lot when the temperature gets high. This was never taken into consideration when conducting FEM analysis. This would require further studies in order to determine if critical temperatures will be reached during regular use conditions and if they will affect the performance enough to make the solution invalid in that case.

Earlier we mentioned the problem to get accurate tool costs because it would require the help from a tool manufacturer. In the cost analysis we got the estimated tool cost from CustomPartNet (2014). The reliability of this site was only tested by comparing numbers from the site with numbers from a polymer supplier regarding part price for a specific part. No such test could be done for the tool cost however. While this is worth pointing out it may not be a big issue since our cost analysis also showed that the tool cost is a very small part of the total cost. Furthermore it should be noted that any potential reduction in transport costs due to lower weight was never included in cost comparison. Limitations set the new transportation cost to be equal to current solution. A potential cost saving would however also depend on the location of manufacturing.

General applicability of the approach

In addition to the outcome being a new concept design with new materials this thesis also provide an approach used in order to do find the results. This approach is described in 1.6 and used throughout the report.

The approach is especially suitable for the automotive industry where weight reduction and cost effectiveness is very important factors. Also due to the fact that the material options evaluated are polymers and light weight metals, the approach used in the thesis are more suitable when these material groups are of high interest. This is especially the case when replacing sheet metal. However the general applicability of the approach should not be seen as limited to these material groups.

8 Final Words

This chapter will present the conclusions of the study and suggestions on how to continue with the work that has been done in this project.

8.1 Conclusion

The task for this project was to investigate if it was possible to find an alternative solution to the current dashboard framework by utilizing alternative materials.

Through our studies it was found that using alternative materials could provide an equally good solution as the current dashboard framework in some areas while performing better in other areas. Using glass fiber reinforced polymers, aluminum, magnesium or a combination of these showed that it was possible to develop concepts with equal strength to the current solution while still reducing the weight by more than 50%. Part of this was thanks to the production methods injection molding and die casting which allowed for a more flexible design.

The opportunity to utilize a more flexible design also brought with it some other advantages. The number of parts could be decreased as well as the number of different parts for LHD and RHD trucks even though they could not be eliminated completely. Having fewer parts resulted in needing fewer tools and together with the use of snap-fit fastening solutions also resulted in a faster assembly time. Even with all improvements mentioned the final production cost of the dashboard framework could be substantially reduced.

All in all it was found that there is large potential in using lightweight materials instead of steel sheet metal. The main challenge working with lightweight materials is still the stiffness. For the materials that were used this is an issue that mainly concerns the polymers. Even though the strength levels were much lower than the breaking point it could still be an issue in situations where a very rigid solution is necessary.

Furthermore, this thesis also provide a transferable approach for general work in the areas of changing material and design of an existing solution. The approach is especially suitable for the automotive industry and includes evaluating an existing solution, finding suitable materials, generate and select a new design, conduct analysis of new design with new materials, compare to current solution and suggest new solution.

8.2 Continued Work

Much time and hard work have been spent to get to the point where the concept is now. Still there is more to do in order to realize the new dashboard framework.

As mentioned earlier in the report the FEM-analysis has been made with Catia V5 which is not the best FEM-program when it comes to reliability and accuracy of results. It would be recommended to let Volvo’s own calculating department examine the new dashboard framework in order to find weak spots that might have passed us by and make adjustments accordingly.

When that is done the design should be revised. Interfaces should be clearly defined and connections should be designed more in detail. This includes holes for self-tapping threads and snap-fit connections. Also it should be ensured that the geometry and connection tolerances are met, this should not be too difficult as this is one of the advantages with the new design. When this is done there might be time to make a rapid prototype to make sure that the concept is compatible with the surrounding parts and connections and make design changes if necessary. This will also help getting a better understanding of the concept.

The next step would be to begin working closely with a polymer supplier in order to finally make a prototype with the correct polymer materials. With a working prototype final testing can be made to evaluate the real solution and make final adjustments to the new dashboard framework.

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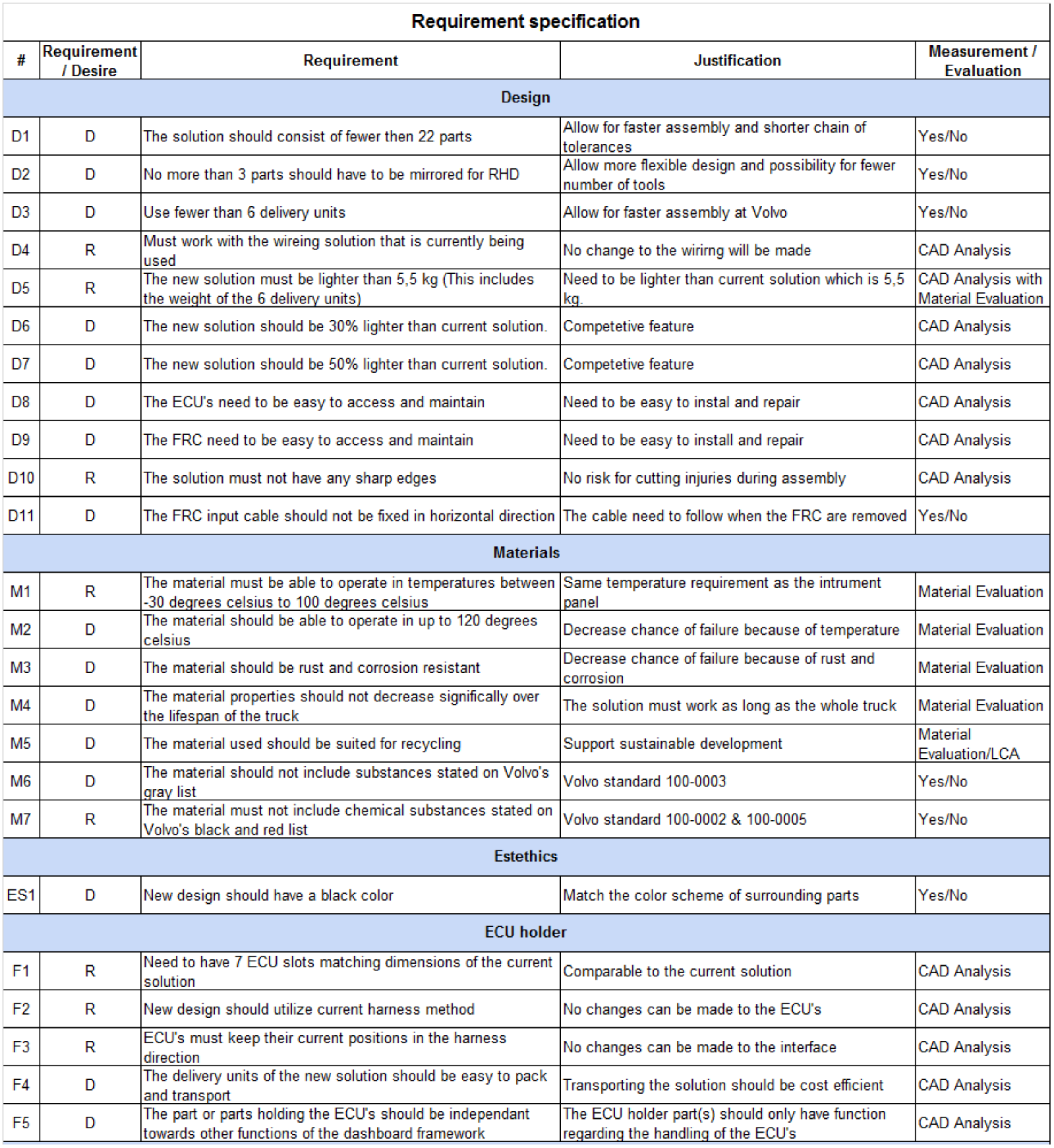
Appendices

A - Requirement Specification

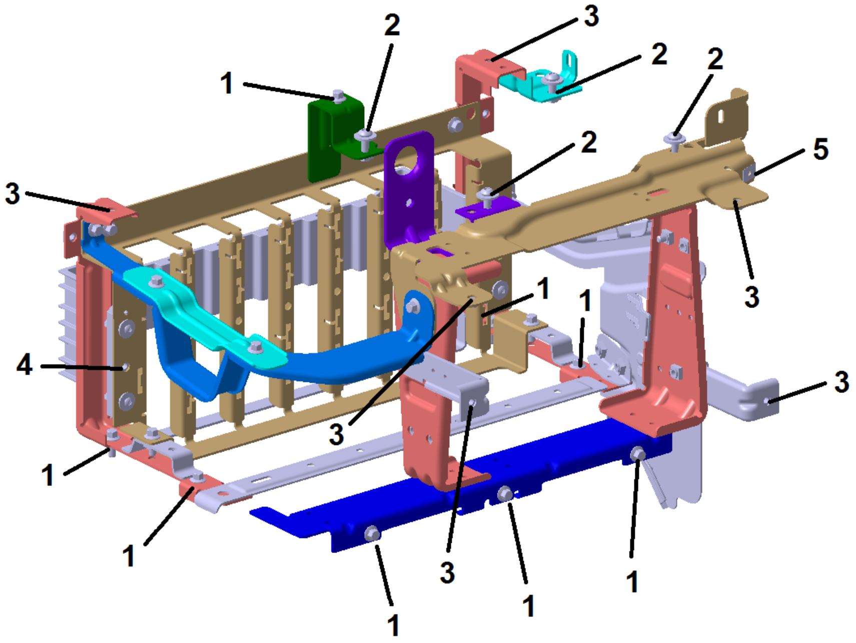


Requirement specification

#	Requirement / Desire	Requirement	Justification	Measurement / Evaluation
Design				
D1	D	The solution should consist of fewer then 22 parts	Allow for faster assembly and shorter chain of tolerances	Yes/No
D2	D	No more than 3 parts should have to be mirrored for RHD	Allow more flexible design and possibility for fewer number of tools	Yes/No
D3	D	Use fewer than 6 delivery units	Allow for faster assembly at Volvo	Yes/No
D4	R	Must work with the wireing solution that is currently being used	No change to the wirirng will be made	CAD Analysis
D5	R	The new solution must be lighter than 5,5 kg (This includes the weight of the 6 delivery units)	Need to be lighter than current solution which is 5,5 kg.	CAD Analysis with Material Evaluation
D6	D	The new solution should be 30% lighter than current solution.	Competetive feature	CAD Analysis
D7	D	The new solution should be 50% lighter than current solution.	Competetive feature	CAD Analysis
D8	D	The ECU's need to be easy to access and maintain	Need to be easy to instal and repair	CAD Analysis
D9	D	The FRC need to be easy to access and maintain	Need to be easy to install and repair	CAD Analysis
D10	R	The solution must not have any sharp edges	No risk for cutting injuries during assembly	CAD Analysis
D11	D	The FRC input cable should not be fixed in horizontal direction	The cable need to follow when the FRC are removed	Yes/No
Materials				
M1	R	The material must be able to operate in temperatures between -30 degrees celsius to 100 degrees celsius	Same temperature requirement as the intrument panel	Material Evaluation
M2	D	The material should be able to operate in up to 120 degrees celsius	Decrease chance of failure because of temperature	Material Evaluation
M3	D	The material should be rust and corrosion resistant	Decrease chance of failure because of rust and corrosion	Material Evaluation
M4	D	The material properties should not decrease significally over the lifespan of the truck	The solution must work as long as the whole truck	Material Evaluation
M5	D	The material used should be suited for recycling	Support sustainable development	Material Evaluation/LCA
M6	D	The material should not include substances stated on Volvo's gray list	Volvo standard 100-0003	Yes/No
M7	R	The material must not include chemical substances stated on Volvo's black and red list	Volvo standard 100-0002 & 100-0005	Yes/No
Estethics				
ES1	D	New design should have a black color	Match the color scheme of surrounding parts	Yes/No
ECU holder				
F1	R	Need to have 7 ECU slots matching dimensions of the current solution	Comparable to the current solution	CAD Analysis
F2	R	New design should utilize current harness method	No changes can be made to the ECU's	CAD Analysis
F3	R	ECU's must keep their current positions in the harness direction	No changes can be made to the interface	CAD Analysis
F4	D	The delivery units of the new solution should be easy to pack and transport	Transporting the solution should be cost efficient	CAD Analysis
F5	D	The part or parts holding the ECU's should be independant towards other functions of the dashboard framework	The ECU holder part(s) should only have function regarding the handling of the ECU's	CAD Analysis

#	Requirement / Desire	Requirement	Justification	Measurement / Evaluation
Connections				
C1	R	Keep the lifting point position of current solution	Volvo requirement from current solution and previous lifting calculations	CAD Analysis
C2	R	Keep the current B-interfaces from current solution	Solution need to work with the rest of the dashboard	CAD Analysis
C3	R	Keep the current C-interfaces from current solution	Solution need to work with the rest of the dashboard	CAD Analysis
C4	R	The soultion must have a flatness tolerance of +/- 0,5 mm against the four interfaces of the FRC	New solution must work with current attachment points	CAD Analysis with Material Evaluation
C5	R	Current cable guide positions must be kept within a 10 mm radius adjustment	This may allow small adjustments to the current cable design for the purpose of innovative design	CAD Analysis
C6	D	Current cable guide positions should not be changed	For compatability reason the cable design should not be changed	CAD Analysis
C7	R	The tolerances must be kept during constant load in its intended environment	Tolerances must be kept during long term driving	FEM Analysis with Material Evaluation
C8	D	The stiffness and robustness of the new solution should be comparable to the current solution	FEM results are compared to current solution in order to establish that strength requirements are met	FEM analysis
Technical				
T1	R	Need to be able to lift 60 kg without breaking when mounted on to the chassi with a safety margin of 1,5 - 2 g	Volvo requirement from current solution and lifting calculations	FEM Analysis
T2	R	Need to be able to support additional G-forces that may occur during driving	Volvo standard requirement.	FEM Analysis
T3	R	The solution must have a lifespan at least equal to the lifespan of the truck	The solution must outlive the truck as a whole	
T4	D	The new solution should withstand an additional vertical applied weight of 160 kg	Solution should not break if a person sits on or lean against the dashboard	FEM Analysis
T5	R	Need to meet the Volvo requirement of frequency in the design during selfpulsation	Volvo standard requirement.	FEM Analysis
Economical				
EC1	D	The total cost of all delivery units of the LHD product should not exceed 250 SEK	New solution should be cost competetive	Cost Analysis
EC2	D	The total cost of all delivery units of the RHD product should not exceed 290 SEK	New solution should be cost competetive	Cost Analysis
EC3	D	The new solution should start generating a profit within the first year of production compared to the current solution	This will support a decision in order to implement the new soultion	Cost Analysis
Environmental				
EN1	D	The total CO2 footprint created by the solution should be lower than the current solution.	Solution need to be a more environmental friendly choice than the current solution.	Environmental Reflection
EN2	D	The solution should be recycleable	Solution need to be environment friendly	Environmental Reflection
Assembly				
A1	D	The new solution should have a shorter assembly sequence than current solution at Volvo assembly line	Should not have longer assembly time than current solution, be cost competetive	Assembly analysis
A2	D	The new solution should have features that support faster assembly	Faster assembly reduces production costs	Assembly analysis
A3	R	The new solution must have features that support avoidance of misassembly	Allow for faster assembly and avoidance of failures	Assembly analysis
A4	D	The new solution should have features that remove the possibility of misassembly.	Allow for faster assembly and avoidance of failures	Assembly analysis
A5	R	The new solution must have an assembly sequence that is suitable for the overall assembly of the dashboard	Avoid any collision or contradictory actions during assembly	Assembly analysis
A6	D	The solution should follow the current assembly sequence of the delivery units	Faster implementation of a new solution if the assembly sequence is similar	Assembly analysis
A7	R	Parts shall not create ergonomic problems for the assembler	Allow for safe assembly	CAD Analysis

B – Screws, Current Solution



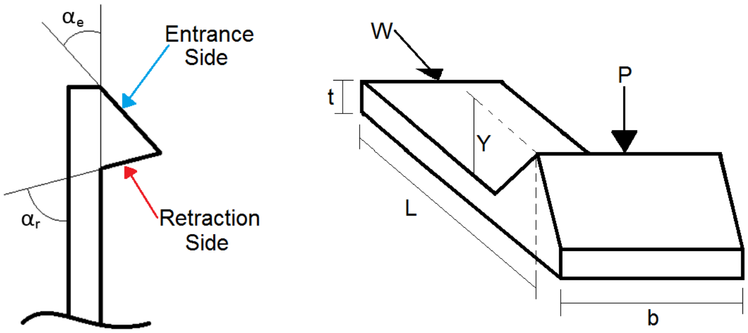
Reference Nr	Screw Type	ID
1	Flange Screw M6x16	984725
2	Six Point Socket Screw M6x20	971322
3	Flange Screw M6x15x17	994193
4	Flange Screw M6x16x18,95	990748
5	Screw St 4,8x19	972081

C - Material evaluation data

Material name	Material Family	Sub family	Source	Density Range (kg/m^3)		Young's modulus Range (GPa)		Yield Strength Range (MPa)		Tensile Strength Range (MPa)		Estimated Price Range (SEK/kg)		Max Service Temperature Range (C°)	
Steel - VSCR 140 STD 311-0002 (Volvo)	Metal	Steel sheet metal	CES	7800,0	7900,0	200,0	221,0	140,0	280,0	270,0	410,0	3,4	3,8	495,0	509,0
Steel - VSHR 350 STD 311-0003 (Volvo)	Metal	Steel sheet metal	CES	7800,0	7900,0	200,0	221,0	350,0	435,0	420,0	550,0	4,2	4,6	473,0	502,0
Aluminum, 354.0, cast, T6	Metal	Aluminum	CES	2780,0	2810,0	73,0	76,7	244,0	270,0	304,0	336,0	17,0	18,8	130,0	200,0
Aluminum, 7249, wrought, T76511	Metal	Aluminum	CES	2790,0	2850,0	74,6	78,4	503,0	556,0	521,0	626,0	16,7	18,4	110,0	170,0
Magnesium, AZ92A, cast, T6	Metal	Magnesium	CES	1810,0	1830,0	45,0	47,3	90,0	172,0	117,0	276,0	24,4	26,9	132,0	149,0
Magnesium, Elektron ZW3, wrought	Metal	Magnesium	CES	1790,0	1810,0	44,0	46,0	195,0	280,0	280,0	355,0	26,8	29,5	130,0	160,0
Zinc-aluminum alloy, ZA-12, general casting	Metal	Zinc-aluminum alloy	CES	5980,0	6080,0	81,0	85,0	205,0	320,0	260,0	405,0	16,0	17,5	90,0	110,0
Zinc-aluminum alloy, ZA-27, general casting	Metal	Zinc-aluminum alloy	CES	4950,0	5050,0	75,0	84,0	235,0	395,0	290,0	445,0	16,6	18,2	90,0	110,0
Duralcan Al-20SiC (p) cast (F3K20S)	Metal	Duralcan	CES	2810,0	2820,0	100,0	102,0	338,0	372,0	338,0	372,0	41,9	55,8	350,0	370,0
Duralcan Al-20Al2O3 (p) wrought (W2A20A-T6)	Metal	Duralcan	CES	3040,0	3080,0	96,0	97,0	460,0	480,0	485,0	500,0	41,9	55,8	280,0	290,0
PA (type 66, 40% long glass fiber)	Polymer	Polyamide (Nylon)	CES	1450,0	1470,0	8,9	11,1	142,0	178,0	144,0	176,0	31,2	36,7	90,0	130,0
PA (type 66, 50% long glass fiber)	Polymer	Polyamide (Nylon)	CES	1550,0	1580,0	10,5	13,1	156,0	194,0	158,0	193,0	29,3	35,9	90,0	130,0
PA (type 66, 60% long glass fiber)	Polymer	Polyamide (Nylon)	CES	1650,0	1690,0	12,5	15,5	169,0	211,0	171,0	209,0	27,4	35,0	90,0	130,0
PC (20% carbon fiber)	Polymer	Polycarbonate	CES	1270,0	1290,0	13,5	14,1	99,2	110,0	124,0	138,0	65,8	72,4	111,0	126,0
PC (40% long glass fiber)	Polymer	Polycarbonate	CES	1500,0	1540,0	11,4	12,0	124,0	136,0	152,0	168,0	30,6	36,2	131,0	147,0
PC (50% long glass fiber)	Polymer	Polycarbonate	CES	1610,0	1650,0	14,1	14,8	138,0	143,0	173,0	179,0	28,8	35,5	133,0	149,0
PET (30% carbon fiber)	Polymer	Polyethylene T.	CES	1410,0	1430,0	24,2	25,4	131,0	145,0	164,0	181,0	70,7	77,7	177,0	195,0
PET (30% long glass fiber)	Polymer	Polyethylene T.	CES	1590,0	1630,0	11,4	12,0	106,0	117,0	133,0	146,0	22,1	25,8	191,0	209,0
PET (40% long glass fiber)	Polymer	Polyethylene T.	CES	1680,0	1720,0	14,1	14,8	122,0	134,0	152,0	168,0	21,7	26,7	192,0	211,0
PET (45% long glass fiber, recycled content)	Polymer	Polyethylene T.	CES	1680,0	1720,0	14,1	14,8	150,0	165,0	187,0	206,0	16,9	23,0	183,0	201,0
PET (60% long glass fiber)	Polymer	Polyethylene T.	CES	1890,0	1930,0	20,2	21,2	123,0	136,0	154,0	170,0	21,1	28,3	194,0	213,0
Polyarylamide (30% glass fiber)	Polymer	Polyarylamide	CES	1420,0	1450,0	9,1	11,3	140,0	174,0	150,0	183,0	53,4	63,7	186,0	207,0
Polyarylamide (50% glass fiber)	Polymer	Polyarylamide	CES	1630,0	1660,0	17,8	22,2	231,0	289,0	234,0	286,0	44,2	54,8	193,0	207,0
Polyarylamide (60% glass fiber)	Polymer	Polyarylamide	CES	1770,0	1810,0	20,5	25,5	223,0	278,0	225,0	275,0	38,0	48,9	188,0	207,0
Polyester SMC (40% glass fiber)	Polymer	Polyester	CES	1750,0	1900,0	10,7	12,5	89,2	108,0	89,2	108,0	25,8	36,7	122,0	138,0
Polyester SMC (50% glass fiber)	Polymer	Polyester	CES	1730,0	2090,0	11,8	14,3	145,0	176,0	145,0	176,0	28,3	41,8	122,0	138,0
PP (50% long glass fiber)	Polymer	Polypropylene	CES	1320,0	1340,0	10,4	11,7	110,0	129,0	115,0	127,0	21,0	27,4	119,0	139,0
PPA (33% glass fiber)	Polymer	Polyphthalamide	CES	1460,0	1490,0	10,9	13,6	166,0	207,0	168,0	205,0	60,1	71,3	215,0	235,0
PPA (45% glass fiber)	Polymer	Polyphthalamide	CES	1630,0	1660,0	15,4	19,3	205,0	256,0	207,0	253,0	52,9	64,2	220,0	240,0
PPS (60% long glass fiber)	Polymer	Polyphenylene Sulfide	CES	1820,0	1860,0	20,2	21,2	118,0	130,0	148,0	163,0	57,6	71,0	270,0	290,0
Grilon BG-30	Polymer	Polyamide (Nylon)	Erteco	1350,0	1350,0	6,5	10,0	110,0	190,0	110,0	190,0	26,8	35,7	100,0	120,0
Grivory GV-4H	Polymer	Polyamide (Nylon)	Erteco	1470,0	1470,0	13,0	14,0	210,0	230,0	210,0	230,0	44,6	62,4	100,0	120,0
Alumina (85)(H880)	Ceramic	Alumina	CES	3470,0	3540,0	244,0	256,0	171,0	189,0	171,0	189,0	11,2	16,8	1440,0	1510,0
Alumina (88)	Ceramic	Alumina	CES	3440,0	3510,0	244,0	256,0	191,0	210,0	191,0	210,0	19,5	30,7	830,0	930,0
Glass ceramic - 0330	Ceramic	Glass Ceramic	CES	2510,0	2560,0	83,9	88,1	161,0	177,0	161,0	177,0	13,9	83,7	527,0	549,0
Glass ceramic - 9606	Ceramic	Glass Ceramic	CES	2570,0	2620,0	115,0	121,0	109,0	120,0	109,0	120,0	13,9	83,7	686,0	714,0

D – Snap-Fit design guidelines

For easier assembly the entrance angle should be low and for harder disassembly the retraction angle should be high (BASF, 2007). This is in general a desired case when it comes to snap-fits. The following figure shows angles and dimensions of a cantilever snap-fit solution used for calculation (BASF, 2007).



Calculating various dimensions and properties of the snap-fit can be done by using the following formulas that is taken from basic beam theory. The following shows formulas used for calculating desired snap-fit dimensions (BASF, 2007). The values correspond to the previous figures.

ε_{Max} – *Max Strain Allowed*

E – *Young's Modulus*

μ – *Coeficient of Friction*

α_e – *Entrance Angle*

Q – *Defelection Magnification Factor (relates to* $\frac{L}{t}$ *and position)*

$$P = \frac{b\,t^2\,E\,\varepsilon_{Max}}{6\,L} \;:\; Max\ Allowed\ Bending\ Force$$

$$W = P\,\frac{\mu + \tan(\alpha_e)}{1 - \mu\tan(\alpha_e)} \;:\; Required\ Mating\ Force$$

$$\varepsilon = 1{,}5\,\frac{t\,Y}{L^2\,Q}$$

Example

The following is an example of the calculation by using a standard polyamide with 30% glass fiber reinforcement.

$\varepsilon_{Max} = 2\% = 0{,}02$

$E = 6500\ MPa$

$\mu = 0{,}3$

$\alpha_e = 30°$

$Q = 1{,}2$

$t = 3\ mm$

$L = 15\ mm$

$b = 3\ mm$

$$P = \frac{3 * 3^2 * 6500 * 0{,}02}{6 * 15} = 39\ N \qquad W = 39\ \frac{0{,}3 + \tan(30)}{1 - 0{,}3\tan(30)} = 38{,}9\ N$$

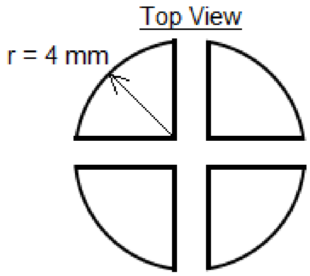
$$\varepsilon = 1{,}5\ \frac{3*1}{15^2*1{,}2} = 0{,}016 = 1{,}6\ \% \qquad \varepsilon < \varepsilon_{Max} : This\ material\ will\ work.$$

$$Y_{Max} = \frac{0{,}02 * 15^2 * 1{,}2}{1{,}5 * 3} = 1{,}2\ \ mm$$

In addition to the cantilever snap-fit shown in previous figures another common design is a circular snap-fit design. The following is an example of how to calculate the max deflection (Y_{Max}) of a circular snap-fit design.

$$Y_{Max} = 0{,}555\ \varepsilon_{Max} \frac{L^2}{r}$$

$$Y_{Max} = 0{,}555 * 0{,}02 \frac{15^2}{4}$$



E - Elimination matrix

		Elimination matrix for:						**Elimination criteria:** (+) Yes (-) No (?) More information is needed (!) Check product spec **Decision:** (+) Pursue solutions (-) Eliminate solution (?) Collect information (!) Check requirement list	
Reference	**Solutions**	**Solves the overall task**	**Compatible with surrounding interfaces**	**Compatible with surrounding cables**	**Compatible with surrounding parts**	**Fulfills demands on the requirement list**	**Reasonable cost of manufacturing (estimated)**	**Note**	**Decision**
1	**The Perpendicular**	+	+	+	+	+	+	*, **, Interface 15 & 22 as seperate part	+
2	**The Crown**	+	+	-	+	+	+	*, **	+
3	**The Top Frame**	+	+	+	+	+	+	*, **, FRC clash (right) Fixed	+
4	**The Palace**	+	+	-	+	+	+	*, **	-
5	**The Triangels**	+	+	+	+	+	+	*, **	+
6	**The Cross**	+	+	+	-	+	+	*, **, Possible clash in front left corner	-
7	**The Symmetrical**	+	+	+	-	+	+	*, **, FRC clash (right) Fixed, Possible clash in front left corner	-
8	**The Square Side**	+	+	+	-	+	+	***, **, FRC clash (left)**	-
9	**The Republican**	+	+	+	+	+	+	**	+
10	**The U**	+	+	+	+	+	+	*, **	+
11	**The Double U**	+	+	+	-	+	+	***, **, FRC clash (right)**	-
12	**The Ace**	+	+	+	+	+	+	*, **	+
13	**The Claw**	+	+	+	+	+	+	*, **	+
14	**The Bend**	+	+	+	+	+	+	**	+
15	**The Hexagon**	+	+	-	+	+	+	*, **, Clash with ECU cables	-
16	**The Frame**	+	+	+	+	+	+		+
17	**The Box**	+	+	+	+	+	+		+
18	**The Double Bar**	+	+	+	+	+	+		+
19	**The Arm**	+	+	+	+	+	+		+
20	**The Large Frame**	+	+	+	+	+	+		+

F - Pugh matrices (weighted)

First Pugh Matrix

Concept Criteria	W	Current solution	The Perpendicular	The Crown	The Top Frame	The Triangels	The Republican	The U	The A	The Claw	The Bend	The Frame	The Box	The Double Bar	The Arm	The Large Frame
		0	**1**	**2**	**3**	**5**	**9**	**10**	**12**	**13**	**14**	**16**	**17**	**18**	**19**	**20**
Low weight	**3**	DATUM	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Low number of parts (One side)	**5**		5	5	5	5	5	5	5	5	5	5	5	5	5	5
Low number of tools (Both Sides)	**4**		4	4	4	4	4	4	4	4	4	4	4	4	4	4
Low complexity of parts/tools	**5**		0	0	-5	-5	0	-5	0	-5	-5	-5	0	5	-5	-5
Efficient transport and packaging	**1**		1	1	0	1	0	1	1	1	0	0	0	1	0	-1
Easy and fast to assemble	**3**		0	3	3	0	0	0	0	3	3	3	0	0	3	3
Lifting robustness as high as possible	**1**		-1	0	0	-1	0	0	0	0	0	0	0	0	0	0
General robustness as high as possible	**2**		-2	0	0	-2	0	0	0	0	0	0	0	0	0	0
ECU holder independency	**3**		3	-3	3	0	0	-3	-3	-3	-3	3	3	3	3	3
Loose FRC cable input	**1**		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Similarity to current assembly sequenc	**1**		0	-1	0	-1	0	0	-1	0	-1	0	0	0	0	0
High ECU accessability	**5**		0	0	0	0	0	0	0	-5	0	0	0	0	0	0
Σ+			16	16	18	13	12	13	13	16	15	18	15	21	18	18
ΣS			0	0	0	0	0	0	0	0	0	0	0	0	0	0
Σ-			3	4	5	9	0	8	4	13	9	5	0	0	5	6
Net value		0	13	12	13	4	12	5	9	3	6	13	15	21	13	12
Ranking		15	3	7	3	13	7	12	10	14	11	3	2	1	3	7
Further development			YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Second Pugh Matrix

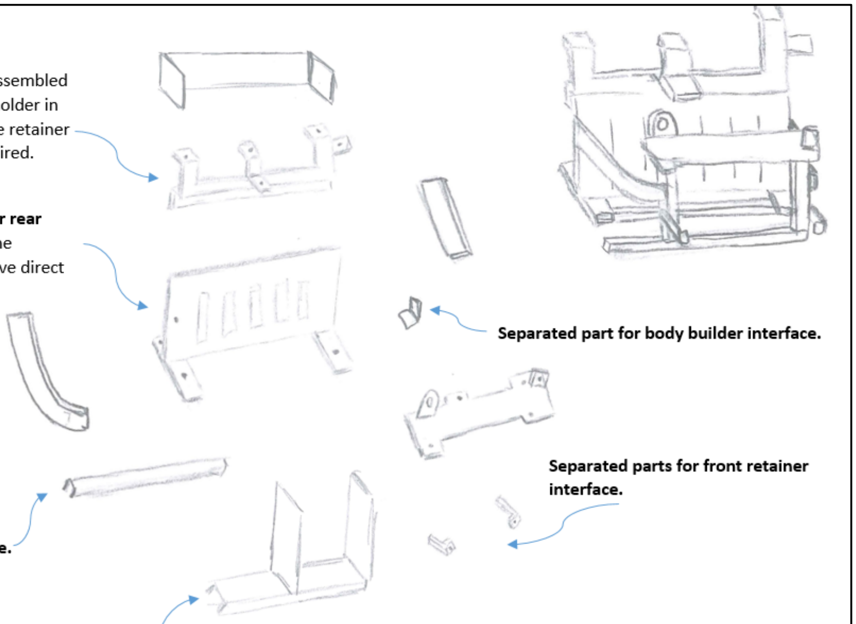
Concept Criteria	W	Current solutio	The Perpen	The Crown	The Top	The Triange	The Republi	The U	The A	The Claw	The Bend	The Frame	The Box	The Double	The Arm	The Large
		0	1	2	3	5	9	10	12	13	14	16	17	18	19	20
Low weight	3	-3	0	-3	-3	0	0	0	DATUM	0	0	0	-3	0	0	0
Low number of parts (One side)	5	-5	5	5	5	5	5	5		5	5	5	5	0	5	5
Low number of tools (Both Sides)	4	-4	0	4	4	-4	4	0		0	4	4	4	4	4	4
Low complexity of parts/tools	5	0	-5	-5	-5	-5	-5	-5		-5	-5	-5	-5	-5	-5	-5
Efficient transport and packaging	1	-1	0	-1	-1	-1	0	-1		0	-1	-1	-1	-1	-1	-1
Easy and fast to assemble	3	0	0	3	3	3	3	3		3	3	3	3	3	3	3
Lifting robustness as high as possible	1	0	1	1	0	-1	1	1		1	1	1	1	1	1	1
General robustness as high as possible	2	0	2	0	2	-2	0	0		2	2	2	2	2	2	2
ECU holder independency	3	3	3	-3	3	-3	3	-3		-3	0	3	3	3	3	3
Loose FRC cable input	1	0	1	0	0	0	0	0		0	0	0	0	0	0	0
Similarity to current assembly sequenc	1	1	1	1	0	1	1	1		0	-1	1	0	1	1	0
High ECU accessability	5	0	0	0	0	0	0	0		-5	0	0	0	0	0	0
Σ+		4	13	14	17	9	17	10	0	11	15	19	18	14	19	18
ΣS		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Σ-		13	5	12	9	16	5	9	0	13	7	6	9	6	6	6
Net value		-9	8	2	8	-7	12	1	0	-2	8	13	9	8	13	12
Ranking		15	6	10	6	14	3	11	12	13	6	1	5	6	1	3
Further development			YES	YES	YES	NO	YES	YES	?	NO	YES	YES	YES	YES	YES	YES

Third Pugh Matrix

Concept Criteria	W	The Perpen	The Crown	The Top	The Republi	The U	The Bend	The Frame	The Box	The Double	The Arm	The Large
		1	**2**	**3**	**9**	**10**	**14**	**16**	**17**	**18**	**19**	**20**
Low weight	**3**	-3	-3	-3	0	0	0	0	-3	0	DATUM	0
Low number of parts (One side)	**5**	-5	5	5	-5	-5	5	5	-5	-5		5
Low number of tools (Both Sides)	**4**	-4	-4	-4	-4	-4	0	0	-4	-4		4
Low complexity of parts/tools	**5**	5	5	-5	5	5	-5	-5	5	5		-5
Efficient transport and packaging	**1**	1	1	-1	1	1	0	-1	1	1		-1
Easy and fast to assemble	**3**	-3	0	3	-3	0	0	3	-3	-3		3
Lifting robustness as high as possible	**1**	0	0	-1	0	-1	1	0	0	0		0
General robustness as high as possible	**2**	-2	-2	0	-2	-2	-2	2	0	0		2
ECU holder independency	**3**	-3	-3	-3	-3	-3	-3	-3	0	0		-3
Loose FRC cable input	**1**	1	-1	0	-1	-1	0	-1	-1	-1		0
Similarity to current assembly sequenc	**1**	-1	0	-1	-1	-1	-1	0	-1	-1		-1
High ECU accessability	**5**	0	0	0	0	0	0	0	0	0		0
Σ+		7	11	8	6	6	6	10	6	6	0	14
ΣS		0	0	0	0	0	0	0	0	0	0	0
Σ-		21	13	18	19	17	11	10	17	14	0	10
Net value		-14	-2	-10	-13	-11	-5	0	-11	-8	0	4
Ranking		11	4	7	10	8	5	2	8	6	2	1
Further development		NO	YES	NO	NO	NO	YES	YES	NO	?	YES	YES

G - Concept Descriptions

Concept 2 – The Crown



Separated Top Rear Bracket – Assembled atop of the Lower bracket/ECU holder in order to meet interfaces with the retainer and the FRC. Mirrored part required.

Integrated ECU holder and lower rear bracket – Symmetric part with the function of holding ECU's and have direct interface to the subframe.

Separated part for body builder interface.

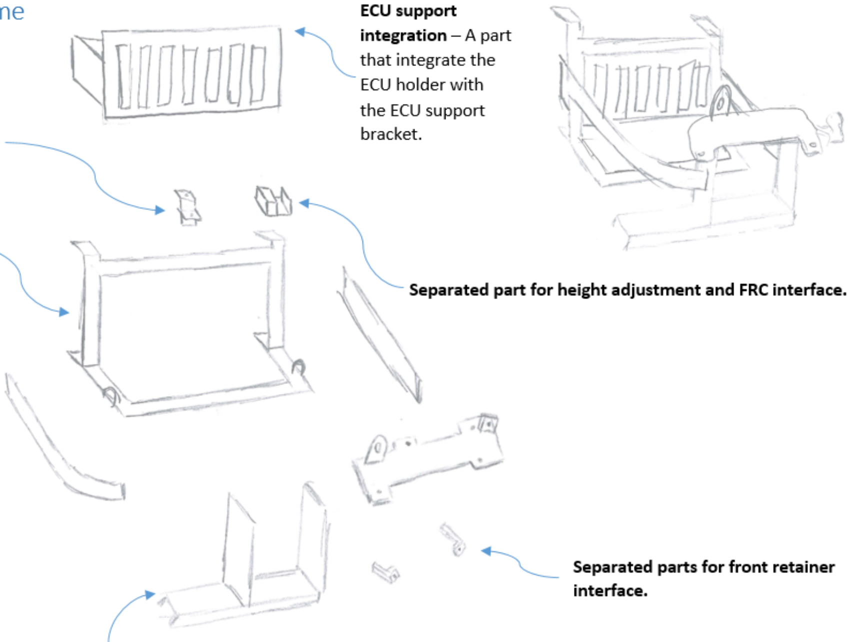
Separated parts for front retainer interface.

Separated bar for cable guidance.

Semi symmetric front lower bracket – Semi symmetric part (rotate for right hand drive) with the function support front top bracket and have direct interfaces to subframe interface to the subframe.

Concept summary: This concept consist of a total of 11 parts and 2 additional parts for right hand drive. The number of required tools are 12. The benefits of this concept is the low number of parts and tools needed and fast assembling.

Concept 16 – The Frame



ECU support integration – A part that integrate the ECU holder with the ECU support bracket.

Separated part for interface to top bracket and FRC.

Rear bracket frame – A symmetric frame that allow the ECU holder to be independent and directly connect the retainer to the subframe. It also provide cable guidance.

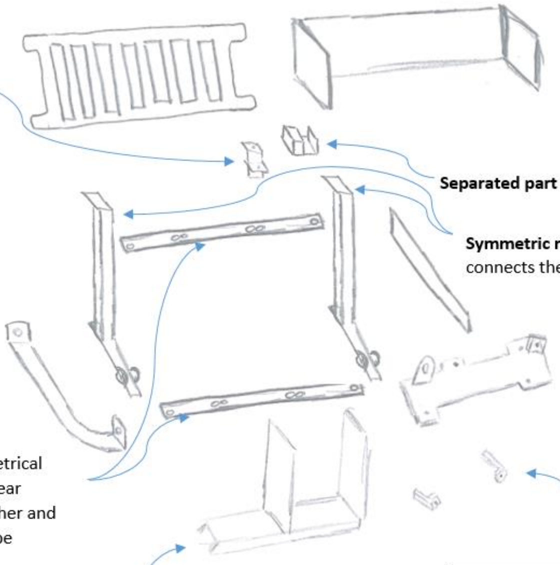
Separated part for height adjustment and FRC interface.

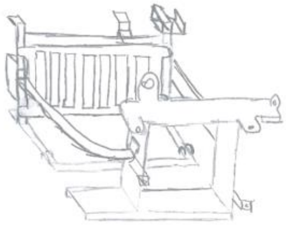
Separated parts for front retainer interface.

Semi symmetric front lower bracket – Semi symmetric part (rotate for right hand drive) with the function support front top bracket and have direct interfaces to subframe interface to the subframe.

Concept summary: This concept consist of a total of 10 parts and 1 additional parts for right hand drive. The number of required tools are 11. The benefits of this concept is the very low number of parts and tools needed and the ECU holder independency.

Concept 18 – The Double Bar





Separated part for interface to top bracket and FRC.

Separated part for height adjustment and FRC interface.

Symmetric rear bracket pillars – Symmetrical parts that connects the retainer to the subframe.

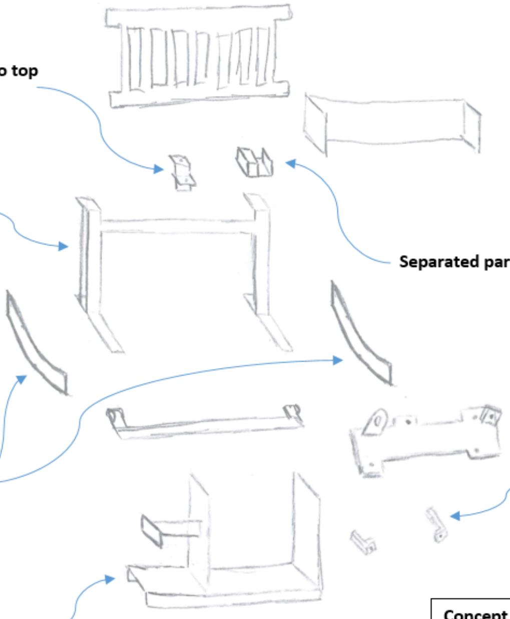
Symmetric bars – Symmetrical parts that connects the rear bracket pillars to each other and allow the ECU holder to be independent.

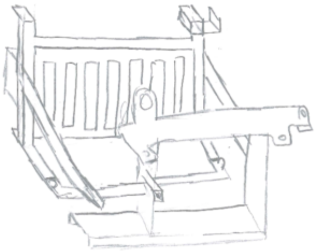
Separated parts for front retainer interface.

Semi symmetric front lower bracket – Semi symmetric part (rotate for right hand drive) with the function support front top bracket and have direct interfaces to subframe interface to the subframe.

Concept summary: This concept consist of a total of 14 parts and 1 additional parts for right hand drive. The number of required tools are 12. The benefits of this concept is the low number of parts and tools needed and the ECU holder independency. The complexity of the parts are also low and the part geometry is flat.

Concept 19 – The Arm





Separated part for interface to top bracket and FRC.

Rear bracket frame – A symmetric frame that allow the ECU holder to be independent and directly connect the retainer to the subframe.

Separated part for height adjustment and FRC interface.

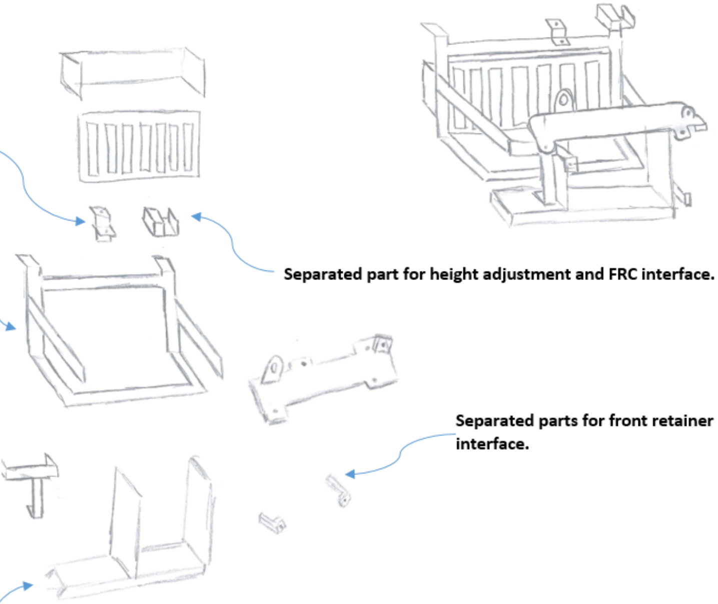
Symmetric side supports.

Separated parts for front retainer interface.

Semi symmetric front lower bracket – Semi symmetric part (rotate for right hand drive) with the function support front top bracket and have direct interfaces to subframe interface to the subframe. It also have an arm on the side to connect side supports and allow it to be symmetrical.

Concept summary: This concept consist of a total of 12 parts and 1 additional parts for right hand drive. The number of required tools are 11. The benefits of this concept are the low number of parts and tools needed and the ECU holder independency.

Concept 20 – The Large Frame



Separated part for interface to top bracket and FRC.

Combined functionality frame – A large part that combines rear bracket with support brackets on the side. This part is symmetric and allow for total independency for the ECU holder.

Separated part for height adjustment and FRC interface.

Extra part – This part is needed for making the large frame symmetrical connection the side support to the front bracket.

Separated parts for front retainer interface.

Semi symmetric front lower bracket – Semi symmetric part (rotate for right hand drive) with the function support front top bracket and have direct interfaces to subframe interface to the subframe.

Concept summary: This concept consist of a total of 10 parts and 1 additional parts for right hand drive. The number of required tools are 10. The benefits of this concept is the very low number of parts and tools needed and the ECU holder independency. But it has a large part with high complexity.

H – Final Concept in its Intended Surroundings