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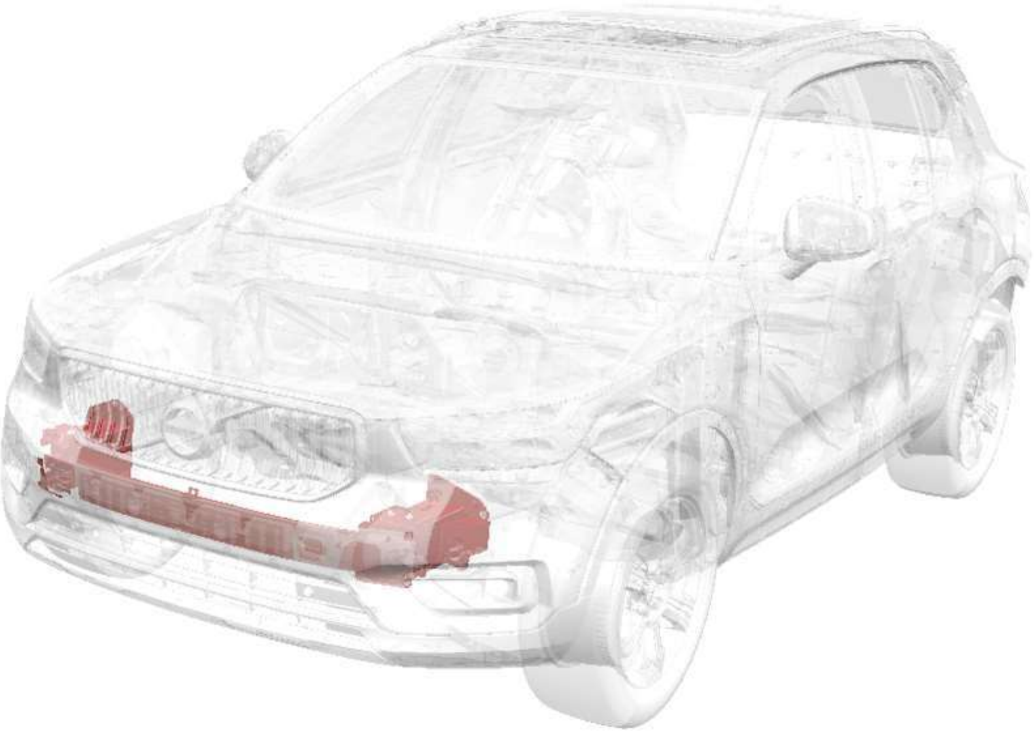

Modeling of Front Bumper system with emphasis on lightweight and low cost

A product development project at Volvo Cars

Master's thesis in Product Development

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2018

MASTER'S THESIS

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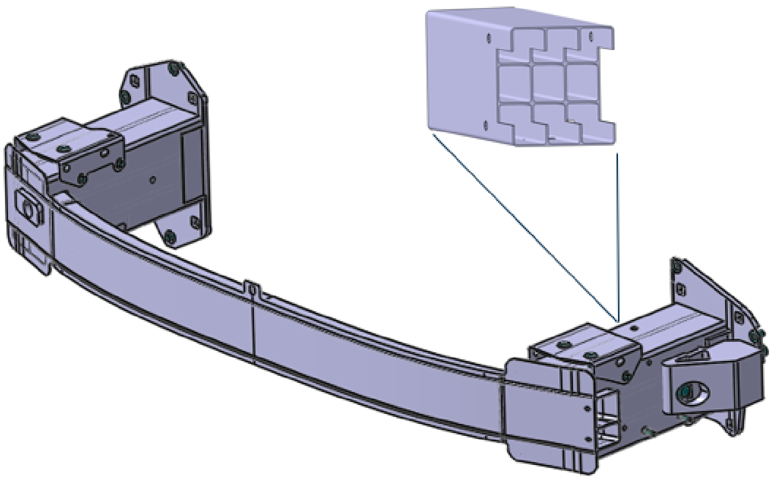

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Modeling of a front bumper system with emphasis on lightweight and low cost
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Abstract

This master thesis report, *Modeling of a front bumper system with emphasis on lightweight and low cost*, is a collaboration between Chalmers University of Technology and Volvo Cars. The goal of the project is to reduce the cost and weight of an front bumper system, also called Crash Management System (CMS) for the latest Volvo XC40 using Design to Profit approach. The current CMS is made out of aluminum in 6000, 7000 series and has a total weight of 9,114 kg.
By defining the current CMS components, the project group divided the CMS into four different categories to be investigated; Front bumper beam, Crashbox, Tow and Reinforcement. By glance, the beam was divided into two cells and the crashboxes into five. Through different brainstorming and evaluation sessions 36 concept ideas for the four categories were created. The ideas were then combined into 25 concepts and thereafter screened to top three concepts by the help of Elimination, Pugh and Kesselring matrices.

The top three concepts were approved by the safety department during a meeting and interview with engineers from the safety department at Volvo. That particularly interview was conducted later than expected and the information given during that interview was expected earlier. Advise The information givens was important for the project group and CMS development, which lead to a decision was taken to only focus on the crashbox since the most potential for improvements exists in that area and for the time limitation to also perform crash simulations on the new CMS. New concepts regarding the crashbox were created in line with the current CMS attributes and requirements. The dimensions for the inner and the outer walls combined with the weight were changed. Several concepts were evaluated and the remaining ones, after filtering, were simulated in a CAE program, Thinlinc. From the simulations the concepts were compared with current one through crash test simulations. The simulation comparison was based on forces ans stop time created during a crash. After many simulation iterations a successful concept was found. The new developed crashbox weighs 8,3 kg which is a weight reduction of 8,93%, saves approximately 7 MSEK/year and has a shorter displacement during a crash. The new crashbox achieved good results and further simulations with the whole CMS are of interest.

Keywords: Safety, Light, Weight, Frontal, CMA, Product, Development, Chalmers, VCC, Volvo Cars

Terminology

A2Mac1	Website including information on competitors car body structures
CAD	*Computer Aided Design.*
CAE	*Computer Aided Engineering.*
CBR	Crashbox Reinforcement
CCM	Software tool to model product and production platform systems using configurable components (autonomous object oriented engineering system models).
CEVT	*China Euro Vehicle Technology*, a car developer and supplier to Volvo Cars, owned by the chinese company Zhejiang Geely Holding Group.
CMA	*Compact Modular Architecture* The latest platform introduced by Volvo Cars and Geely, used in the new XC40.
CMS	*Crash Management System*
Constellium	A world wide supplier of Aluminium to automotive, aero and packaging industry with headquarters in the Netherlands.
DFA	*Design For Assembly.*
DFM	*Design For Manufacturing.*
Euro NCAP	*European New Car Assessment Programme.*
FBR	*Front Bumper Reinforcement.*
Geely	A chinese car brand company owned by Zheijang Geely Holing Group.
GTR	*Global Technical Regulations.*
IIHS	*Insurance Institute of Highway Safety.*
LCA	*Life Cycle Assessment.*

PEST-analysis *Political, Economical, Socio-cultural and Technological* analysis that together create an understanding of the business environment.

SPOC *Severe Partial Overlap Crash*

SWOT-analysis *Strengths, Weaknesses, Opportunities and Threats analysis*, that could apply to a company as well as to a product idea.

Table of Contents

1 Introduction

The following document is a planning report written by two students from Chalmers University of Technology regarding the master thesis, "Modeling of a front bumper with emphasis on lightweight and low cost", in collaboration with Volvo Cars, Gotheburg. The planning report will give a brief explanation of the project, how the approach for performing the master thesis will be set up where selected methods and tools are defined and explained more in detail. The report will included a Gantt-schedule where dates for important tasks and milestones are set for the whole project period.

1.1 Project Background

Today, cars are frequently facing new requirements to be fulfilled in order to be competitive and innovative on the market. The requirements are for example related to new legislation of safety demands, emission regulations, but also to customers and their preferences. As these requirements are being fulfilled the complexity in the cars is increasing as more components are being added and material in important areas is changed in order to fulfill targeted requirements. As the requirements to reduce emissions and develop high safety cars are constantly updated, car manufacturers are forced to take action in either changing the cars design, weather if it is the engine structure, aerodynamic or material selection. In the automotive industry, the material used for the car body is highly interesting, as the effort to reduce the weight of a car body due to the environment and CO2 regulations, whilst maintaining other attributes and producing end customer appealing vehicles. The trend has therefore been to switch from steel to aluminum in different areas, as in the the front crash management system (CMS) which is the main focus in this project. Volvo Cars philosophy is to use the right material at the right place that ensures lower weight, fuel consumption, better recycle reuse possibilities and safety. However, there is a need for improvement of the weight and cost of the CMS using Design to Profitability (DtP) approach together with a chosen supplier.

1.2 Project purpose

The purpose of this project is to, within the time limit, model a front bumper system (CMS) with emphasis on lightweight and low cost that will be used in the latest Volvo XC40, manufactured by Volvo. To achieve an effective project flow with good results, previously and newly gained engineering knowledge skills will be used during the project. Relevant information that benefits the performance of the project and the company will be processed and evaluated. This will generate an overview of the current situation and provide ideas for future solutions.

1.3 Problem Statement

The need to continuously improve the safety in a car is required, in order to preserve a safe environment for the driver and passengers if an accident is occurred. The difficulty is to develop a CMS that maintain all safety requirements as the current CMS while at the same time decreasing weight and cost of the system.

1.4 Scope

In this work different solutions for the CMS are to be studied, with the purpose of reducing cost and weight without compromised attribute and packaging demands. This will be done by performing benchmarking on OEM:s to gather relevant information about their solutions. The need to study and understand the current CMS for low-, and high-speed frontal crash load cases is of interest to develop e a suited solution. To complement the work, a collaboration with chosen supplier will also be conducted for further improvements and guidance.

1.5 Objectives

This master project is mainly an investigation regarding findings of new possible design for the CMS in the latest Volvo XC40. In order to benefit from the project, some objectives have been defined and set. The following objectives are defined to support and guide the master project in the right direction. No numbers or percentage is given due to the aim of the project is to achieve maximum improvement in every area given. Percentage can mislead the project result and in worst case ruin the result. Any improvement of the weight and cost while keeping the safety is a good result compared to current solution.

- Lower weight
- Reduce CO2 emissions
- Reduce total cost
- Improve recyclability and reuse
- Improve safety

1.6 Volvo Cars

Volvo is a unique car company, where everything starts with people. Since 1927 Swedish culture and focus on humanity have all helped to shape Volvo's philosophy, to help people make their life easier and more enjoyable whilst also protecting them form harm. The company's statement is: "Cars are driven by people, the guiding principle behind everything we make at Volvo therefore is and must remain safety". This emphasis on safety, quality and people, has been a feature of the company's cars ever since. As has for passion of pioneering, automotive and environmental innovation of distinctive Swedish design. This rich heritage continues to inform what Volvo does today and shapes its future. Volvo cars might never had happened if there was not a meeting between two friends, that shared a passion for cars and a vision to start a Swedish car company, in a Stockholm restaurant 1924. After that meeting Volvo's founders, Assar Gabrielsson a engineer specialist and Gustav Larson a talented engineer with a background on engine design began to make plans for making the finest Swedish car possible. At that time Assar and Gustav also worked for the bearing company SKF, who owned the brand name Volvo. Volvo stands for

"I roll", therefore owned by SKF who produced roll bearings.

The initial design concepts were created in Gustavs apartment in Stockholm in mid 1925 and in 1926 the first test of ten prototypes began, personally funded by Assar. In April 1927 the first Volvo car was introduced, a two litre ÖV4, with nick name Jacob rolled out from the factory at Hisingen, Gothenburg. Three factors contributed to Volvo's early success: Sweden's growing capabilities, availability of premium local steel and a genuine need for strong high quality cars as other vehicle brands tented not to survive long on rugged Swedish roads. Since then, Sweden's distinctive social culture, its respectful nature and focus on social being have all contributed to Volvo's unique success. Volvo has always had unique Swedish approach on car design, to satisfy human needs. This approach can be led to Volvo's early and luxury car, PV44 launched 1944, that was a major brake through. Volvo's aim has always been to produce premium quality cars to make life much easier with improved technology to not only make driving enjoyable but also more safe, that have saved many lives around the world. The PV44 was introduced with the worlds first three point belt, that have saved more than one million lives. [1]

Volvo's mission is to increase the driver experience and safety, where the goal from year 2020 is that no one will be killed or seriously injured in an accident, when driving a Volvo. This by making produced cars smarter, by intelligence technology that detects danger, prevents accident before they even happen. The next step is fully autonomous cars that will increase the drivers and passengers possibility to enjoy life more when driving a Volvo car. The next generation of Volvo Cars in year 2019 will also be hybrid models where the environment and customers will benefit tremendously regarding low emission and costs. Volvo's environmental approach was stated in 1976 when the US used the Volvo 240, to set those standards. It was also that year the first lambdasond was ever used, in a Volvo 240. Since then Volvo have striven to reduce the environmental impact and increase the usability. The electricity in Volvo's factories comes from hydroelectric power and in line to build the most safest car, Geely, Volvo's owner since 2010, the company still continues to improve technology. [2]

1.7 Volvo XC40 and CMA platform

The brand new Volvo XC40 is built on the latest CMA platform, Figure 7, Compact Modular Architecture, developed in collaboration with Geely. The platform is used in smaller car models at Volvo, compared to the SPA platform used in other Volvo models. The CMA platform is also providing customer a premium feeling, since they share the same technology in many areas. For the CMA platform, designers and engineers at Volvo have introduced new and unique finesses as the driving feeling, safety and digitalisation technology in the car is new and improved. The platform will allow powertrain, electrical systems and different technologies to fit the platforms architecture. The safety level on the XC40 is high due to the safety functions that are offered. There are standard functions in the car, for example City Safety, Oncoming lane mitigation, and Run-off mitigation. City safety is helping the driver to avoid accidents in low speeds by detecting objects through a radar camera placed in the center of the windshield, behind the rear mirror. The system continuously scans the environment in front of the car for pedestrians, cyclist and cars in order to prevent accidents to appear if the collision risk is to high, by auto breaking the car in speeds up to 45km/h if driver is not alert enough. Oncoming lane mitigation prevents from crashing into oncoming cars if the driver by accident enters oncoming lanes. The system will activate and indicate the driver to steer back by discrete counter movements in the steering wheel, thereafter the driver needs to steer back the car entirely in order to avoid an accident. The car model is equipped with SIPS, meaning that the side structure of the car is made of ultra-high strength steel and softer grades steel to withstand severe side impacts. There are many other standard functions but also optional ones that complement each-other that results in a highly safe car. [3]

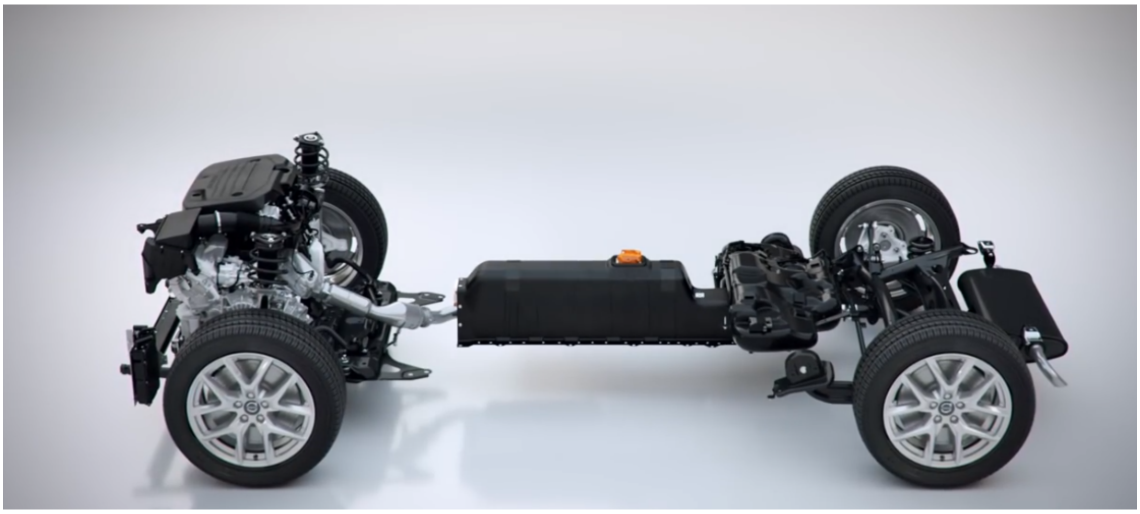


Figure 1: Compact Modular Architecture (CMA) platform for Volvo XC40 [4]

1.8 Frontal crash beam

The body structure of the latest XC40, built on the CMA platform is seen in Figure 2. Seen in the figure, the frontal crash beam system, that the project will be based on, is made of aluminum today. The CMS consists of five major parts that are seen in the figure and these are; frontal crash beam (1), headlight support (2), crash boxes(3) Front Bumper Reinforcement (FBR)(4) and attachment plates (5) all welded or bolted together, creating one common system. The system consists of more components that are not visible in the picture but will be shown and explained in detail in the final report. The visible differences in the CMA platform compared to the SPA platform are the attachment areas and the FBR. Attachments plates welded to the CMS are used on this platform in order to attach the CMS to the side wide members, using bolts. Figure 3 shows the overlap crash test performed by Volvo for the XC40, where the CMS was tested and verified with good results.

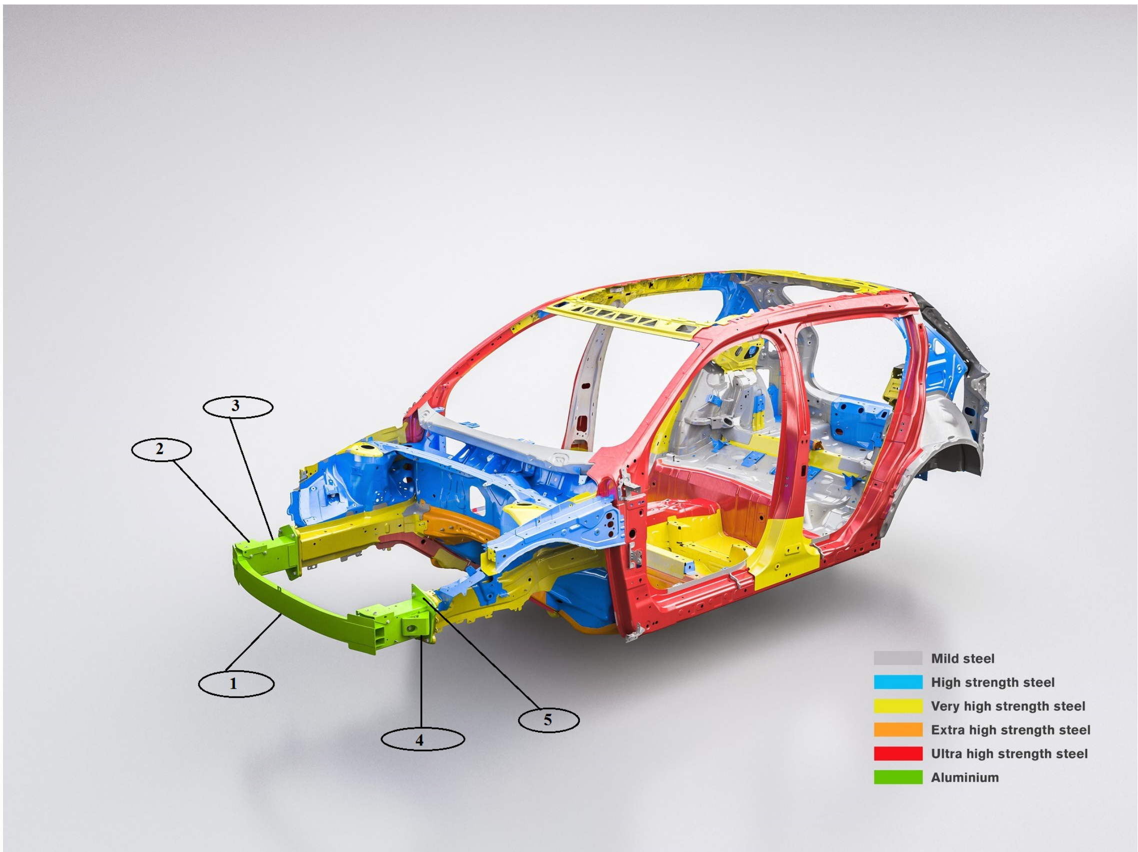


Figure 2: Body Structure Volvo XC40 [5]

Figure 3: Overlap crash test XC40 [6]

1.9 Key suppliers and stakeholders

The key-supplier, also a stakeholder, in this project is Constellium, which is an global leader and innovative producer of aluminum. Constellium offer material solutions for the aerospace, automotive and packaging markets. Constellium was one of the supplier in collaboration with Volvo Cars when developing the latest Volvo XC60. The possibility to receive help regarding Finite Element Method (FEM), Desig For Assembly (DFA) and Design For Manufacturing (DFM) is also possible at Constellium and therefore a important stakeholder in this project. The outcome in this project is also of interest for Volvo Cars and Chalmers University of Technology as the project is conducted at Volvo Cars most of the time, where also supervising and meetings are held. Supervisions is also a central part at Chalmers university both for guiding us students who are performing the project in a academic way but also for grading our thesis report and presentation.

1.10 Limitations and delimitations

Since time is a important and limiting factor to consider in this project, the project work will only regard the frontal CMS for the latest Volvo XC40 and therefore only be suitable for that model, for now. The research will mostly be focused on the European market where most of Volvo's top competitors are located. As the project comes to its ending, the goal to produce a real prototype that is not related to any manufacturing process improvements due to time, but actions will be taken regarding appropriateness in manufacturing and cost efficiency. Only the Reinforcement component in the CMS for the Volvo XC40 is patented by Volvo cars, the rest of the components are free on the market to be used. Therefore, patent searches will not be conducted and handled by Volvo in this project. The only supplier that we will collaborate with is Constellium, chosen by Volvo Cars, there is therefore no need to evaluate and compare different suppliers appropriateness for this project.

2 General structural mechanics

This section will inform the reader about some basic structural mechanics theory that is useful to possess for this project.

2.1 Mechanical beam stress

In mechanics, there are three types of tensions, tensile, compressive and shear stress. Tensile stress is when two equal and opposite forces are applied on the material at the same position. The material keeps the initial volume but changes shape. The material changes the shape due to expansion in the tensile direction, which makes the material smaller and longer. Compressive stress has two equal forces pointing at each other instead. This makes the material shorter and thicker. Shear stress is similar to tensile stress. What differentiates them is that equal and opposite forces occurs in different positions. This also causes the material to change shape, but not in the same way as tensile stress does. For example, shear stress would deform a rectangle into a parallelogram. These stresses can be seen in Figure 4 and 5. [7]

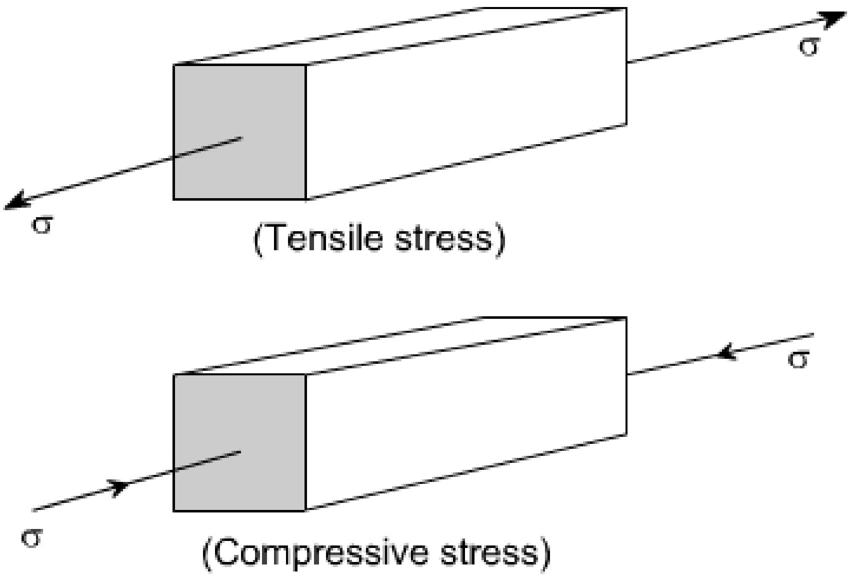


Figure 4: Tensile and Compressive stress [8]

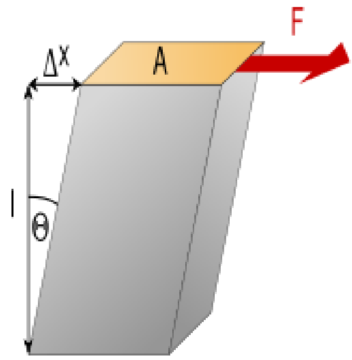


Figure 5: Shear stress [9]

2.2 Load during beam bending

When a load/force is applied on a beam, shear stress occurs. The load causes reaction forces at the beam's support points, which means that the support points are performing as counter forces to some extent. The beam will result in a bending deformation, if the load is too high and also get fractured in worst scenario. How the bending deformation will look, depends on the placement of the support point(s) and the placement of the load. The support points are of several types:[7]

- Simply supported – The beam is supported on both ends which can rotate and is free from moment resistance.
- Fixed – The beam is supported on both ends and restrained from rotation.
- Over hanging - The beam is supported on both ends, but it extends beyond one of the support points.
- Double overhanging - The beam is supported on both ends, but it extends beyond both of the support points.
- Continuous – The beam extends over more than two supports.
- Cantilever – It is a projecting beam that is fixed at one end.

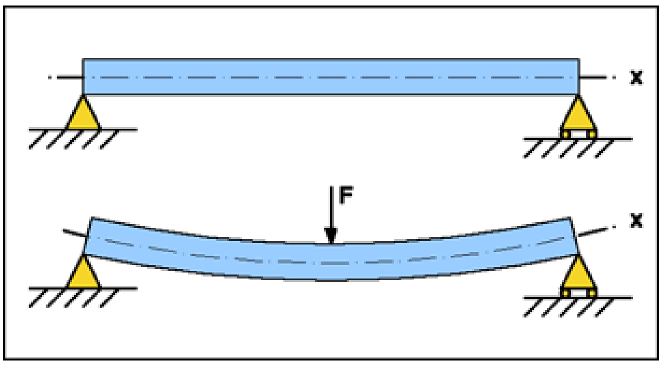


Figure 6: Beam with two support points [10]

2.3 Torsion of a beam

Torsion occurs when a beam who is attached to one end, starts rotation about its longitudinal axis. Twist shear stress occurs in the axis cross section. For axes with circular sections, the deformation always is that each cross sectional area through the axis remains flat and non deformable, even after the distortion. The axis behaves as if it is composed of a large number of very thin and flat discs, whose end faces are distorted a small angle relative to each other. The sum of all small distortions give an total distortion φ of the shaft. [7]

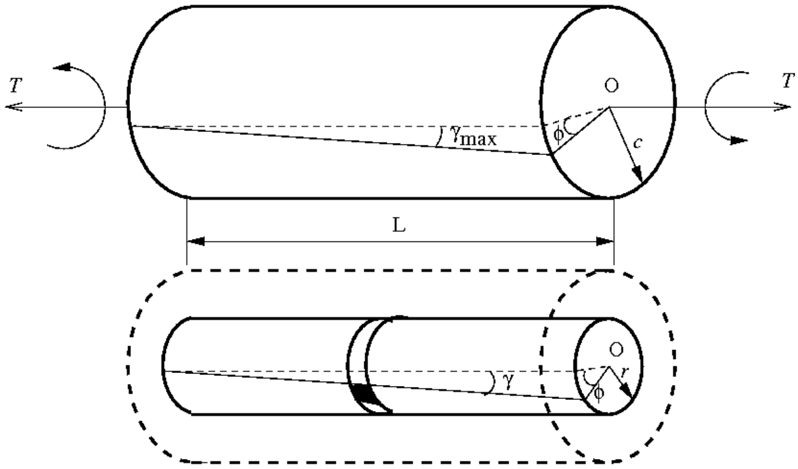
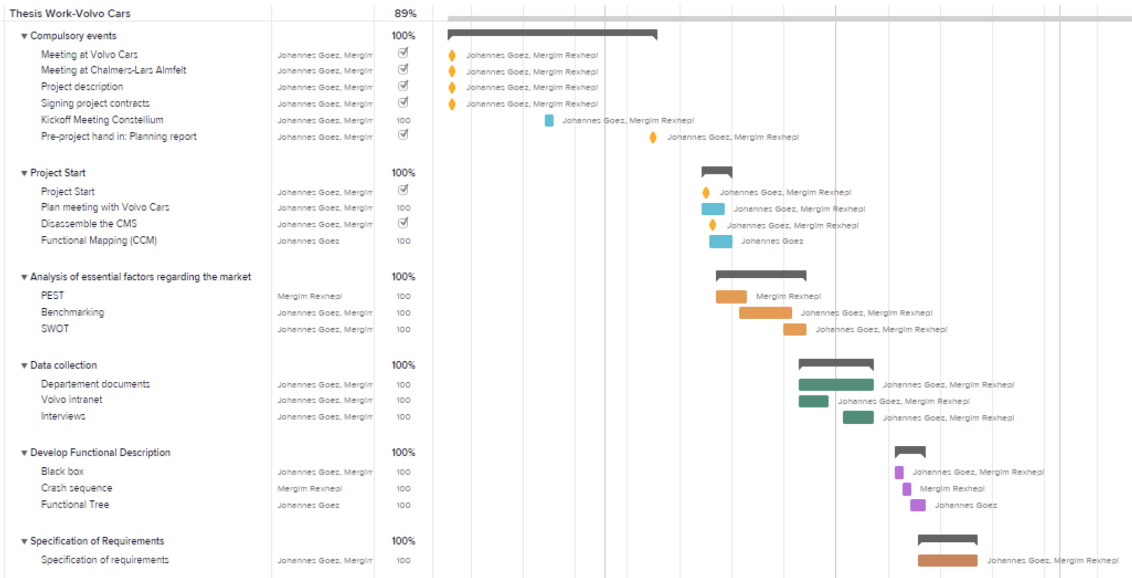


Figure 7: Torsion of circular cylinder [11]

3 Time schedule and methadology

The master thesis started in February 2018 and ended in June 2018. The group started by making a planning report, which took two and half weeks. When that was done, the work continued by analysing the market and created requirements for the following four weeks. The gained knowledge were thereafter used to develop a final product that fulfilled all requirements and project goals. Figure 8 shows the project Gantt scheme for the whole project time. All activities and milestones set in order to have an efficient and well structured project flow. The group did in between these tasks different activities to bond, have fun and think about other things besides the project. The purpose of the activities is also to improve communication and dedication among the group to pursue a good project work until the end. It is also important that this gantt schedule was changed during the project, because of unexpected obstacles.



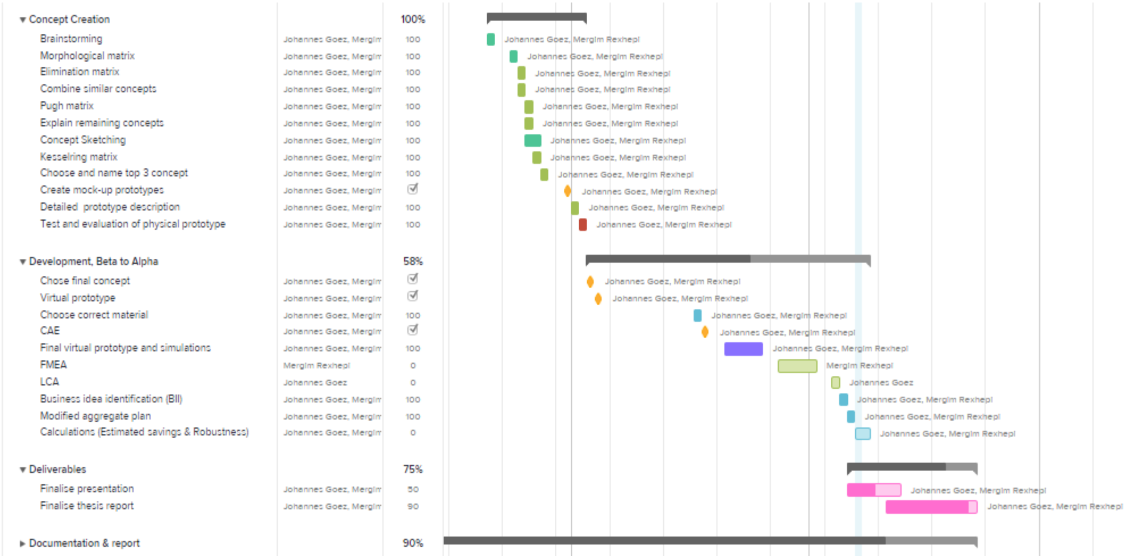


Figure 8: Gantt schedule

Our methodology introduces the methods and tools that we planned to use in the master thesis. These methods are later presented by a theoretical description and a discussion regarding why, when and how we will use each method. A general process map of our methodology can be seen in in Figure 9.

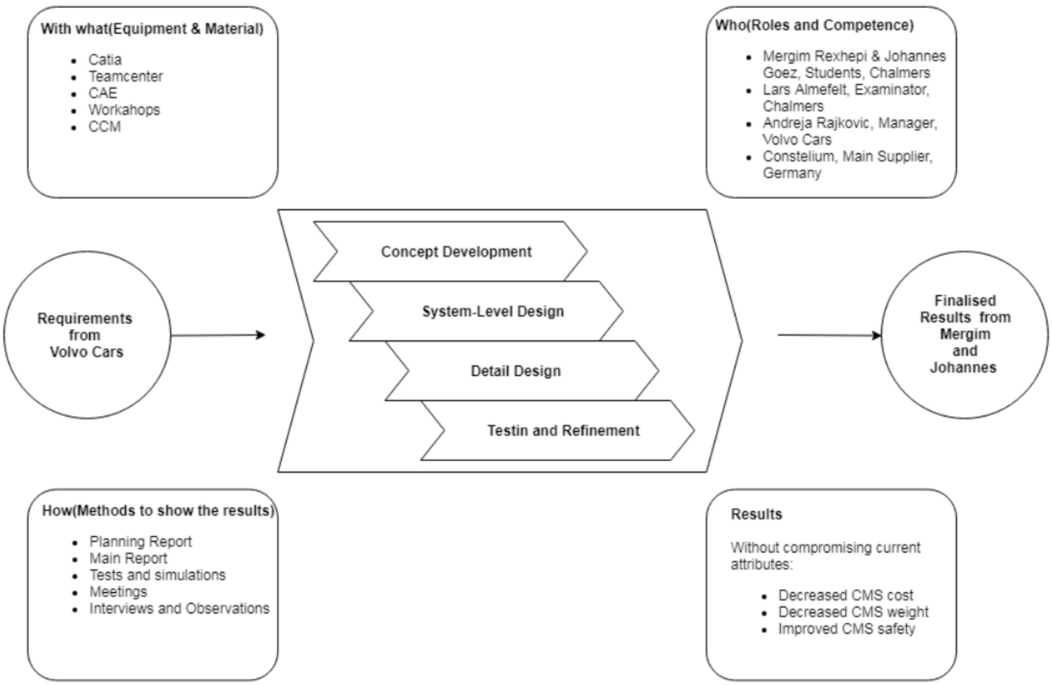


Figure 9: Project methodology [12]

4 Theory on associated legislations, regulations and materials

The following chapter gives valuable information concerning safety regulations, material specifications and standard manufacturing methods used in the automotive industry today.

The governments in countries around the world are tightening the regulations for CO_2 emission due to increased greenhouse emission. In latest years, new standards have been introduced to the automotive industry, the European Union set a CO_2 standard that the European car manufactures had to meet the requirement of releasing maximum 130 g/km CO_2 in 2015. The latest legislation from the European union is the new target for year 2020 is to achieve a CO_2 emission of 95 g/km[13]. The newly introduced goals are not only applied for the European market, but also China, Japan and the US that also have introduced laws to decrease emissions. In order to meet the newly regulations, car manufacturers are investing in innovative technologies that will result in energy efficiency of vehicles produced. As Volvo has the goal to only produce hybrid cars from year 2019, electrification combined with light weight is important as aspects e.g aerodynamic, cost and sustainability will be improved, which is important to a premium car brand as Volvo.

By decreasing the weight of a vehicle the energy efficiency is improved, but the improvement in weight could affect the crash worthiness. It is therefore crucial that new designs that are light weighted still has to meet all safety regulations. An agreement to create regulations for vehicle approval was set up in 1958 by the United Nations (UN). These regulations were established to function as an trading tool internationally that describes how regulations are established and how they are functioning where an approval under a given regulation created by one country, can be accepted by other countries that applies the regulation.[14] The regulations stated in the agreement are categorised into different sections, whereas the approvals relevant for this project are related to crash worthiness. The chosen approvals include different aspects within safety. These approvals cover different safety aspects of a vehicle such as rear and frontal collision. Within the scope of the project, UN Regulation No.94 and No.33, which relates to front and overlap collisions are specifically relevant when evaluating the final concept. Two overlap test, small and moderate are performed by crashing a vehicle into a fixed barrier with soft end, see Appendix 10. For the small overlap test, the speed is 64km/h and cover 25% of the frontal structure, see Figure 10 and for the moderate offset test the vehicle travels in a speed of 56 km/h and cover 40% of the frontal structure [14][15]. Both tests aims at testing three factors to determine how a vehicle rates in the moderate overlap and small overlap frontal tests: structural performance, injury measures and dummy movement[14]. During small overlap frontal crashes the vehicles outer edges are primarily affected since they are not well protected by crush-zone structures. The forces generated in the crash have the ability to go into the front wheel, suspension system and firewall. It is not unusual that the wheel is forced into the footwell, generating more intrusion in the driving compartment that could result in serious leg and foot injuries. To improve the occupant protection in small overlap crashes, the safety cage symbolising the cabinet frame, needs to withstand crash forces that are not tempered by crush-zone structures. The full width front bumper crash test cover the whole front structure and aims at placing high demands on the system in the front and rear seating positions. The crash will test the forces that are loaded on the occupants chest and its deflection. The result will force manufacturers either to maintain current solution or improve the restraints for the whole car. Testing the CMS and the destruction that it creates on the car body and occupants is performed in a speed of of 56km/h.[15]

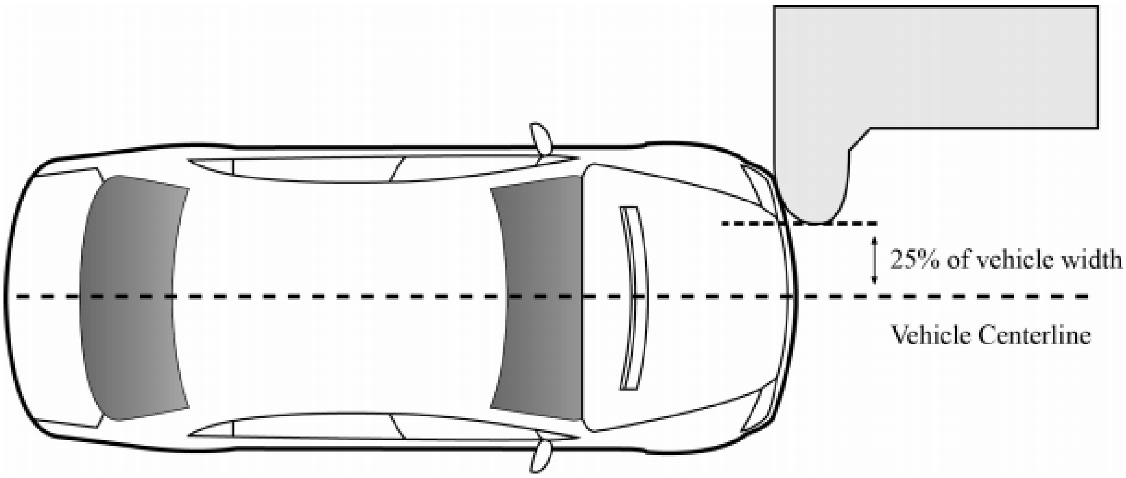


Figure 10: Small overlap crash

Figure 11 shows that not all countries are following the regulations stated by the UN in 1958 and also countries joined in 1998. The agreement created in 1998 concerns Global Technical Regulations (GTRs), which unlike the 1958 agreement, "do not require mutual recognition of approvals or certification". This agreement was introduced to include countries that already established and used their own approvals. For example, in USA newly produced vehicles regulates approvals through the Federal Motor Vehicle Safety Standards (FMVSS) [16]. The standards set by the FMVSS "are widely regarded to be functionally equivalent to many of the UN's Regulations".[14] These regulations, regardless of organisation, it is highly valuable when a vehicle approves the safety regulations set by these organisations, UN and FMVSS. [17]

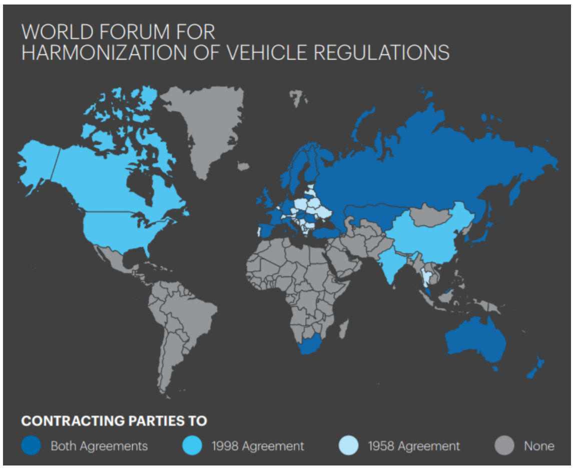


Figure 11: Countries following the UN regulations.[14]

4.1 Materials for structures

Due to cost, form-ability and application know-how, steel is the material that is mainly used for forming the parts of the car body. Volvo uses roughly 85000 tons of steel each year for their sheet metal parts [18]. S. Anderson writes in a article that, "we are leaving the steel era and entering an age of the automotive material options" [19]. For vehicle manufacturers to pass the new emission regulations, they need to further investigate alternatives on materials that can be used instead in order to save weight and mechanical perform the same. Areas like cost and lacking knowledge about manufacturing capabilities and mechanical behaviour have hindered many car companies to use material as magnesium, composites and plastics etc. Looking further into the automotive car industry, the trends are stating: "today steel, tomorrow aluminium, 2020+ CFRP/aluminium structures" [20, 21].

Many car companies already uses aluminium for many parts in their cars as a substitution for steel, which is 40% lighter. A few examples of car companies that has implemented aluminium more in their new cars than other is Ford and Jaguar. The Ford F-150 has the outer layer of the car body in entirely aluminium and Jaguar XE sedan's body structure is 75% made of aluminium [19]. The numbers are clearly showing that car manufacturers in countries in North America, Europe and Asia are starting to use aluminium instead of steel in many different parts. [22]. When using aluminium, it is important to know that different series of aluminium exists. 5000, 6000 and 7000 series are the most commonly used in car parts. What differs them is that 6000 series is better when it comes to possessing more mechanical properties and form ability. The 7000 series has more high strength properties but is brittle and 5000 series is cheaper but performs less in properties that are mentioned for 6000 and 7000 series. [22]. Approximately 1,8 billion kilograms of aluminium will be used in body panels by 2018, at least if the estimation of Ducker Worldwide's estimations in their research is right. Novels that is one of the leading supplier in the world of aluminium sheets, states that not only will aluminium decrease the weight with 40%, but it will also be safer since it can absorb 100% more energy than mild steel [23, 24]. One of the major problems of using aluminium instead of steel is that the thickness of the part has to be increased. This can be a big problem when space is not your friend.

Aluminium is an environmental friendly metal and can be recycled several times without losing its properties. This saves 95% of the energy needed for primary production [25]. This has been noticed in the economy of the car manufacturer, since they have a good circular economy. More than 90% of the aluminium that is recycled form a car can be reused to make new aluminium products [26]. Novelis has shown some great numbers regarding energy and emission in their research. Car with high aluminium usage has 20% lower energy consumption and 17% lower emission during a life cycle [23]. However if aluminium is compared to steel regarding assessing the sustainability through a complete life cycle , meaning from minerals to recycling, steel is more environmental friendly. According to GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation model), to create 1 kg of steel which produces 3.6 kg of greenhouse gases it takes 27 MJ. To create 1kg from scrap steel, it takes 19 MJ and produces 1.2 kg of greenhouse gases. 1kg of aluminium to be created, generated 149 MJ and 10 kg of greenhouse gases. To create 1kg of scrap aluminium, it takes 13 MJ and 0.9 kg of greenhouse gases. Concerning this information, we can clearly see that even if an aluminium used car will have less emissions, it may not be as energy efficient as a steel used car. Having all this information, it is hard to say if aluminium or steel is more sustainable [19].

5 Analysis of essential factors regarding the market

The analysis results of the essential factors of the development for the CMS, concerning market, competitors and technology are described in this section. The results are about market trends, competitors solutions and Volvo's CMS position.

5.1 The market trend of the CMS

To determine the trend of a market, it is crucial to investigate internal products as external. There is four general perspectives to be considered and those regard political, economical, socio-cultural and technological surroundings. To understand each of these fields, a PEST analysis have been conducted. It resulted in a broad and well-structured overview of relevant trends and helps elaborating potentials and making decisions.[12] When introducing an update on a CMS to the market, it is of high interest to continually analyse the market and possibilities for being successful. In this case, when an update is being introduced in other countries, factors e.g import and export legislation has to be taken into consideration. These factors can have a major impact on the opportunity to introduce the update on other markets.

PEST	
Political factors	Unclear issues regarding the new taxes in USA. Tougher regulations for the automotive industry around the world has been introduced, since the environmental concerns have increased. Developing countries for local automotive industry protection adopts new extreme tax policies.
Economical factors	Many companies in the automotive industry became bankrupt and disappeared from the market in 2008 when the economic recession took place. Fuel prices are increasing. Commodity prices are increasing. China is trying to become world's largest economy. It is still unclear when the boom will end.
Socio-cultural factors	Europe and USA are having a declining birth rate. The amount of people in one car, when carpooling, is increasing. People are becoming more aware of the environmental impact,which has shown in their eco-friendly actions.
Technical factors	Technologies that has better impact on the environment are introduced on the market. Shared technologies has shown to have substantial benefits. Improving energy efficiency and health related technologies is where the major focus is applied. Many possibilities can be provided by the availability of new and recycled materials. Technologies that supports self-driving vehicles are being developed by major corporations.

Table 1: PEST

5.2 Collected information about the competitors CMS solutions

To be able to develop our own CMS in a proper way and reach desired objectives, we collected information regarding the competitors CMS. Most of our answers and information needed regarding competitors, were gained by performing a deep benchmarking. In this benchmarking, some major competitors were compared to each other for different attributes. This tool enabled us to see the current situation on the market today. The benchmarking was performed by finding information on competitor's websites, a2mac1 and online reports regarding similar CMS. The results of our benchmarking can be seen in Table 2 and 3. An explanation of the titles in Table 2 can be find in Figure 12.

59 different cars	**Structure weight [kg]**	**Width**	**Length**	**Height**	**Thickness**
Beam (min-max)	0,832 - 5,312	4 - 245	435-1422	14-227	1,06-4,08
Average	2,98	91,58	640,18	122,25	1,85
Box (min-max)	0,16 - 1,253	28-339	37-365	35-277	1,2-4,08
Average	0,52	130,9	136,46	112,47	1,99

Table 2: General CMS Benchmarking [27].

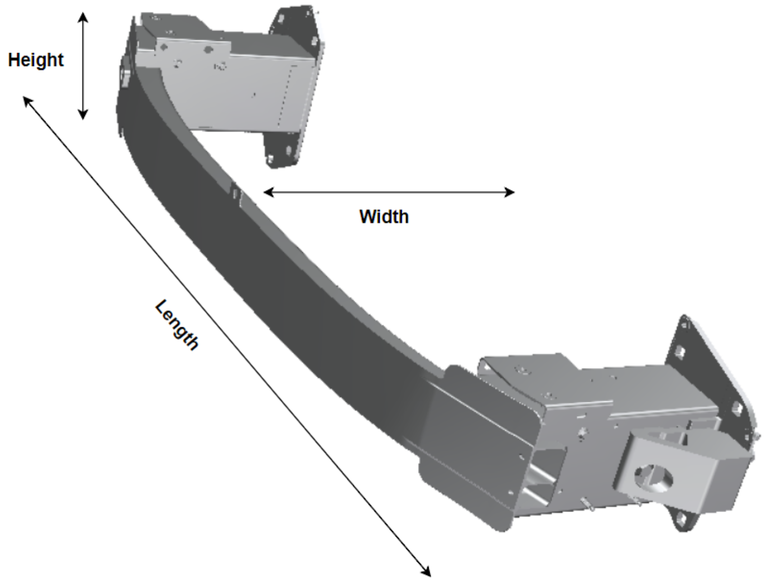


Figure 12: Title description of Table 2

Car model	Structure weight [kg]	Material	Design	Cells	Process
Volvo XC90 2015	Beam: 5,007 Box: 1,77	Aluminium Aluminium	Beam overlapping No reinforcement Welded No plug-in	2 6	Profile Profile
Audi A6 2011	Beam: 2,56 Box: 0,752	Aluminium Aluminium	Beam overlapping No reinforcement Welded No plug-in	2 2	Profile Profile
Audi Q3 2011	Beam: 1,187 Box: 0,443	Aluminium Aluminium	wierd solution No reinforcement Welded No plug-in	2 2	Profile Profile
BMW 7 series 2015	Beam: - Box: -	Aluminium Aluminium	Beam overlapping Different reinforcements Welded Plug-in	1 3	Profile Profile
BMW X1 2010	Beam: 1,948 Box: 0,576	Steel Steel	Beam overlapping No reinforcement 2 Plates welded together No plug-in	0 1	Stamping Stamping
Mercedes A-class 2013	Beam: 4,148 Box: 0,718	Aluminium Aluminium	Beam overlapping No reinforcement Welded Plug-in - wierd	2 2	Profile Stamping
Kia Sportage EX 2011	Beam: 3,182 Box: 0,352	Steel Steel	Beam overlapping No reinforcement 2 Plates welded together No plug-in	0 1	Stamping Stamping
Nissan Qashqai 2014	Beam: 4,256 Box: 0,249	Steel Steel	No beam overlapping No reinforcement 2 Plates welded together No plug-in	2 1	Stamping Stamping
Peugeot 3008 2016	Beam: 1,319 Box: 0,413	Aluminium Aluminium	No beam overlapping No reinforcement A hexagon welded box No plug-in	2 3	Profile Profile
Volkswagen Passat Variant 2015	Beam: 2,646 Box: 0,418	Steel Steel	No beam overlapping Reinforcement beam No reinforcement 2 Plates welded together No plug-in	2 2	Stamping Stamping

Table 3: CMS Benchmarking [27].

5.3 Information on where Volvo XC40's CMS stands in the market today

To understand which position Volvo Cars holds within the market, a SWOT *(Strength, Weakness, Opportunities, Threats)* analysis was also conducted. This analysis made us aware of the strengths and weaknesses of Volvo's existing CMS:s and provided us with opportunities and technologies available for our business.[12]

SWOT	
Strength	Works good for overall performance. Prevents driver and occupants from being crushed in an accident. Environmental friendly Integrated in a car that has won several prices for being safe. Easy to replace after deformation. Increases the brand trust High safety standards Involved in researches
Weakness	Weighs a bit too much Costly Some of the current solutions can be improved further. It is a new way for Volvo of solving the system Has its bests effect under 120 km/h
Opportunities	The weight and cost can be decreased after redesigning some Solutions that Volvo still sees potential in to improve. Possibility to be used in future cares and steer the market. Increase the cars safety. Increase market share Decreases car emissions Parts in the system can be integrated to one. Crashbox cells that can be improved
Threats	Competitors in the automotive industry. Wrong predictions of the market Minds with constrains. The oil price New and high existing taxes New technologies

Table 4: SWOT

5.4 Data collection

In order to get important and useful information, we have done some data collection. Besides using Volvo's servers and internet, we have interviewed different employees. We carefully choose the persons we interviewed in the different phases, in order to maximise the gained information regarding the CMS. The engineers at the front structure department at Volvo Cars where very useful to interview and we also tried to interview random people in the city of Gothenburg to get an input from their perspective, but they did not know much about the CMS.

The interviews that were executed in-depth, semi-structured and unstructured. The semi-structured and unstructured interviews had follow-up questions to maintain a flow in the conversation and therefore lead to a more detailed information collected. In this way, the interviewees were allowed to have deeper discussion by providing space for thoughts and feelings. We were prepared to that interviewees may not have the possibility to participate due to limited free-time and therefore interviews through Skype, telephone or mail were a fact. This sometimes lead to shorter interviews were many questions were not answered.

Some observations in real life and online through Volvo's intranet were also be made. This step was important since it covered areas that were not discussed during the interviews and therefore gave us a perspective of the CMS in action instead and thereby valuable information.

we also planned to do a standard and customer needs list, because it is of high relevance to get the customers voices heard. Since the CMS that we will developed is something that most of the car buyers probably never will see and therefore have very low knowledge about. Because of these aspects, we chose to not do a customer needs list. We also chose to not do a standard list since the manager at Volvo Cars told us that the standard lists is used by the suppliers and they are not relevant for this work.

6 Develop Functional Description and Requirements

Solutions are hard to develop without a vision, therefore it is of high interest to first identify the main task. There are many valuable and different methods to use when identifying functions, but some of them are more suitable than others, when considering the nature of this master thesis. This chapter goes through the group's process of developing the functional description and requirements.

6.1 Identification of the main function of the system

The main function describes the behaviour of the system when being exposed to an input. When identifying the main function, a Black Box is appropriate to start with. It shows what the system should turn the input operand into. The reason of creating the black box diagram is to gain a clear perception of what the system actually has to do.[28]. Figure 13 visualise the Black Box of the CMS.

Figure 13: Function to prevent loads and energy from penetrating vehicle cabin

The input operand here is *Applied loads and energy on the CMS* and the output is *Decreased generated loads and energy.* The main function is now identified thanks to the Black Box. This project's main function is to help preventing people involved in the crash from being exposed to damage.

6.1.1 Component mapping

In order to create an overview of the existing components in the current CMS, we set up a map consisting of all parts and how they are connected in the CMS, see Figure14. The parts are defined and thereafter linked together in order to create a clear map with the different hierarchies. In relation to this a similar map was created, called function-means tree, in order to understand each components function. This map is an important mean during the concept generation and development phase of a new CMS since it helps to generate and discuss new ideas and thoughts. The created function-means tree of the current CMS can be seen in FigureA.

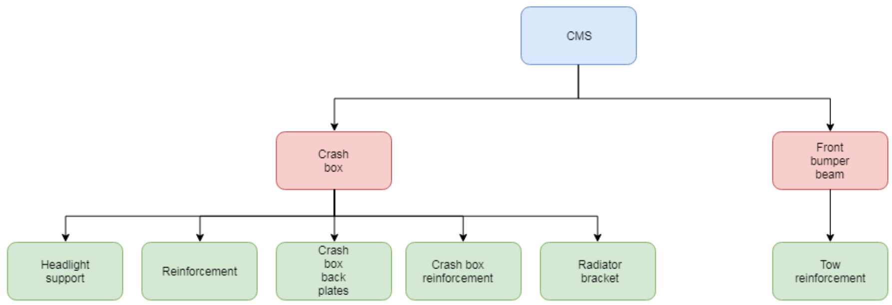


Figure 14: Component mapping of the CMS

6.2 Components of the CMS

The CMS consists of several different parts and components. Every specific part and component that are valuable for the project are described in the sections below, see Figure 15 for current CMS overview.

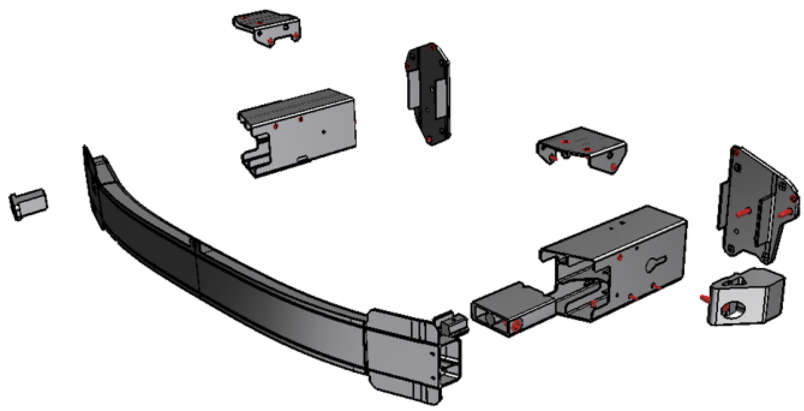


Figure 15: Exploded view of the CMS

6.2.1 Front bumper beam

The crash beam, see Figure 16, is made of aluminium 7000 series due welding properties and safety requirements that Volvo Cars need to fulfill. The hollow beam is created by extrusion from a solid aluminium part and the profile of the current beam is seen in Figure 16. The rounded shape of the beam is created by being placed under a press that applies a load on the beam in order to create a round shaped beam, seen in detail in Figure 17. The rounded shape is more of an design manner since a round shape in this car gives the designer the freedom to design all parts and components around the CMS to what Volvo wishes for, the shape follows the function. The rounded shape gives an improvement in stiffness as the beam is bent outwards [16]. In order to minimise the weight the beams front structure, see Figure 17 is milled in the upper and lower section of the beam. The upper section is not milled in the center where a bolt is placed in order to attach the beam to the radiator support for extra radiator support. The milling process saves weight since material is removed and the removed material is later recycled and money is being returned at the same time. The milled area is not removed entirely down or up to the rectangular beam since there are regulations to follow regarding a minimum height of the flange [16]. The flange increases safety in low speed crashes both from cars with higher and lower ground clearance. The cells in the profile are asymmetrical due to the towing equipment that is located on the right side of the car. The beam is held in place by being welded to the crash boxes on each side.

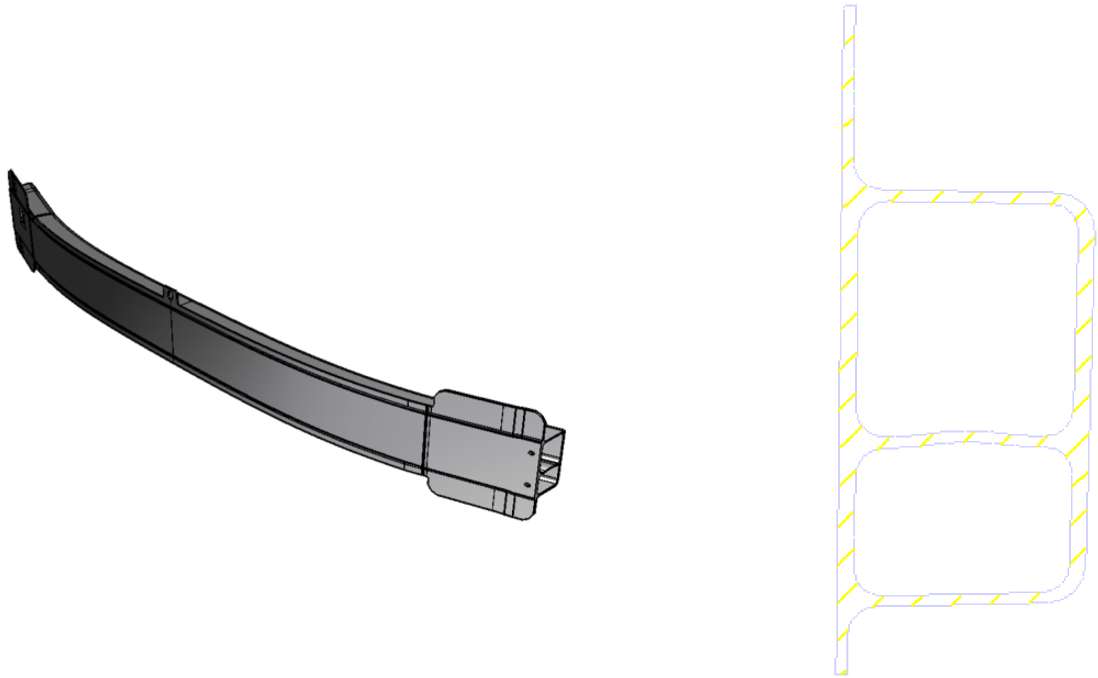


Figure 16: The frontal beam (left) and the beam profile (right)

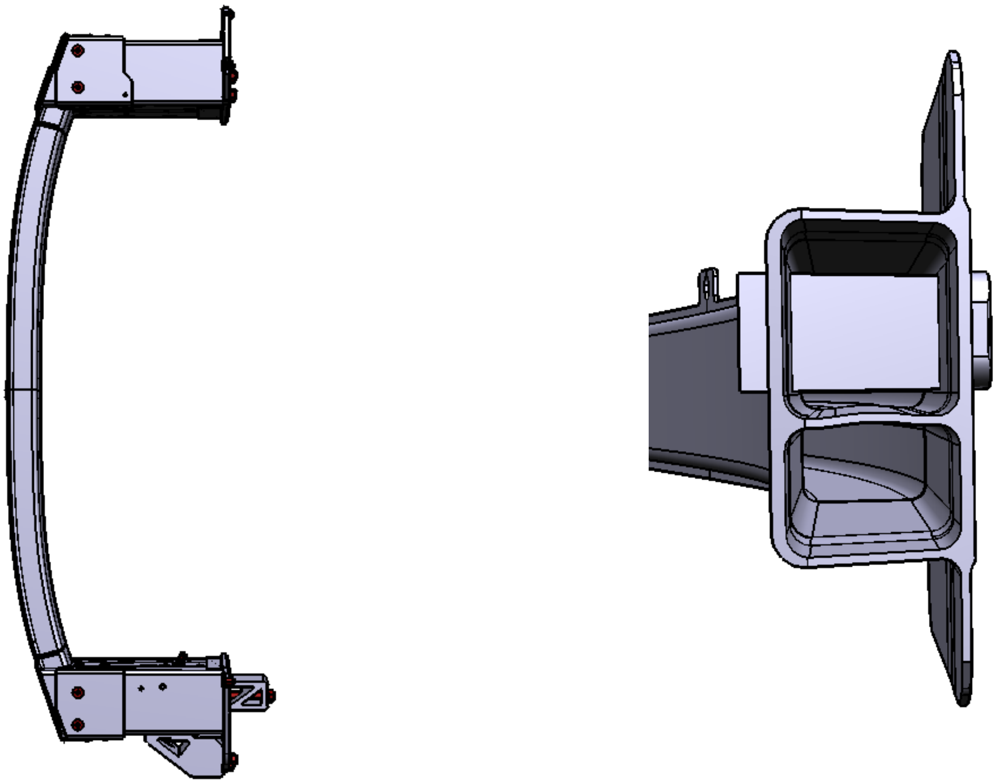


Figure 17: The profile of frontal beam (left) and the beam flange (right)

6.2.2 Headlight support

The headlight support, see Figure 18, is used to mount the headlights on. The form and construction of the support is important in order to get a good placement of the headlights. The support is designed in 6000 series aluminium after the chosen design for the headlights have been set, this in order to achieve a good outer body design whilst maintaining a robust construction. The support on both sides are attached on the crash boxes using bolts.

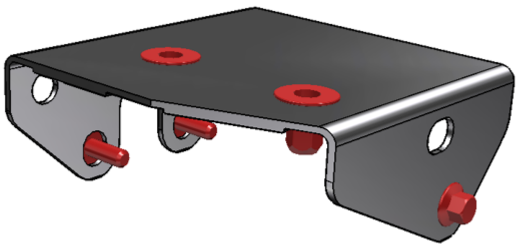


Figure 18: Headlight support

6.2.3 Crashboxes

The crashboxes are made out of 6000 series aluminium and welded to the beam and crashbox back plates. The crashbox back plates are then bolted to the wide side members. The shape of the boxes dictates the force level that enters the cabin during a frontal crash. In Figure 19, the boxes can be seen divided into five cells and those cells have notches designed in the front meaning that the force that could enter the compartment is limited during low speed crashes of 15 km/h [29]. The CMS will get damaged during low speed crashes and is therefore tested by Allianz in order to calculate the damages and cost for low speeds. The purpose is to make sure that the boxes are not destroyed in a bigger scale during low-speed crashes, but only the front beam. This gives the opportunity to change the complete CMS at a workshop easily and thereafter use the car again without any affection to the wide side members. Replaceable parts are an important aspect to consider when developing a CMS, from a service cost perspective. During high speed crashes the boxes are designed to be triggered into buckling in a right order to reduce the high forces created to enter the cabin [16].[30]

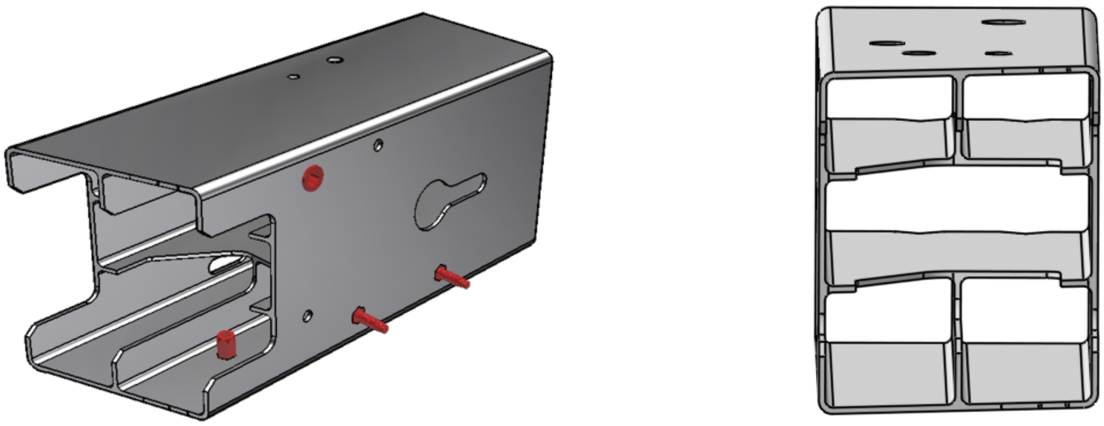


Figure 19: The crashbox (left) and the crashbox profile (right)

6.2.4 Reinforcement

The Front Bumper Reinforcement(FBR), made out of 6000 series aluminium, see Figure 20, screwed with bolts on to the crashbox. Since the engine bay is asymmetrical the need of extra FBR is needed to balance both sides of the frontal area. In other Volvo car models built on the SPA platform, the FBR is placed on the front beam itself and the crashbox back plates do not exist, instead the crashboxes are placed inside of the wide side members and bolted from the side.

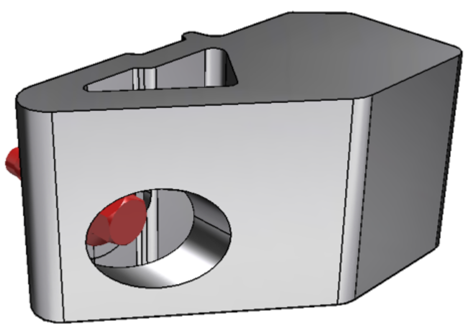


Figure 20: Reinforcement

6.2.5 Crashbox back plates

The plates, in Figure 21 are welded to the crash boxes and bolted to the wide side members, where the purpose is to hold the whole CMS in place. The plates also have a square lump welded on the back side of the left plate and located inside the wide side member. The lump is designed to make sure that the right wide side members are not clamped together during SPOC or full width accidents. This generates a robust construction that prevents unnecessary failure to occur where the higher force is applied. A clamped wide side member will allow high forces to enter the driver compartment and neglect the purpose of the FBR as the support from the wide side member is reduced drastically.

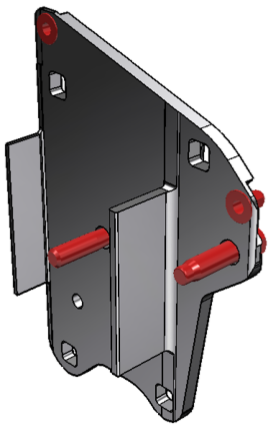


Figure 21: crash box back plates for the CMS

6.2.6 Tow reinforcement

The towing reinforcement, see Figure 22, made out of 6000 series aluminium, is placed on the right side in the upper cell of the beam profile. It has a T-shape since an anti-rotation motion is needed for this part, as the towing hook is being screwed into position the T-shape prevents the whole towing area to rotate. It is also beneficial during use, high forces are generated in different directions as the car is being towed. The tow reinforcement is welded in front and back to the beam. The tow reinforcement is placed in a bigger whole than itself in the front beam in order to be welded around all edges without corners. The welding offset between the tow reinforcement and beam is useful in this situation in order to prevent cracks from occurring in areas around the tow reinforcement on the beam as the car is being towed away.

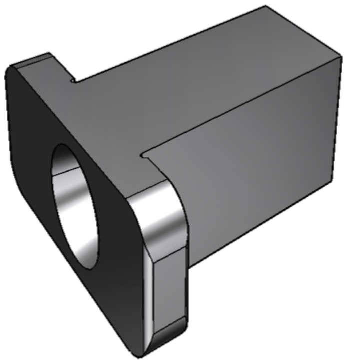


Figure 22: Towing area for placement of tow-hook

6.2.7 Crashbox reinforcement

Since the impact forces are high during accidents, the need of a inner solid crash box reinforcement (CBR) is required to withstand forces, see Figure 23. The CBR is bolted from the back through the crashbox back plates and the side through the Reinforcement. It is placed on the inside of the crashboxes and made out of 6000 series aluminium. As the crashboxes are long in dimension the buckling of them is reaching a higher buckling speed with forces moving closer to the engine and dash panel. The absorbed forces and energy will be reduced, when the buckling reaches the CBR.

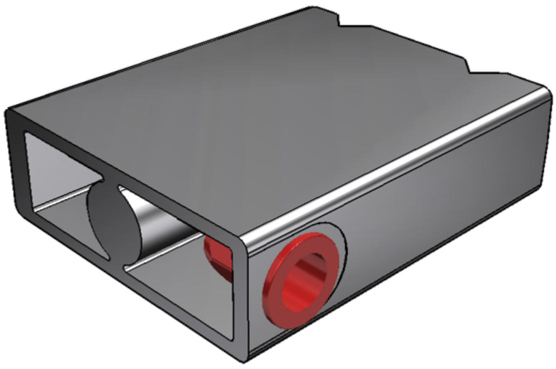


Figure 23: Reinforcement places inside the crash boxes

6.2.8 Radiator bracket

Radiator bracket components, see Figure 24, are placed inside of the crashboxes. The bracket is welded on the inside of the crashbox. The radiator is bolted on the radiator bracket from underneath the crashboxes.

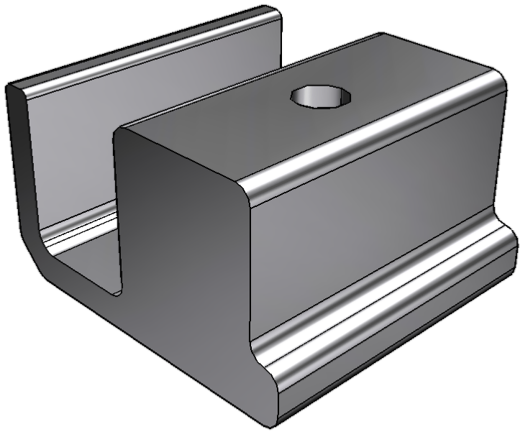


Figure 24: Radiator support for fixing the cooling system

6.3 Crash sequence mapping

A combination of doing the black box and the theory behind the different components of the CMS, led the group to creation of a process flow. This process flow were called crash sequence and were conducted in order to understand how the CMS behaves[28]. It is important to design a CMS that is well balanced with the interior structure in order to reduce the risk of injuries of the occupants. [31]

When high forces are applied on the frontal structure of the car, the occupants are the first priority to keep safe from high forces. Forces created during a crash are high and affect the whole frontal structure including the dash panel in front of the cabin. The roof, a-pillar should barely deform during a crash in order to protect occupants safe in a cage. This is challenging as it is crucial to maintain a good vehicle pulse index throughout the crash sequence.

A frontal crash sequence starts with the front bumper beam as it takes the first hit and energy creates a G-force. The bumper needs to absorb it effectively in order to reduce the energy created from the high forces that tries to penetrate through the whole car. It is crucial to make sure that the front bumper beam is not loosen from the crashboxes since the remaining energy is transferred to the crashboxes where they are being buckled and reducing the penetrating force to a reasonable level and keeping it constant there. The G-force created is high and the car is accelerating faster than the occupants since they are not firmly attached to the seats. This means that the occupants are moving free until the G-force reaches a certain level which thereafter activates a tightening belt and stops the human body to move freely forward and thereby decelerating the occupants bodies inside of the car. [31] [16] Figure 25 shows the distribution of forces on the frontal structure during frontal accidents.

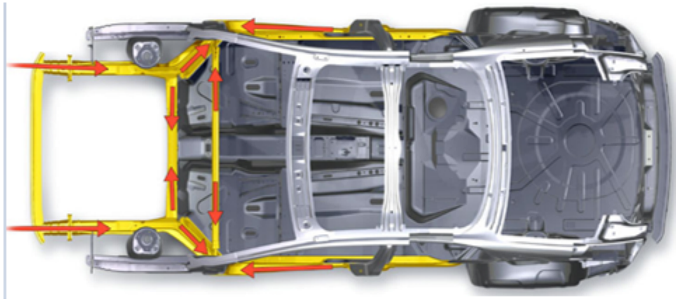


Figure 25: Distribution of forces in frontal accidents

6.4 Specification of requirements

Descriptions, of what a product or CMS has to do and that could be measured and verified is called *requirements* [12]. Requirements can be based on different factors e.g weight, cost or performance. For a CMS to be considered acceptable, it has to fulfill all the stated requirements [28]. When all of the requirements are brought together into a list, they create a *Specification of requirements*. The requirements in our Specification of requirements are based on the existing CMS.

We have also added non-measurable requirements. These requirements are functions that only describes what the CMS will have to do, but it is very important that these also are fulfilled. Besides requirements, a number of different desires were also stated. These desires are not demands, but by fulfilling these desires, the CMS become higher valued and more competitive against similar CMS's. Therefore, these desires were useful during concept evaluations, because the concept fulfilling the majority of the desires in a most satisfied way is the most beneficial one to choose. [28]

The specification of requirements document were the backbone of the work and therefore used as a tool for verifying that the progress of the project were going in the right direction. This document were of course revised and adjusted continuously during the project, since it was stated in the early phase of the work where we lack knowledge about the CMS. The specification of the requirements can be seen in Figure 26 and 27.

Specification of Requirements						
Project Modeling of a front bumper with emphasis on lightweight and low cost						
Authors: Project Group			*Created: 2018-04-09 Modified: 2018-06-06*			
	Criteria		*Target value*	*R/FR/D*	*Weight*	*Verification method*
	Main Function					
		Protect driver and occupants in case of a frontal accident				CAE
1.	**Performance**					
	1.1	Protect driver and occupants in case of a frontal accident		R		CAE
	1.2	Force that the crashbox should manage	< 170 kN	D	5	CAE
	1.3	The time it should take for the crashbox to remove the energy	< 24 ms	D	5	CAE
2.	**Environment**					
	2.1	Made of recyclable material		R		Material database
	2.2	Use non-toxic material only		R		Material database
3.	**Life Span**					
	3.1	Life span	Until deformation	R		
	3.2	Number of cycles	Until deformation	R		
4.	**Maintenance**					
	4.1	Replaceable CMS		D	5	3D modelling
	4.2	Minimize water accumulation inside crashboxes		D	3	
5.	**Quantity**					
	5.1	Produced units	100000/year			Production calculation
6.	**Size**					
	6.1	Width(Whole. From reinforcement to attachment plate)	< 1253 mm	R		3D modelling
	6.2	Width(Crash box)	< 102 mm	R		3D modelling
	6.3	Width(Bumper beam)	< 1147 mm	R		3D modelling
	6.4	Length(Whole. From beam to attachment plate)	< 359 mm	R		3D modelling
	6.5	Length(Crash box)	< 305 mm	R		3D modelling

Figure 26: Specification of requirements Part 1

	6.6	Length(Bumper beam)	< 586 mm	R		3D modelling
	6.7	Height(Whole)	< 240 mm	R		3D modelling
	6.8	Height(Crash box)	< 125 mm	R		3D modelling
	6.9	Height(Bumper beam)	< 149 mm	R		3D modelling
7.	**Physical tests**					
	7.1	Maximum award on the Euro NCAP crash test		R		Crash test
8.	**Weight**					
	8.1	CMS weight	< 9,114 kg	R		3D modelling
	8.2	CMS weight	< 9 kg	D	5	3D modelling
9.	**Material**					
	9.1	Corrosion resistance		R		Material database
	9.2	As little material variation as possible components		R		Bill of Material
10.	**Time Schedule**					
	10.1	Final date on final concept	6/5/2018	R		Gantt chart
	10.2	Final date on the report	6/15/2017	D	3	Gantt chart
11.	**Safety**					
	11.1	Contributing to protect the driver and occupants from injuries		D	5	CAE
12.	**Construction**					
	12.1	Shall fit the current body of Volvo XC40		R		3D modelling
	12.2	Ability to use the current process to attach the CMS		R		3D modelling
	12.3	Maximum number of components included in the CMS	13			
13.	**Assembly**					
	13.1	Same type of fastening methods		R		3D modelling
14.	**Aesthetics and finish**					
	14.1	Have same dimentions as the current CMS		R		3D modelling
15.	**Components**					
	15.1	Allow components to be mounted on the CMS		R		3D modelling

Figure 27: Specification of requirements Part 2

7 Concept creation

In order to develop the requirements and functions into solutions for the new CMS, a concept creation process were conducted. In this phase, ideas will not only be created but also combined in a correct and systematic way with each other. In order to pick the right concept that will result in a perfect final concept, we had to evaluate and compare all the concepts and therefore needed a number of different steps. These steps are presented in this chapter.

7.1 Idea generation

The idea here was to start generating multiple ideas through a number of brainstorming sessions to be able to make our creative ideas heard. The reason for not only having one session is due to increasing the concept generation for each component in the CMS. In this way a bigger variation of concept could be carried out. No constrains was set on the ones performing the brainstorming even if the ideas were unrealistic. This allowed the concept generation to not get narrowed down and get incorrect performed. Before we started brainstorming each component, we found a component called Crashbox Reinforcement, that we found not needed and that we could remove. We chose instead to distribute some of this component's weight to the crashbox. We also found a component called Radiator System, that we have to make make a few changes and adopt after choosing a final concept. This, because of the strong connection between Crashbox and the Radiator System. There were also two more components that were no need to change since there are heavily linked with other components around the CMS and those were Attachment Plates and Headlight Support. This left us with four components to develop, Front Beam, Crashbox, Reinforcement and Tow. 4 brainstorm sessions were generated since there were 4 components to develop, one for each component. The ideas were created by each person in the group alone, in order to not influence each other. All of the ideas were sketched and named and then discussed, explained and compared to the other ideas after each session.[12]

There were 36 ideas in total, which resulted in variants of each component and a good freedom of choosing. A Morphological matrix, as seen in Figure 28, 29, 30 and 31, was used to combine the solutions of the different components into a complete visualised working system.[12]. The pictures being used in the Morphological Matrix are hand made sketches of the different components conducted from the Brainstorming sessions. By using this matrix, a systematic approach to the generation of concepts could be made and a large number of concepts were created [28]. In this project, the main task is to bring down the weight and cost of the CMS. Therefore, it was important to consider how these aspects could be decreased when combining the components into a whole solution.

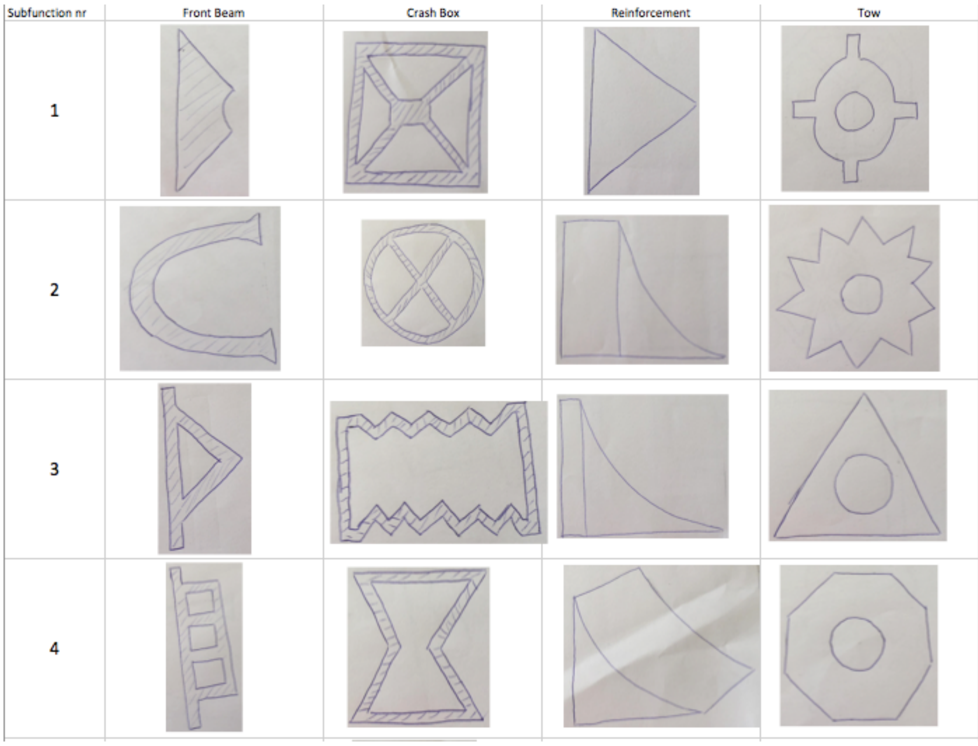


Figure 28: Morphological matrix Part 1

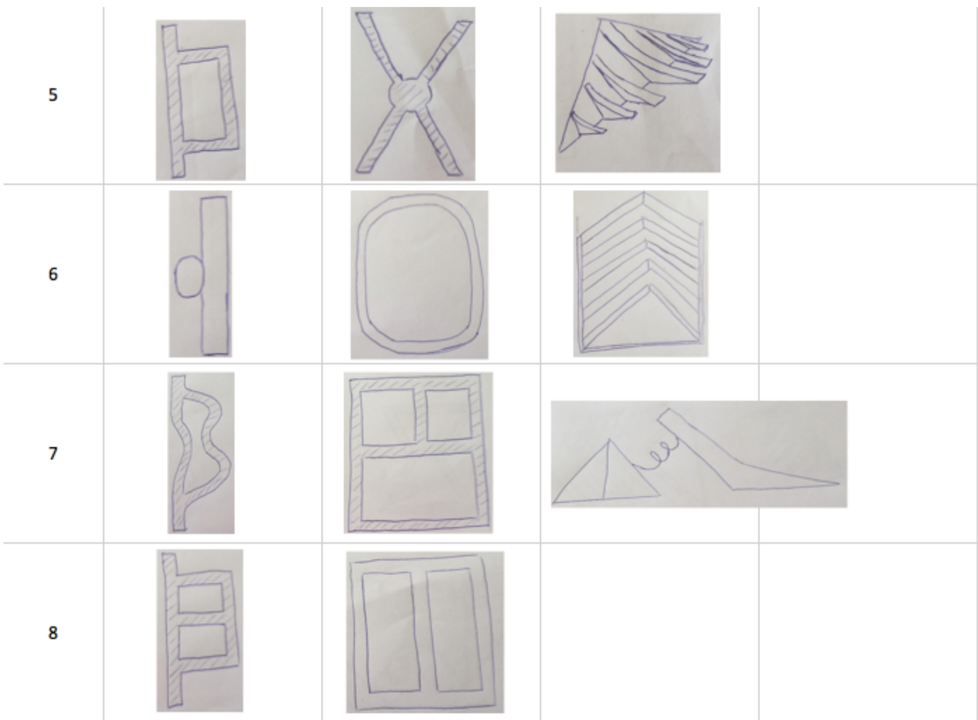


Figure 29: Morphological matrix Part 2

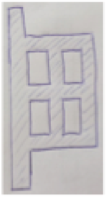
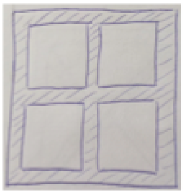
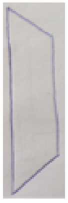
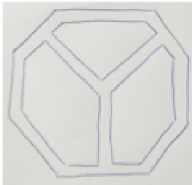
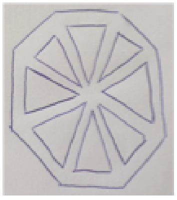
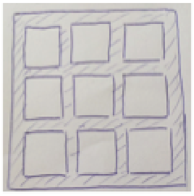
9				
10				
11				
12				

Figure 30: Morphological matrix Part 3

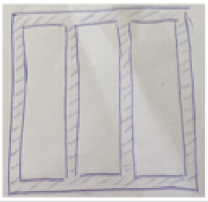
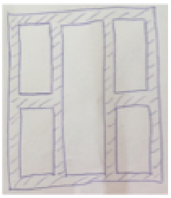
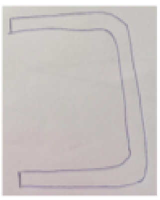
13				
14				
15				

Figure 31: Morphological matrix Part 4

The purpose of the Morphological Matrix is to visualise the combination of different ideas from different components into Concepts. To give a better understanding of the used matrix, an example of how combinations in the Morphological matrix could look like, is showed in Appendix C. Each combination is represented with one colour. Every idea in each component were used at least one time in a combination and a total of 25 concepts were created. All of the combinations can be find in Figure 32. A name for each part number in Figure 32, can be find in Figure 33.

Concept Nr	Front Beam	Crashbox	Reinforcement	Tow
1	1	1	6	3
2	2	3	5	3
3	3	8	5	2
4	4	14	7	1
5	5	7	6	1
6	6	6	6	2
7	7	13	4	4
8	8	1	1	1
9	9	6	5	2
10	10	5	4	3
11	5	6	5	1
12	1	7	7	3
13	9	12	6	3
14	7	5	1	1
15	8	2	3	1
16	2	2	2	2
17	5	15	5	1
18	8	11	5	4
19	7	10	6	3
20	3	4	2	3
21	3	8	5	1
22	10	9	7	4
23	8	14	3	3
24	6	5	4	3
25	5	8	5	1

Figure 32: All concept combinations

Front Beam	Crashbox	Reinforcement	Tow
1. Pit triangle	1. X-rectangle	1. Triangle	1. Sight
2. U-shape	2. X-circle	2. Ramp	2. Star
3. Bow	3. Wave rectangle	3. ThickRamp	3. TriangleHole
4. Ladder	4. Hourglass	4. ThickerRamp	4. HectagonHole
5. One Rectangular	5. X-shape	5. SkeletonRamp	
6. Ball Wall	6. Cicle	6. TriangleRamp	
7. Eight	7. Robot face	7. SpringRamp	
8. Two rectagular	8. Suicide doors		
9. Multipe rectangular	9. 4-windows		
10. Knife	10. Peace		
	11. Octangon		
	12. Blocks		
	13. 3-LongDoors		
	14. Current		
	15. Banana		

Figure 33: All concept names

7.2 Concept Filtering

The first step were to see if the concepts that we have created met the requirements in the specification of requirement list and for this, a elimination matrix were used to filter out the concepts that did not met the requirements. An Elimination matrix looks at a number of different criteria that is specified to it and runs the concepts through them. The concept is then told if it satisfies the criteria or not. The concept is ready to continue in the development if it satisfies the criteria, but if the concept does not satisfy the criteria, it gets eliminated. A final comment can also be added to the result of the matrix.[28]

Since there were a quite big number of concepts, the elimination matrix were a good start that removed many concepts that were not suitable for this work already in the early phase. Thanks to the Elimination Matrix, the potential of keeping the more realistic concepts increased and it showed which concepts were fit for continuation in the developing process in their current states. A own touch to the Elimination matrix were used. Instead of putting concept into the matrix, we chose to put in the solutions of the different components. Our Elimination matrix can be seen in Appendix D. Each solution that did not pass the elimination matrix were marked in red. In this way, a deeper understanding of why some of the concepts did not pass the Elimination matrix were gained. The Elimination matrix brought down the number of concept from 25 to 8. After the elimination matrix was completed, we had three similar concepts. Therefore, we looked further into those and combined them into one concept and went down to six concepts. The red marked list together with the combined similar concepts can also be found in Appendix D.

7.3 Concept Comparing

Now when the concepts had been reduced significantly and similar concepts had been combined, we started using another matrix, called Pugh matrix. The Pugh matrix compares the different concepts based on a set of criteria that is chosen by the user(s) of the matrix. All the concepts are lined up in the matrix and one of these concepts are chosen as reference, which the other concept will be compared to. For each criteria, the concepts are given a + (plus), - (minus) or 0 (zero). Plus indicates that this concept performs this criteria better than the reference, minus indicates that this concept performs this criteria worse than the reference and zero indicates that both performs this criteria equally. It becomes apparent which concept is performing better than the others when all the criteria's is compared and the scores are counted. [12]

To get a better overview of which of the concepts performs this step best, we compared them to each other by using 3 Pugh matrices, instead of only use one concept as reference. In this case, it was appropriate to use three Pugh matrices in order to be completely sure of our decision. We were also aware of that we could make exceptions after this stage is done if one of the concepts that we really believed in did not make it through this matrix. The conducted Pugh matrices can be seen in Appendix E

As seen in the different Pugh matrices, we have different concepts as references for comparing the other concept against. They were randomly decided to be the referencing concept. The concepts were ranked based on the net value and the lowest number is the best and the highest is the worst performing concept. Concepts 6 lost in all of the different matrices, because it had a to weak construction and was removed from further investigation. The concept showing best results after adding all three matrices were concept A. All of the concepts, except concept 6, showed potential of being a final solution in the Pugh method.

A evaluation on the criteria "size" were made after completing the matrices and a decision were made that it were not useful since all the concepts were of the same size. We could have realised this after the first or second matrix, but it did not cost us that much time just going through it.

The final evaluation were proceed by a Kesselring matrix. This matrix is used to get a more detailed scoring of the concepts. It is a little bit similar to the Pugh matrix, but the major differences is that the scoring is based on criteria's that have a weighted value, depending on how important they are. The concepts are scored to scale in this matrix instead of having a reference concept that all the concepts are being compared to.[28] There is a chance to get the same results as in Pugh matrix if the same criteria is used, since these two matrices are similar to each other.[12] To avoid the same results as in the Pugh matrix and to be able to decrease the amount of concepts even more, desires as criteria were also used in this matrix. This brought forward the concepts that could best compete against the competitors, because we think that our desires is what will make a difference in the market.

The kesselring is shown in Appendix F, where the score and rank is defined in detail for each concept. As seen in the kesselring matrix, there is an ideal concept and rated criteria. Higher rating on a criteria means higher score to gain and that it is more important to take into consideration. The kesselring resulted in three remaining Concepts, Concept A, 18 and 19.

However, all the concepts that passed the kesselring matrix were thereafter sketched and given a special name in the next section. Naming the sketches made them more special and easy to differentiate from other concepts.

7.4 Practical evaluation of promising concepts

To understand how the concepts behaves, physical models were created. Only two of the three remaining concepts were created as physical models. Due to similarities in crashboxes between Rimmer and Peace, they were created in one prototype. The Cross concept is represented as the other prototype. The models of the remaining concepts were constructed by first conducting basic research on how to configure and assembly both models and also by looking into Chapter 2 "General structural mechanics". The models were created by using foam blocks and aluminum foil as material. The foil is used to cover all parts representing the CMS in metal. The tools used to create the models were found and provided by the production system laboratory (PSL) at Chalmers, such as glue guns, saws and files. Both models, offset model and full width model, were created in 1:4 scale and can be seen in Figure 34. The offset prototype will represent the Cross concept and the full width prototype will represent the Rimmer and Peace concept.

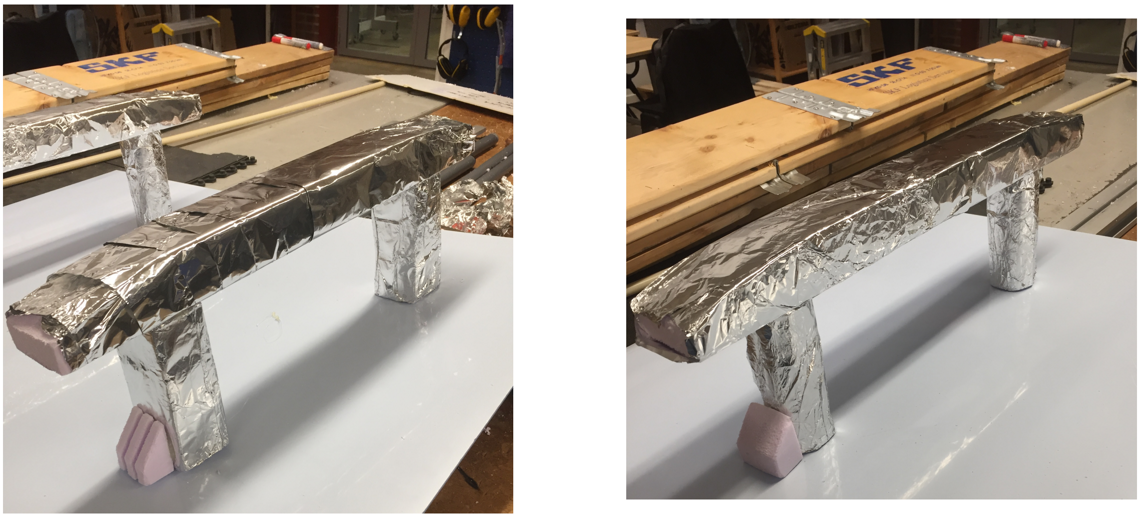


Figure 34: The offset prototype (left) and the full width prototype (right)

The concepts are described more in detail in the following text sections regarding their functions. Each of the concepts remaining have been described in further detail regarding their functions with sketches on the whole system concept. The conducted tests for the models were performed by applying them with loads representing a crash in the front beam and crashboxes. By feeling and observing the construction before and after the force load, understanding the deformability of construction design of the concept is obtained.

7.4.1 The Cross concept

The Cross have similarities in design as the current CMS. The crashboxes are rectangular with a reinforcement cells designed as an X-shape through the whole box. The reinforcement that is placed on the side of the crashboxes is designed as a solid triangle that will function well during offset crashes. The frontal crash beam is designed as an hollow rectangular profile combined with a sheet in front. The cells in the crashbox is illustrated with two holes that will deform the crashboxes in a desired way during the crash test of the mock-up. A completed visialisation of the Cross concept and belonged components are shown in Figure 35.

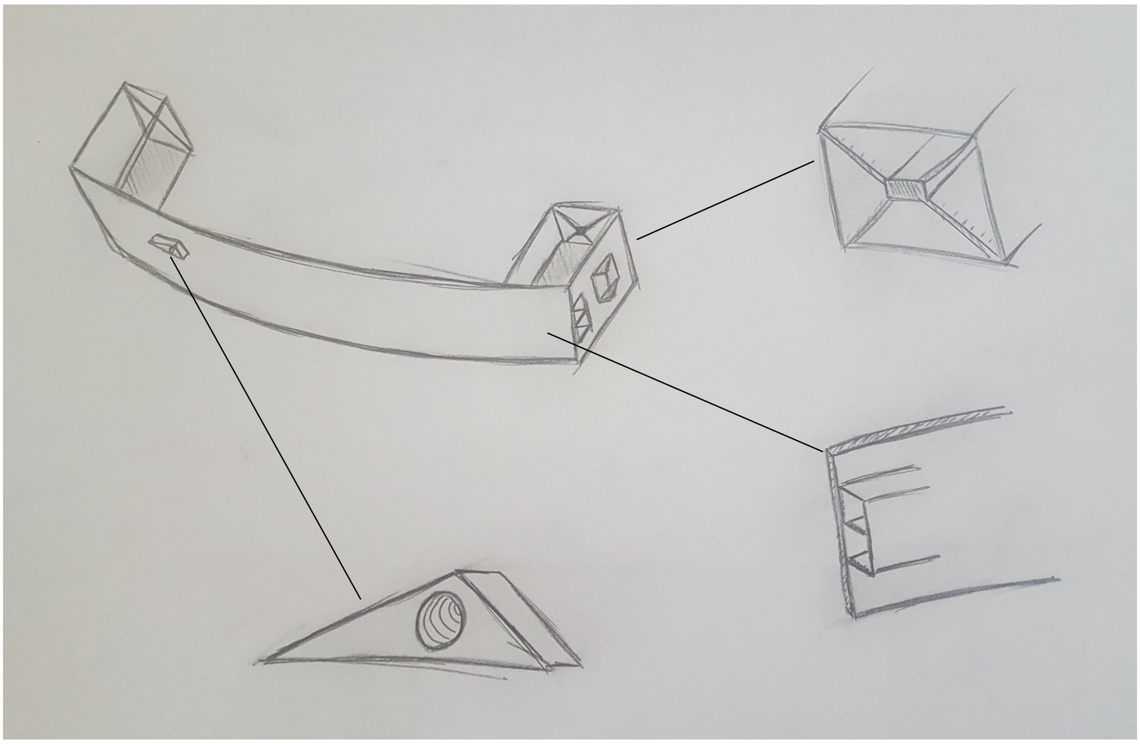


Figure 35: The Cross CMS concept

7.4.2 The Peace Concept

The Peace have similarities in the frontal beam design as the current CMS. The crashboxes are octagon with three reinforcement cells designed as an Y-shape through the whole box. The reinforcement that is placed on the side of the crashboxes is designed as separate triangles that will function well during offset crashes, but also decrease weight. The frontal crash beam is designed as an solid rectangular profile instead of an "Eight-shaped" profile that is difficult to perform a test on. The cells in the crashbox is illustrated with three holes that will deform the crashboxes in a desired way during the crash test of the mock-up. A completed visialisation of the Peace concept and belonged components are shown in Figure 36.

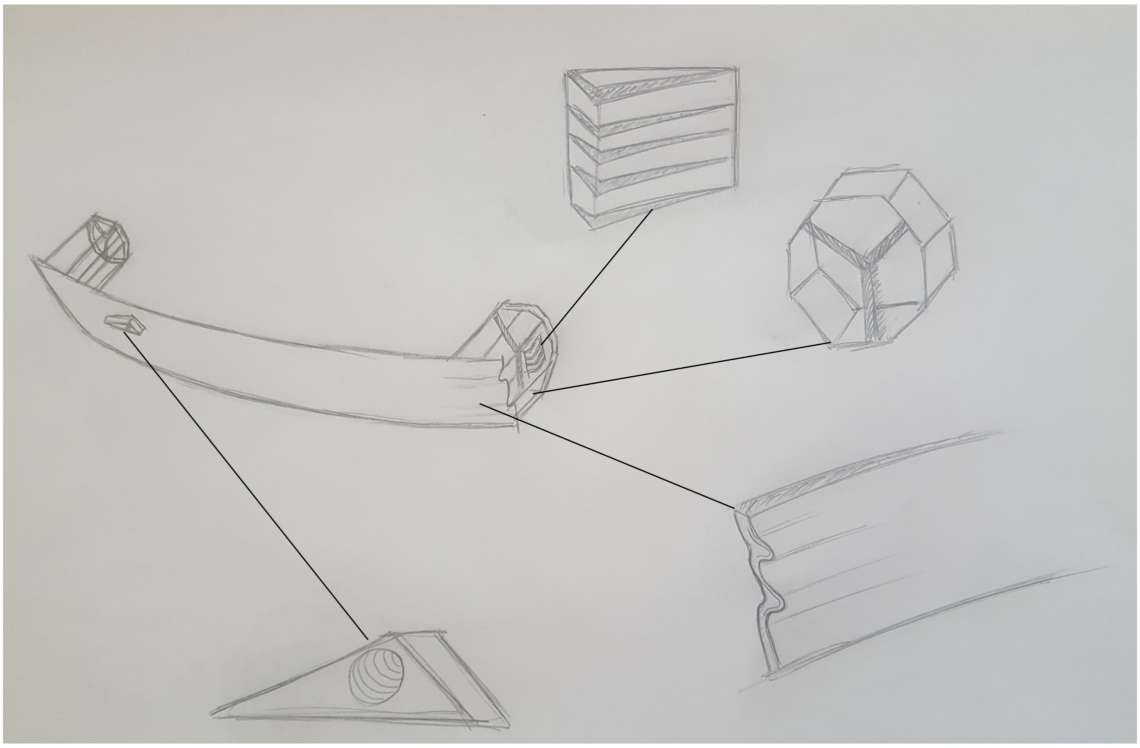


Figure 36: The Peace CMS concept

7.4.3 The Rimmer concept

The crashboxes in the Rimmer are octagon with seven cells as reinforcement a rim spokes through the whole box. The reinforcement that is placed on the side of the crashboxes is designed as triangle spokes that will function well during offset crashes, but also decrease weight. The frontal crash beam is designed as an solid rectangular profile just like the Cross concept. The concept was not created an mock-up of due to the octagon spokes in the crashboxes that will make sure that the crashtest on the mock-up will not perform fairly and therefore excluded.A completed visialisation of the Rimmer concept and belonged components are shown in Figure 37.

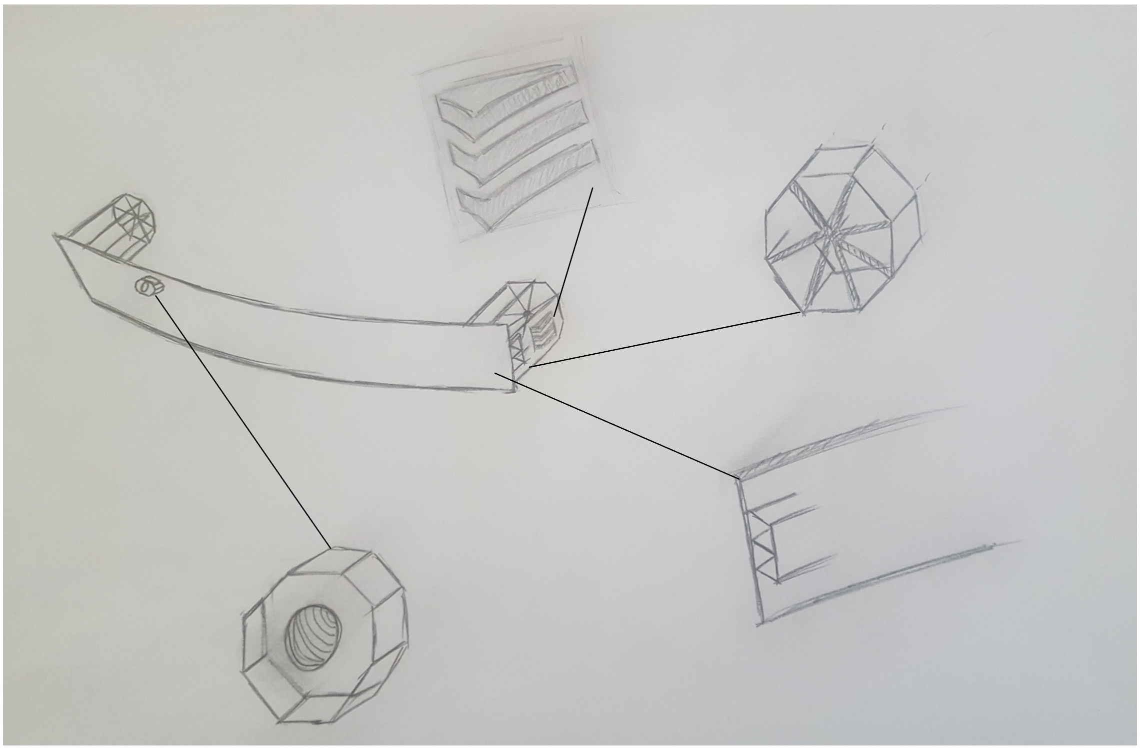


Figure 37: The Rimmer CMS concept

7.4.4 Offset deformable barrier, ODB, crash test

Since the foam was not so formable and gave difficulties to take out precisely material, a decision to only make three wholes in the crashboxes representing all the cells were taken. On offset prototype we conducted an offset crashtest, meaning the the front bumper system was crashed in an 40 percent overlap. To illustrate the force that a real CMS is exposed to, a plank were used and pushed down hard with hands on the beam. This did not go so well, since the hands did not generate enough energy. Instead, a person who weighs 75KG placed the plank on the CMS and stood at it. This worked out better and it resulted in wrinkles on the crash boxes and a bent bumper beam. The results for this test is shown in Figure 38.

Figure 38: The bent bumper beam (left) and the wrinkled crashbox (right)

7.4.5 Full width frontal, FWF, crash test

As stated in the first test, the foam was hard to form exactly according to our wishes. The octagon crashboxes had a smaller area and therefore no more than two holes could be create. On the full width prototype, we did the full width frontal crash test. This means that the entire front side of the CMS gets exposed to forces. Learn by doing. Instead of placing one plank that covers the entire frontal side of the CMS and pushing with our hand, we went directly to standing on the plank. The same person got to stand on the plank, 75KG, and the outcome was two fractured crash boxes. The results for this test is shown in Figure 39.

Figure 39: The failure of the CMS (left) and the wrinkled crashbox (right)

The models provide important information regarding the solutions realisation and feasibility through simple tests. They also illustrated the fundamental actions intended for the concept. After the tests, more information was gained on which of the remaining concepts was the most appropriate on by its ability to solve the problem and fulfills the demands in a best manner. The information is important to use during the final concept selection phase and will be presented in the next chapter.

8 Development of a final concept

This chapter consist of choosing the final concept, Beta, and how that concept then is developed into a Alpha concept.

This chapter began by having some interviews that were planned to happen already in chapter 6, but due to interviewees having fully booked schedules the interview had to happen in this phase. The interviewees were senior simulation employees and they explained the crashsequence of the current CMS in detail which can be seen in section 6.3 "Crash sequence mapping". The top three solutions were also presented to them and the discussion went deep in how the components could be developed. The interviewees gave provided the project with good advises. Since the The Cross Concept showed best results in the previous chapter and considering what the interviewed employees said, we chose Concept A as our final concept. The Cross Concept's sketch together with the prototypes, showed in the previous chapter, is now considered as prototype Beta. Due to time limitation and the desire to generate good results, a decision that the project will from now and on only focus on crashboxes. The interviewees also touched really much on that the crashbox will give best results if the cells have square shapes and that all cells should be of same size. Because of that we transformed the cross shaped walls in the crashbox into plus shaped walls.

8.1 Virtual prototype

After choosing Beta and deciding that the project will focus on crashboxes, creation of the virtual prototype began. This prototype included more detailed information for example material and dimensions. It also gave a more clear sight of how our product that will be mounted in the car could look like. This prototype is a computer aided design, CAD, which is a 3D-model and is made in Catia V5. Catia V5 were a important tool for our development of turning Beta to Alpha, because this allowed us to make our CMS in real dimensions, try out different ideas and also save a lot of time and money. It saves a lot of time and money, because it is easier to fail and redo prototypes in a computer than in real life. This 3D-model will also make it possible for us to run simulations and test in the computer without needing to build full scale prototypes for this purpose, which we would not had time for.

Since Volvo had the requirement that our CMS should fit in the existing Volvo XC40, we decided to not change the dimensions of the crashbox. The dimensions can be seen in the "Specification of Requirements". The current crashbox have the same thickness on all walls and we thought that it could be a good idea to try it too. Even if the interviewed employees said that it is better to have thicker inner walls than outer walls, we decided that it could be good to see were the thickness should lie around when it comes to our design. Many different 3D-models were made and Figure 40 shows the ones with most potential. The top row in the figure represents the crashboxes with 2,3 mm thicknes on each wall, same thickness on the walls as the current crashbox. The lower row in the figure represents the crashboxes with

1600 g, same weight as the current crashbox when the crashbox reinforcement also is included.

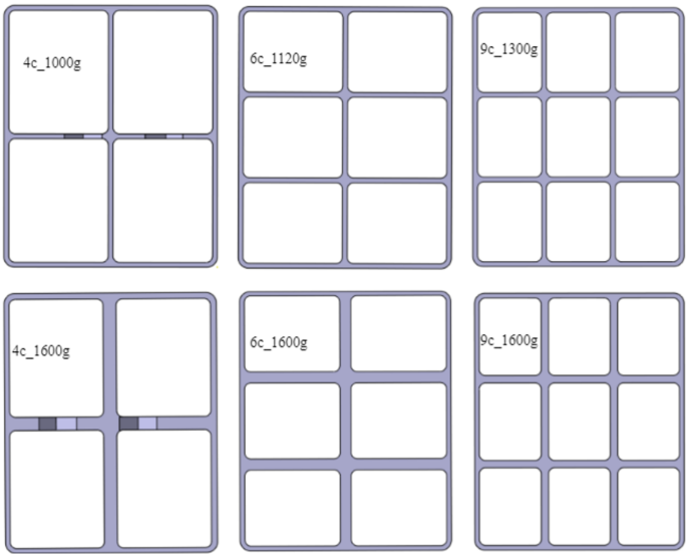


Figure 40: The relevant virtual prototypes for this project

Aluminum 6000 series were chosen for the crashbox, since it matched both the stiffness and strength that were wished for the crashbox. Volvo also uses the aluminum 6000 series in their current crashbox.

8.2 Testings of our virtual prototypes

Computer Aided Engineering, also called CAE, is an valuable tool for this development. In this tool, the virtual prototype were imported and crashed. This did not just save us a lot of money and time, it also showed us very important diagrams. As user of this software, you are able to choose what you want the software to show you. In Figure 41, we had force vs time, where the force is on the Y-axis and the stoptime is on the x-axis. Each of the lines represents one of the relevant designs. Each curve have a color and the curve's name is written in the figure with the same color. The curves has the same name as their structure had in Figure 40 in the previous section. As it is seen in Figure 41, the current crashbox with reinforcement, 5C in the Figure, can take higher forces than the current crashbox without reinforcement, Ref in the Figure. This causes damage on the side wide members, which means that they have to be changed. It is also seen in Figure 41 that none of the designs really matches the force on the current crashbox without reinforcement and at the same time matches the stoptime on the current crashbox with reinforcemt. We realised that in order to match both the force and the time, we had to make some modifications. These CAE tests where made in our computers at Volvo Cars.

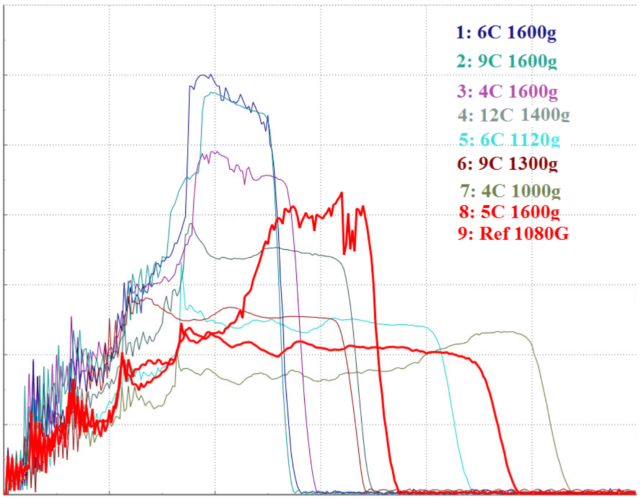


Figure 41: The virtual prototype CAE simulations, force vs stoptime

8.3 Last modifications on the Virtual prototype

Entering this stage with force and time in our minds, plenty of different designs with thicker inside walls than the outer walls were made. Eventually it resulted in a diagram, see Figure 42, that showed us better better results than the current one, but we were not satisfied. In Figure 42, we had force vs time, where the force is on the Y-axis and the time is on the x-axis. The curve that we got were not that even and because of that we decided to modify the design one more time. We changed the thickness of the walls again and ran the CAE-test. This time, a more even curve were conducted, see Figure 43, and the decision that this solution will be the Alpha prototype we made.

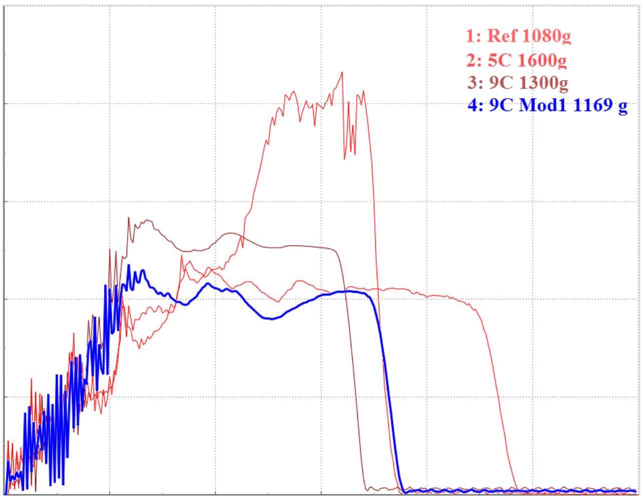


Figure 42: CAE simulation after the first modification, force vs stoptime

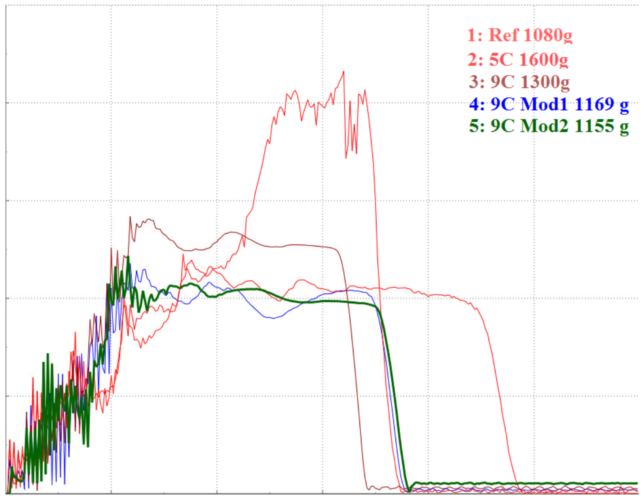


Figure 43: CAE simulation after the second modification, force vs stoptime

A new type of diagram was made, see Figure 44, for showing the force vs displacement, force on the Y-axis and displacement on the x-axis. It is seen in Figure 44 that Alpha has shorter displacement than the current one. Figure 45 shows the current used crashbox in Volvo XC40 with a red square that marks were the changes are made. Figure 46 is a description of solution principles along with design rationale and this is how our crashbox differs from the current one. Figure 47, shows our final prototype Alpha.

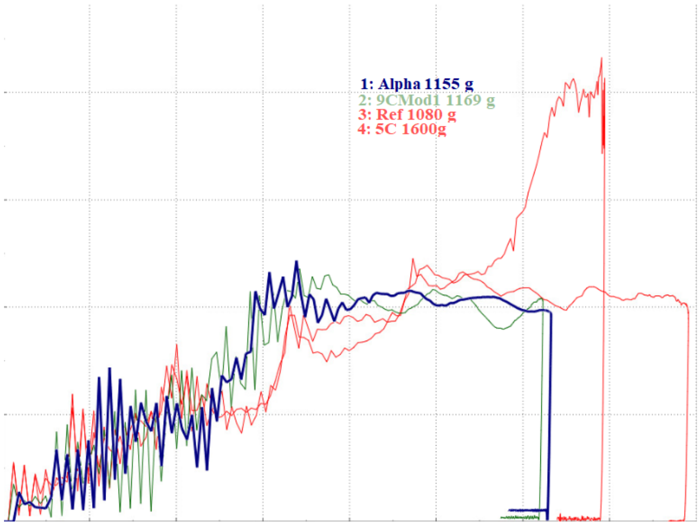


Figure 44: CAE simulation showing force vs displacement

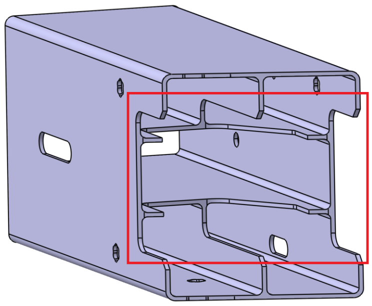


Figure 45: Current crashbox with a red mark were the changes are made

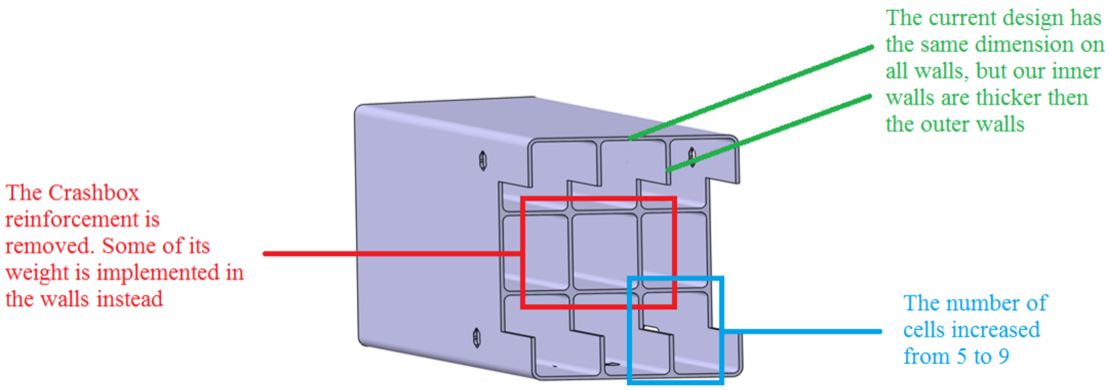


Figure 46: Alpha together with solution description

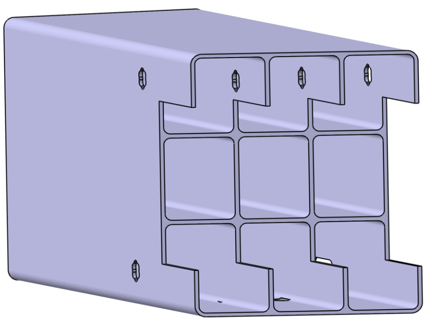


Figure 47: Alpha Prototype

The only problem found with this design is that the inner walls covers/overlaps the holes were other components e.g radiator support of the car will be fastened. This can be seen in Figure 48.

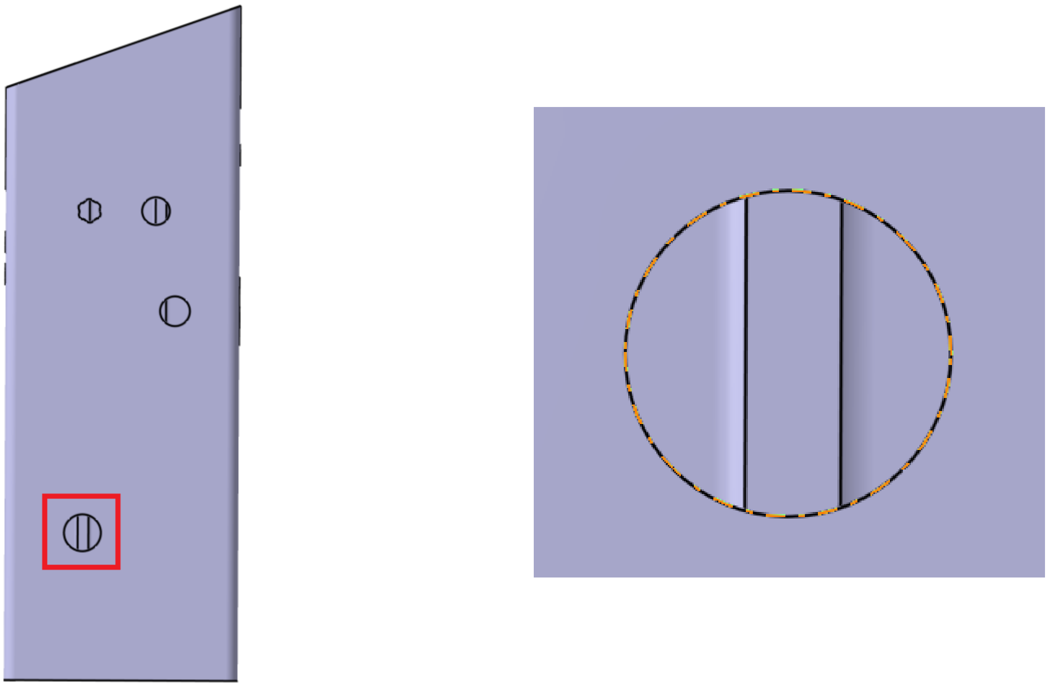


Figure 48: Inner wall overlapping component hole (left) and a closeup on the overlap (right)

8.4 Comparison of the markets CMS platforms

A Modified Aggregate Project Plan was created to increase understanding of our final concept's value from the consumer's perspective, based on level of technology applied to the product. In a normal aggregate project plan, a companies projects are inputted and compared to each other , but we had do modify it a little bit since we want to compare Volvo's CMS against the ones on the market. To compare the different CMS models , the table 3 were used with the different CMS models that were benchmarked in the beginning of this project. The CMS's from that list were used, because it includes the competitors CMS that are currently sold on today's market. The different CMS's will be positioned in the plan based on "Establishing Technology" and "Consume Value Perception" [32]. The scale used in the "Establishing Technology" goes from base model to radical change and the "Consume Value Perception" goes from no change to new core. The plan has four different areas and those are brand support, derivate, platform and breakthrough. This plan is called "Modified aggregate plan", because the traditional plan includes a comparison of the company's own project. A visualisation of the created plan is showed in Figure 49.

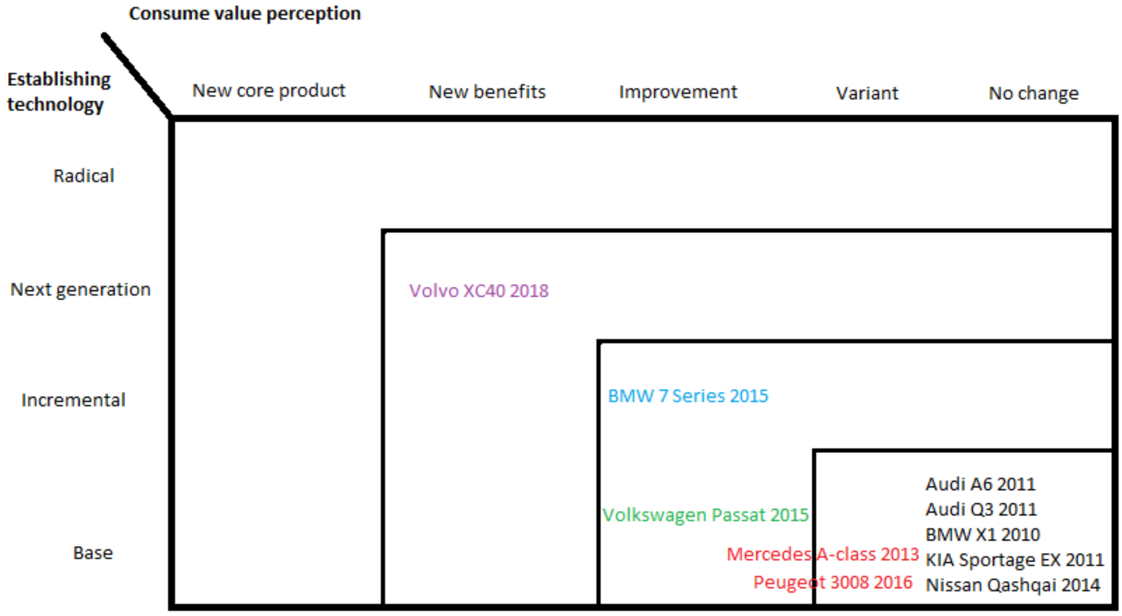


Figure 49: Modified Aggregate Project Plan

Before creating this plan, we had made a lot of benchmarking about CMS's that are out on the market. It was seen, already in the benchmarking process, that Volvo's CMS is up in the front. But getting this plan in front of us, made us realise how much Volvo is leading in technology in safety areas, for example the CMS. This plan also confirmed that this project do not need to create a whole new model of the CMS and that we just could develop the already existing CMS. This plan also proved that Volvo has been better when it comes to development of the CMS safety and the plan could be of value to show the customers. What makes Volvo stand out is their innovative solutions on the frontal bumper system that decreases the injuries and fatalities during overlap and full width crashes, this is a sign of next generation and new benefits creativity. However, seeing that many different companies having base technology shocked us and we had to look further into these results. The same base technology in cars from 2004 were found, which is 14 years ago and there is a possibility that it goes back even more.

8.5 Business Idea Identification

The idea of conducting an Business Idea Identification is to obtain and gain understanding of the commercial value for the chosen idea. By utilising this method the technologies that are used in this project are transformed into realistic customer needs. The method is based on, Properties, Users, Advantages, and Benefits that are related to the product idea. In this case the users are set to be Volvo as the CMS is not interacting with the end consumer physically and therefore not of interest for the end consumer as they in a safety context only expect Volvo to develop a safe family car. By defining properties related to technologies that are used in the product, the users that will benefit from the properties, Volvo Cars will increase their knowledge and understanding regarding the value that the CMS will offer. The Table seen in

Figure 50 represent the Business Idea Identification for the Cross product.

Properties	Volvo and Users	Advantage	Benefit
Can protect occupants in a crash	In hazardous conditions the occupants should be able to survive a crash whilst driving a Volvo XC40 by deforming well	The CMS will not work as an solid barrier and kill the occupants in both cars. This also includes ODB crashes	Improved safety standards
Can be used as base for outer parts	The manufacturer used the CMS as a base for attaching outer parts and cooling system	The CMS is no only functioning as protection but as a attachment base for other cars	Decreased number of parts by having the CMS as attachment base, money is saved and complex design are reduced.
Resistant to harsh environmental conditions	Consumer that will drive the car in harsh conditions outdoors	The conusmers could use the car in rain, snow and other weather conditions and offered the same of safety function from the CMS	The consumers will safe money in vehicle repair and service during usage
Easy to assembly	Manufacturer want to increase production	By having a good design the maufacturer will have it easier to produce more parts and systems	The assembly time is reduced and money is saved
Maximum two persons to install it	Manufacturers demands more efficient work by the employees	The employees will not need unnessecary manpower	The labour time is reduced and money is saved
Scalable system for different car models	Manufacturers want more efficient work by using the same system in many Volvo car models	The production is streamlined and more CMS are produced	Money are saved and work is modularised
Simplified construction design	Reduce overall production cost	Decreased overall car price	Gain more potential customer due to fair car prices
Lifespan, until deformation	The CMS is used for protection during crash and therefor has a infinite life span until deformation	The CMS will function as required by manufacturer unless deformation is a fact.	If no deformation, the life span is until the car is scrapped
Limited deformation in low speed crashes	Decreased manufacturing and development costs	The CMS is changed easily	The consumer will benfit from low repair costs as the CMS is replaceable
Light weighted product and produced in aluminium	The CMS will function for protecting and at the same time reducing the total weight of the car	Simplified design and reduced cost in the long term e.g environmental impacts	The driving range is improved and money is saved by the consumer

Figure 50: Business Idea Identification

As the need for a safe and cost friendly end product is needed on the market, Volvo can apply the Business Idea Identification for the defined properties, Advantages and Benefits. The property *Simplified construction design* is a good example of a benefit that the consumer is affected by. As the construction of the new CMS is simplified in some areas e.g the extra reinforcement inside the crashboxes and compensated in the thickness of the crashboxes instead. This will reduce the cost for manufacturing the thereafter the overall car price which can lead to increased market shares.

The minor changes are of importance as the competition on the market is tough, especially from big manufacturers as Audi, BMW and Mercedes. Volvo will increase their knowledge in their customers they need to define how the Cross CMS will give value to end consumers, following with a validation of the idea in order to make the product idea more robust and realistic. By conducting a Business Idea Identification will provide Volvo with information as, who will the customer for the total end product be, what is unique about this CMS and how is Volvo going to increase their revenue and market shares through the qualified and unique properties. By introducing a CMS in a new car the risk of failure is high in case lack of benchmarking and knowledge through methods.

The completed Business Idea Identification for the Cross CMS shows several properties that are related to safety and production whereas cost is an underlying factor. The technology used in the CMS is strongly related to safety requirements that need to be fulfilled in order to pursue Volvo's vision for the upcoming years. The end product is a Volvo car that is equipped with active safety functions but also passive functions, as the Cross CMS. The production related properties in the Business Idea

Identification refers to the ease the assemble the product to the car body during production by the workers. Manufacturing, Cost and Safety are technologies that have been included during the whole development process and also included in the final product, Cross.

8.6 Calculations of weight and cost savings

Component	**Current part weight (kg)**	**New part weight(kg)**
Reinforcement	0,991	0,991
Right Crashbox	1,07	1,155
Left Crashbox	1,082	1,155
Front bumper beam	2,5	2,5
Right Headlight support	0,1	0,1
Left Headlight support	0,1	0,1
Right Crashbox back plate	0,8	0,8
Left Crashbox back plate	0,996	0,996
Right Crashbox reinforcement	0,535	0
Left Crashbox reinforcement	0,434	0
Right Radiator bracket	0,075	0,075
Left Radiator bracket	0,072	0,072
Tow reinforcement	0,153	0,153
Screws	0,206	0,206
Total weight (kg)	**9,114**	**8,3**

Total weight reduction **0,814 kg = 8,93 %**

Figure 51: Weight calculations for the current Volvo XC40 CMS and the new CMS

Cost

Crashbox reinforcement:

Tools: 440 000 SEK

Component: 65 SEK/Car

Sales: 100 000 Cars/Year

100 000 x 65 + 440 000 = 6,94 MSEK/Year

Raw material

Total weight reduction: 8,93%

Aluminum: 18 SEK/KG

Sales: 100 000 Cars/Year

0,0893 x 18 x 100 000 = 160 740 SEK/Year

Cost savings **100 000 x 65 + 440 000 + 0,0893 x 18 x 100 000 = 7 100 740 SEK/Year**

Figure 52: Cost calculations for the crashbox reinforcement

9 Discussion

This chapter discusses the important aspects in the thesis regarding obstacles, methods and results.

9.1 Obstacles

The biggest obstacles that we faced were planning of meetings/interviews and handling the computer softwares. Before starting the project, we sat down for two weeks and made a plan. In this plan it was clear when every step in the project should be conducted. After the project had started, we realised that booking a meeting with engineers at Volvo Cars was not easy as booking a meeting with teachers at Chalmers University. At Chalmers we were used to book meetings a few days and maximum a week before, but at Volvo we had to book meetings at least two weeks before. This became a real problem when we came to the step "Crash sequence mapping", because when we tried to book a meeting with the interviewees just a couple of days before we wanted the interview them, but were rejected due to busy schedules a month ahead. Due to this we had to start creating functions, requirements but also concept and pick the top three among them without having deep knowledge about the crash sequence. The crash sequence was important to us since it would have described important steps during a crash that we could have thought of in the concept generation phase. As it is written in the beginning of the "Development of a final concept" phase, we had to make an important decision to only further investigate the crashboxes after gaining much more knowledge from the delayed interviews regarding crash sequence and structure.

We also had to deal with and learn different softwares both before and during the project. When we got the computers from Volvo we thought that every software that we needed would be available, but that was not the case. For every software that was important for the project, e.g Catia V5, we had to send in an application regarding access. It took us three to seven days before getting access to each software. This disturbed our plan, because when we for example wanted to conduct the simulations towards the project end, we had to apply for access and also create a specific account that is only used for the simulations. This paused our workflow since we were stuck and could not move on in another way. While waiting for access we wrote in our report instead, but that was not what we wanted to do while sitting at Volvo since that was a task to could be done from home. The application for access was not the only problem with the software. Time was also wasted when the software did not work properly and support was needed.

9.2 Methodology and Methods

This project's development process was planed to look like a waterfall. This way of working means that a product development phase is started and until that phase is completed, the next phase can not start. After we got to experience the difficulties of booking meetings and accessing softwares, we realised that this way of working can not be continued if we want to complete the work in time. Instead we implemented an agile way of working, were we could work with phases in parallel to each other. This was not optimal since we could not follow our plan completely, but had to be done. Another reason for this to not be optimal is that we got the interviews we needed four weeks later, which meant that the interviews were conducted after the creation of the top three concepts. The information given by the interviewees resulted in a decision to focus and only develop the crashboxes. If we would have possessed this information in the data collection, four weeks earlier, the result would have looked differently which will further be explained under "Results" in this chapter.

We thought that our development process through the whole project worked good and also the methods used. We would have skipped some methods, if we were employees at Volvo. The methods that we would have skipped are those that Chapter 1,2,4,5 and 6 provided. This, because of Volvo already had somebody who created this useful information in their data base where the developers just can access and get desired information from. If we would have got our interviews right on time, we think that we only would have created ideas for the crashboxes. This would have resulted in not wasting our time developing too many component concepts since we had limited of time.

A research in concept screening methods was also made and the ones we found were similar to the elimination, pugh and kesselring matrices we used, only the differed by method names. In that case, it was hard to pick other methods. If we were a bigger team with many experts from different areas, we could have skipped the screening methods and brought up the concepts one and one on a projector and explained their attributes. In this case, we would have been able to evaluate and score the different concepts while they shown on the projector. One method approach that we could have changed was the Pugh matrix. Since we did all three matrices without pausing, we felt that we got affected when conducting the second and the third matrix by the decisions in the previous matrix. If we would have done these three Pugh matrices again, a bigger time gap between them would have been used.

Our plan from the beginning included a life cycle assessment (LCA) and a failure mode and effects analysis (FMEA) of the Alpha prototype. Due to the desire to learn the CAE software and in order to understand the values that the CAE simulation provides we chose to skip these to methods. Other reasons for skipping the LCA and FMEA were that the current CMS was already made of aluminum meaning that Volvo already had conducted LCA analysis with good results. Beyond that one of the interviewees told us that learning the CAE software is a master thesis itself and that we therefore should focus more on the simulations in order to maximise the time we had left. Learning the CAE software basics took many hours, some days we worked more than eight hours per day.

9.3 Results

We are very happy with our results of this project, since our two biggest objectives were to reduce the weight and cost of the CMS and we managed to do that. We started with no specific percentage that our objectives should meet, but we would not have changed our way of working even if this would not be the case. This, due to the high expectations we had on ourselves and therefore we worked towards maximising the results of the project work.

We planned to make more simulations in different types and also a physical crash test but the time was not enough. A desire is to run simulations on the new CMS integrated in the car where full width and overlap tests are simulated but also a real physical crash test. As mentioned, we are very proud of our results but we do not know if our CMS works in all situations since we did not have time to run all the different types of simulations, but the ones conducted provides a good base for further development

We provided the Elimination matrix with our own touch. We think that the touch was really good for this project, since the matrix often only shows which concepts ideas pass and not. With our touch, the user will know exactly which ideas pass and which did not and also why since we added a comment for those concepts ideas. It is very important to know that the Elimination, Pugh and Kesselring matrices are based on our assumptions and that the chance of the results being completely the same if somebody does the same process is almost zero. It is also good to know that in this phase of the project, the specification of requirements were not completely stated. Because of this, the decision that were made were more subjective decisions that were based on our current knowledge about the work and the concepts. It must be emphasised that the concepts that were removed, were not completely deleted from the project. They were just not taken into consideration in the rest of the development process. It was important to use the results from these matrices as a guideline when choosing the final concept and not follow them blindly, because these results are partly subjective and estimations.

We made two basic prototypes, offset and full width, representing the top three concepts. The offset prototype was tested in a offset crash and it showed good results. It gave us a good insight of how our CMS could behave. The full width prototype was tested in a full width crash test and it got destroyed. We were not so happy about this result since we thought that it got destroyed because of the glue was not strong enough and that the person who stood on the wood plate on top of the prototype lost his balance. This caused an uneven distribution of force on the prototype. We think that the test would have showed better results if a machine would have applied forces on our prototype, since it would have distributed the forces better over the frontal bumper beam and the CMS.

The group took the decision to only continue developing the crashboxes after the delayed interviews. This was one of the most important decisions that we made, since we would not have been able to run simulations and make calculations if the development of the whole CMS continued. In that case, we think that we maximum could have provided some Catia V5 models. We also had some results from the CAE simulations that can be seen in the force vs time and force vs displacement diagrams. We found these simulations relevant as they also reflect the mechanical studies made in chapter 2, where the interest laid in the compressive stress. We were really proud of these values, but we were not proud of the color of the curves. If the reader pays attention to the colors on the curves, he/she will notice that the color of the curves that represents a specific prototype differs in Figure 42, 43 and 44. It would have been better if each prototype would have a specific color during all simulations.

In the end, everything resulted in a prototype Alpha that almost met all the requirements and desires. It did not meet one requirement and that was *Allow components to be mounted on the CMS.* It is the inner walls in the crashbox that covers some of the holes were other components are supposed to be mounted in. This was not a problem for us since it was of higher importance and interest to focus on the performance of crashbox and that it was not a problem if components could not be assembled on the crashbox. The importance was to get good values and that holes could easily be adapted afterwards, also stated by the engineers during the interviews.

10 Conclusion

The result of the project was focused on the crashboxes where the most potential of improvements existed, in line with the time limitation for this project. A satisfied and successful result has been showed and verified in simulations where the new and redesigned crashbox, made in 6000 series aluminium, is fulfilling all objectives stated in the beginning of the report. The specified requirements were also fulfilled except for one, *Allow components to be mounted on the CMS*. The following points states the improvements done in the new crashbox.

- Reduced total crashbox weight by 8,9%
- Reduced total crashbox cost by 7 MSEK/Year
- Improved recyclability and reuse for both crashbox and total CMS through material savings.
- Maintained attributes and improved safety, verified in simulations.

There have been many challenges during the project, most of them been related to simulations. One might believe that it is easy to redesign a crashbox (or complete CMS) and to perform good results with. It is not about designing a crashbox that is stiff as possible, it is mainly about balanced stiffness and softness. Therefore, the need to start balance requirements as, low cost, low weight, reasonable forces and short stop time during crash have to be found and that is challenging as the requirements are often fighting against each other. In combination with the five monthly time period of this master thesis, the challenge to perform more simulations for further improvements was challenging as the simulations phase is time consuming and a master thesis itself.

The academic and real life work are different from each other as the need to plan several weeks ahead is crucial. This, in order to conduct the interviews and meetings early making sure that needed information is received on time.

11 Recommendations for future work

Since our project time was limited, we could not manage to proceed with everything we wished for. The following bullet points are our recommendations for future work:

- In this project the crash simulations were performed with a barrier that was parallel to the crashbox. The next step would be to perform crash simulations with a barrier that is not parallel to the crashbox. This test will generate different data that could be helpful in further development of the crashbox.
- Crash simulations that includes the whole CMS and the whole car are needed.
- Some modifications of the crashbox holes need to be conducted since the holes of the new crashbox are covered by the inner walls.
- Further investigation of the other CMS components is valuable for reducing the cost and the weight of the CMS even more.
- Check with the supplier Constellium if the new developed crashbox is feasible to produce.
- In order to gather real crash data, a physical crash test on a Volvo XC40 including the new CMS is of interest.

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Appendices

A Functions means tree using CCM software

The software used to create a Functions Means Tree (FMT) is called CCM. The purpose of the process is to define and describe in a systematic way that the CMS does. The conducted FMT helps to define how different parts are interdependent from each other. This advantage will help to understand how and what parts need to be re-located or redesigned in later phases to generate innovative concepts.
The final FMT for the current CMS is presented in Figure 53 and 54, where both figures creates a whole FMT. The figures shows functions and solutions that are located and analysed in detail for the whole CMS. The top white box (to the left) is representing the entire CMS and therefore located on the top with multiple functions and solutions followed. Three colors are seen in the figure(s), where the blue boxes are representing *Functional Requirements* that are set for the current CMS. The yellow boxes represent *Design Solutions* that are solutions for the the previous functions. The green boxes located in the end of the FMT represent *Components* are representing different design solutions.

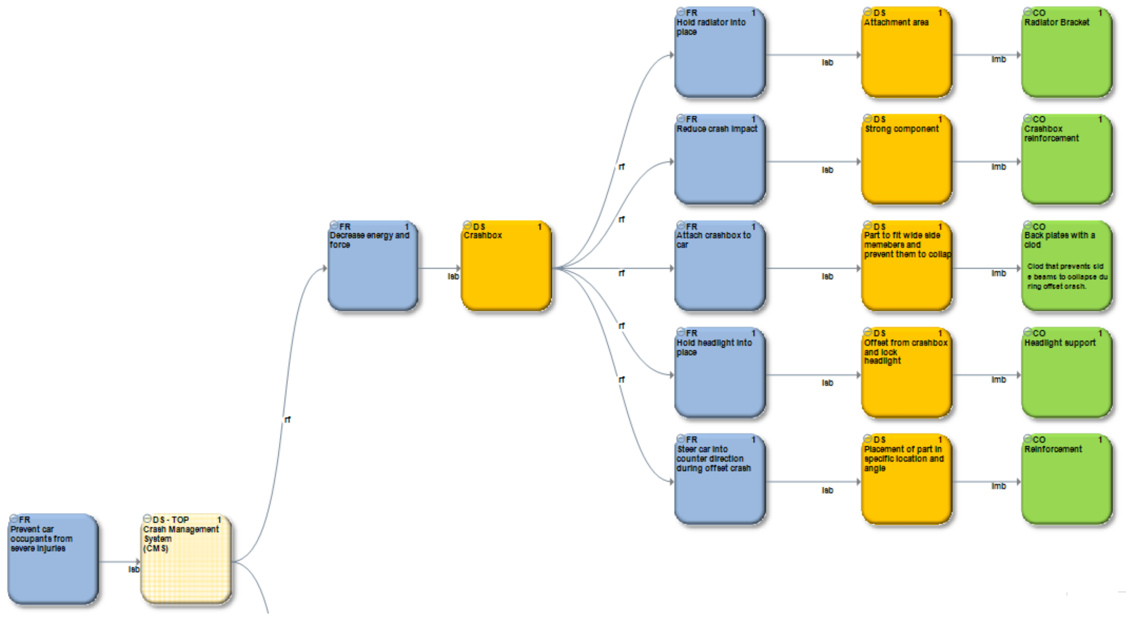

Figure 53: Close-up of upper part FMT

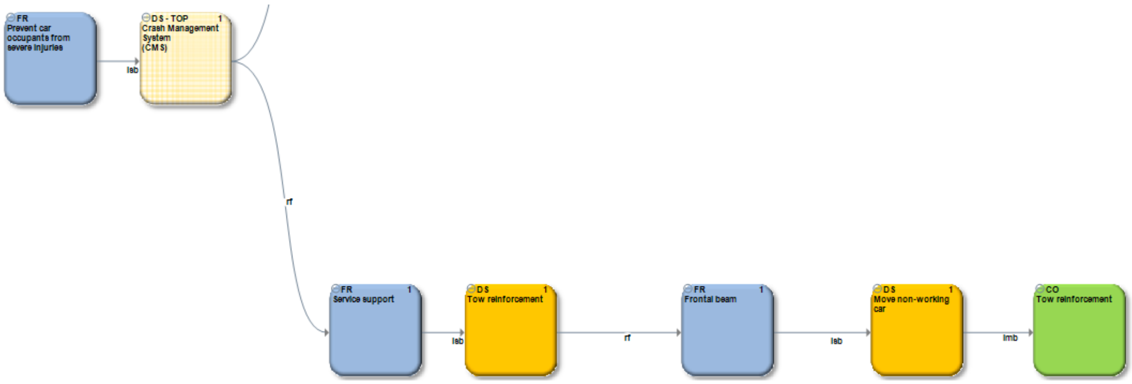

Figure 54: Close-up of lower part FMT

B Small overlap crash Barrier Design

The fixed barrier consists of a steel plate placed vertically with a radius on 115 degrees located on the right side edge, see Figure 53. The plate in the front has a thickness of 38,1 mm and is 1000 mm wide excluding the radius area. The width of the front barrier is wider than the back in order to avoid secondary contacts with the test vehicle during the crash and affecting the results. The barrier is 1524 mm high and placed on the floor and attached to a unit for rigidity, see Figure 56 . The height of the base unit is 1840 mm, 3660 mm wide and 5420 mm deep. The base unit consists of reinforced concrete and laminated steel with a mass of 145,150 kg. The fixed barrier is attached on the right side of the base unit in order to allow a continued car motion after the first contact with the fixed steel barrier. Depending if the test is a small overlap or moderate the front surface is different. If small overlap crash test the barrier surface contacting the vehicle first is made of steel and in moderate crash tests the front barrier is made of aluminium honeycomb.[15]

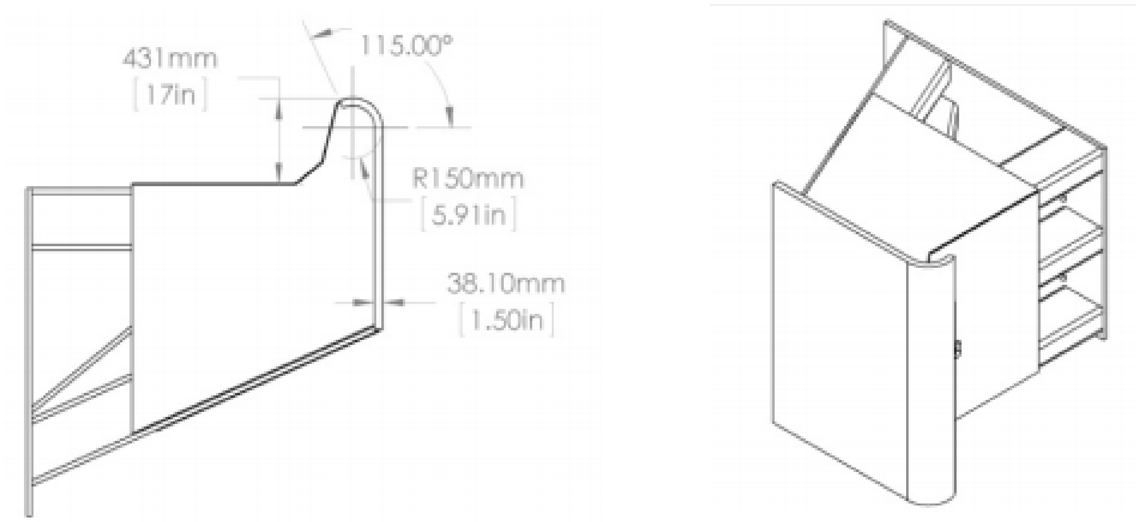

Figure 55: Top view of small crash barrier

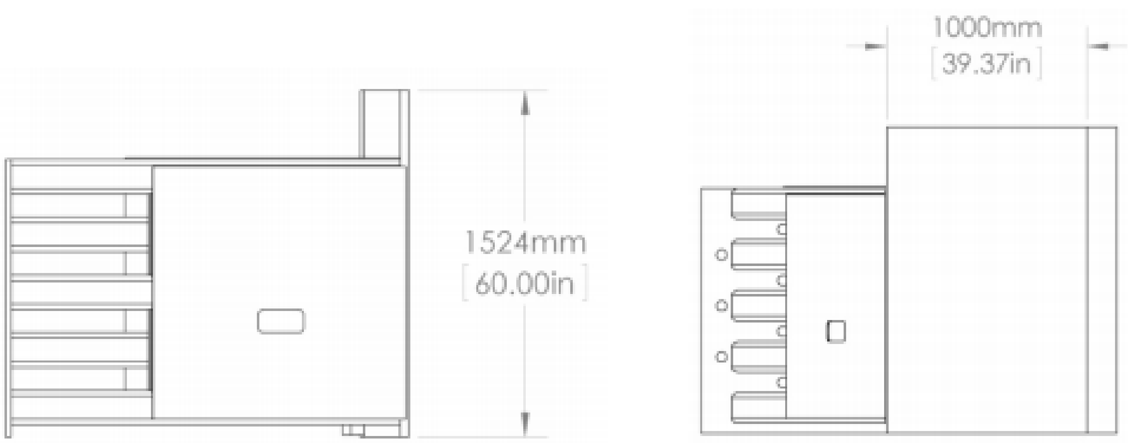

Figure 56: Profile view of small crash barrier

C Morphological matrix

The figure below shows an example of several component combinations conducted during the concept creating phase.

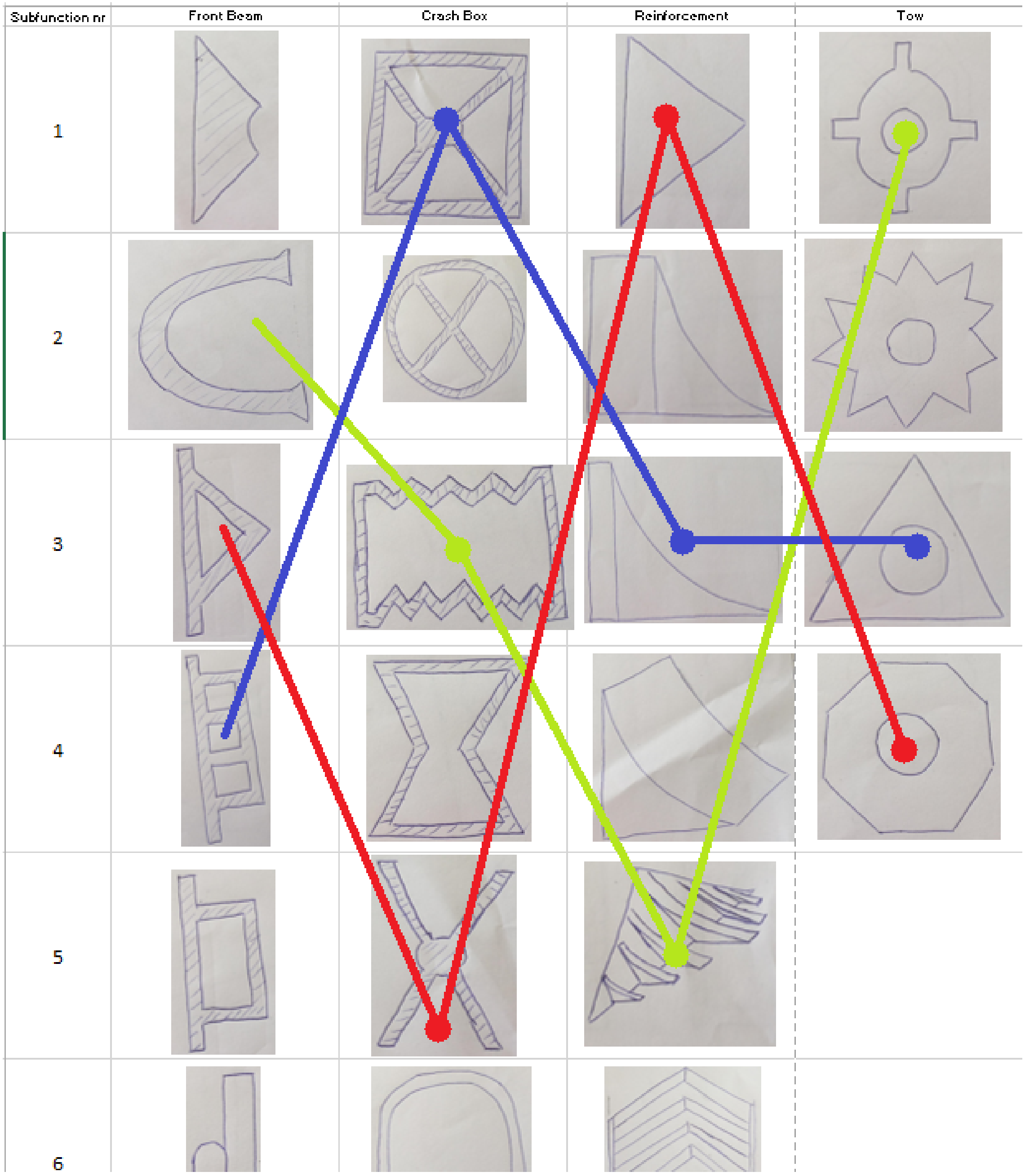

Figure 57: Component combination in morphological matrix

D Elimination matrix

Figure 58 and Figure 59 shows the final elimination matrix. Figure 60 shows eliminated ideas (red), passed combined concept (green), a list of which concepts that got passed the elimination matrix, which concept that were combined and final results.

Chalmers	**Elimination Matrix for** **Complete Solution Crash Management System Volvo XC40**
Created by: Johannes and Mergim	Created: 2018-04-23 Modified: 2018-04-24

Elimination Criteria	**Decision**
(+) Yes	(+) Continue work on solution
(-) No	(-) Eliminate solution
(?) Additional information requi	(?) Search additional information
(!) Control specification	(!) Control specifications
(M) Modifications	(M) Modifications desirable

A: Crash reliability
B: Weight
C: Cost
D: Stiffness
E: Recyclability
F: Realistic
G: Assembly
H: Manufacturing

No.	**Solution**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**Decision**	**Comment**
1	Pit triangle	+	-							-	Solid structure
2	U-shape	-								-	Widens during crash
3	Bow	-								-	Flattens during crash
4	Ladder	+	+	+	+	+	+	+	+	+	
5	One Rectangular	-								-	Flattens during crash
6	Ball Wall	+	+	+	+	+	+	+	+	+	
7	Eight	+	+	+	+	+	+	+	+	+	
8	Two rectagular	+	+	+	+	+	+	+	+	+	
9	Multipe rectangular	+	+	+	+	+	+	+	+	+	
10	Knife	+	+	+	+	+	+	+	+	+	
11	X-rectangle	+	+	+	+	+	+	+	+	+	
12	X-circle	+	+	+	+	+	+	+	+	+	
13	Wave rectangle	+	+	+	-					-	Not well structured

Figure 58: Part 1 elimination matrix

14	Hourglass	+	+	+	+	+	+	+	+	+	
15	X-shape	-								-	Not realistic and reliable
16	Cicle	+	+	+	+	+	+	+	+	+	
17	Robot face	+	+	+	+	+	+	+	+	+	
18	Suicide doors	+	+	+	+	+	+	+	+	+	
19	4-windows	+	+	+	+	+	+	+	+	+	
20	Peace	+	+	+	+	+	+	+	+	+	
21	Octangon	+	+	+	+	+	+	+	+	+	
22	Blocks	+	+	+	+	+	+	+	+	+	
23	3-LongDoors	+	+	+	+	+	+	+	+	+	
24	Current	+	+	+	+	+	+	+	+	+	
25	Banana	-								-	Weak structure
26	Triangle	+	+	+	+	+	+	+	+	+	
27	ThickerRamp	+	-							-	Solid structure
28	ThickRamp	+	+	+	+	+	+	+	+	+	
29	Ramp	+	+	+	-					-	Crack varning
30	SkeletonRamp	+	+	+	+	+	+	+	+	+	
31	TriangleRamp	+	+	+	+	+	+	+	+	+	
32	SpringRamp	+	+	+	+	+	-			-	Darling/not reliable
33	Sight	+	+	+	+	+	+	+	+	+	
34	Star	+	+	+	+	+	+	+	+	+	
35	TriangleHole	+	+	+	+	+	+	+	+	+	
35	HectagonHole	+	+	+	+	+	+	+	+	+	

Figure 59: Part 2 elimination matrix

Concept Nr	Front Beam	Crashbox	Reinforcement	Tow
1	1	1	6	3
2	2	3	5	3
3	3	8	5	2
4	4	14	7	1
5	5	7	6	1
6	6	6	6	2
7	7	13	4	4
8	8	1	1	1
9	9	6	5	2
10	10	5	4	3
11	5	6	5	1
12	1	7	7	3
13	9	12	6	3
14	7	5	1	1
15	8	2	3	1
16	2	2	2	2
17	5	15	5	1
18	8	11	5	4
19	7	10	6	3
20	3	4	2	3
21	3	8	5	1
22	10	9	7	4
23	8	14	3	3
24	6	5	4	3
25	5	8	5	1

Concept Nr Passed
6
8
9
13
15
18
19
23

Combined Concept
A: 8, 15 and 23

Final result
A
6
9
13
18
19

Figure 60: Eliminated concepts and combined ones

E Pugh matrix

Figure 61, Figure 62 and Figure 63 shows three different pugh matrix iterations, every iteration with a different concept as reference.

Chalmers	Pugh Matrix - First iteration					
Created by: Johannes and Mergim	Created: 2018-04-25					
	Modified: 2018-04-25					
	Alternatives					
Criteria	A	6	9	13	18	19
Compatible with other OEM CMS	Reference	-	0	+	0	0
Force absorbation		-	-	+	0	0
Assembly		-	-	0	0	0
Stiffness		-	-	+	0	0
Crash		-	0	-	0	0
Manufacturing		+	+	-	-	0
Size		0	0	0	0	0
Weight		+	+	-	0	0
Cost		+	+	-	-	0
Sum +	0	3	3	3	0	0
Sum 0	0	1	3	2	7	9
Sum -	0	5	3	4	2	0
Net Value	0	-2	0	-1	-2	0
Ranking	1	6	1	4	6	1
Further Development	Yes	No	Yes	Yes	Yes	Yes

Figure 61: First pugh matrix iteration

Chalmers	Pugh Matrix - Second iteration					
Created by: Johannes and Mergim	Created: 2018-04-25					
	Modified: 2018-04-25					
Criteria	Alternatives					
	A	6	9	13	18	19
Compatible with other OEM CMS	0	-	-	Reference	0	0
Force toleration	-	-	-		0	-
Assembly	0	-	0		0	0
Stiffness	-	-	-		0	-
Crash	0	-	-		0	0
Manufacturing	+	+	+		0	+
Size	0	0	0		0	0
Weight	+	+	+		0	+
Cost	+	+	+		0	+
Sum +	3	3	3	0	0	3
Sum 0	4	1	2	0	9	4
Sum -	2	5	4	0	0	2
Net Value	1	-2	-1	0	0	1
Ranking	1	6	5	3	3	1
Further Development						

Figure 62: Second pugh matrix iteration

Chalmers	Pugh Matrix - Third iteration					
Created by: Johannes and Mergim	Created: 2018-04-25					
	Modified: 2018-04-25					
Criteria	Alternatives					
	A	6	9	13	18	19
Compatible with other OEM CMS	0	-	-	+	+	Reference
Force toleration	0	-	-	+	+	
Assembly	0	-	0	+	0	
Stiffness	+	-	-	+	+	
Crash	+	-	-	0	0	
Manufacturing	0	+	+	-	-	
Size	0	0	0	0	0	
Weight	0	+	+	-	-	
Cost	0	+	+	-	-	
Sum +	2	3	3	4	3	0
Sum 0	7	1	2	2	3	0
Sum -	0	5	4	3	3	0
Net Value	2	-2	-1	1	0	0
Ranking	1	6	5	2	3	3

Figure 63: Third pugh matrix iteration

F Kesselring matrix

The kesselring created for finding top three rated concept is seen in Figure 64

Section of criteria	Weight	IDEAL Rating	IDEAL Weighted score	Concept A Rating	Concept A Weighted score	Concept 9 Rating	Concept 9 Weighted score	Concept 13 Rating	Concept 13 Weighted score	Concept 18 Rating	Concept 18 Weighted score	Concept 19 Rating	Concept 19 Weighted score
PERFORMANCE													
Force absorbation	5	5	25	4	20	2	10	5	25	5	25	3	15
Accurate Stiffness	5	5	25	4	20	2	10	2	10	3	15	5	25
WEIGHT													
Structure	4	5	20	4	16	5	20	3	12	3	12	5	20
MANUFACTURING EASE													
Low complexity of parts	4	5	20	5	20	3	12	2	8	4	16	4	16
CRASH PROTECTION													
Small overlap crash	5	5	25	5	25	3	15	3	15	3	15	3	15
Moderate overlap crash	5	5	25	5	25	2	10	4	20	4	20	5	25
Full width front impact	5	5	25	5	25	3	15	4	20	4	20	4	20
MAINTENANCE													
Low water accumulation	2	5	10	3	6	5	10	2	4	2	4	3	6
AESTHETICS													
Level of innovation	3	5	15	2	6	3	9	4	12	4	12	5	15
Total		45	190	37	163	28	111	29	126	32	139	37	157
Relative total		1	1	0,8	0,9	0,6	0,6	0,6	0,7	0,7	0,7	0,8	0,8
Average		5,0	21,1	4,1	18,1	3,1	12,3	3,2	14	3,6	15,4	4,1	17,4
Deviation		0,0	4,3	0,8	5,9	0,8	2,9	0,9	5,3	0,7	4,3	0,8	4,5
Median		5	25	4	20	3	10	3	12	4	15	4	16
Rank		IDEAL		1		5		4		3		2	

Rank	Concepts
1	A
2	19
3	18
4	13
5	9

Figure 64: Kesselring matrix

Modeling of Front Bumper system with emphasis on lightweight and low cost

A product development project at Volvo Cars

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