Development of a new oil pan

Utveckling av ett nytt oljetråg

Degree project for Mechanical engineering

Oscar Hermansson
Mona Najib

The department of Industrial and Materials Science
Chalmers University of Technology
Gothenburg, Sweden 2020

EXAMENSARBETE 2020

Development of a new oil pan

Utveckling av ett nytt oljetråg

OSCAR HERMANSSON
MONA NAJIB

The Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

Development of a new oil pan
Degree project for Mechanical engineering

OSCAR HERMANSSON
MONA NAJIB

Advisor and Examiner: Gert Persson, the Department of Industrial and Materials Science

The Department of Industrial and Materials Science

CHALMERS TEKNISKA HÖGSKOLA

SE-412 96 Gothenburg

Sweden

Telephone: +46 (0)31 – 772 1000

Gothenburg, Sweden 2020

Acknowledgements

This degree project was conducted through ÅF at Volvo Trucks in Gothenburg and the department of Industrial and Materials Science at Chalmers University of Technology. It is the finishing project of the three-year mechanical engineering education with specification mechanical design.

We would like to thank our supervisor at ÅF, Emil Pettersson, for his unending patients and for always answering questions even while deep in thought. Without your guidance and calm statue this experience would most likely have been terrifying. The same thanks goes to Lena Larsson, the client, who has also acted as a supervisor at Volvo Trucks during the project, your enthusiasm and ingenuity gave us energy and inspiration when the days were tough.

Neither will we forget the team at ÅF, especially Emil Olsson and Per-Axel Olsson, for their help and great company. Thomas Gatenberg and Lennart Cider were invaluable resources for the project, and it is good to see that Volvo trucks is likeminded in that regard.

We would also like to thank our supervisor at Chalmers, Gert Person, for keeping everyone in your vicinity realistic. It has most definitely been invaluable.

Both of us has grown from this experience and hope you’ve all done the same.

Abstract

The High Capacity Transport project started in 2009 with the idea that larger amounts of goods could be transported by every truck currently in deployment in Sweden, effectively reducing the CO_2-emissions from each ton transported. To accomplish this, many different companies, universities, research institutes as well as the government were involved to secure the necessary expertise and backing.

One thing done to increase the capacity of the truck was to lower the chassis to expand the loading volume. This reduction of clearance has put the oil pan to close to the ground and caused the unwanted consequences of impacts and scraping during runtime. To solve this issue the High Capacity Transport division at ÅF in conjunction with Volvo Trucks established a degree project with the aim to design a more durable oil pan.

The methodology included several product developments methods, such as a customer needs analysis to establish the requirements for the oil pan, an internal and external benchmarking to gain information of existing oil pans and inspiration for the concept development process. Those concepts were later evaluated and grated based of the earlier stated requirements and the result yielded a redesigned oil pan that, with additional confirmation, could serve as a viable solution to the issue.

Sammanfattning

High Capacity Transport projektet startade 2009 med idéen att större kvantiteter kunde transporteras av samtliga lastbilar som körs i Sverige, vilket skulle reducera utsläppen av CO_2 relativt varje ton gods som transporterats. För att uppnå målet har många olika företag, universitet, forskningsinstitut samt regeringen involverats för att erhålla den nödvändiga kunskapen och kapitalet.

En modifiering utförd för att utöka lastbilens kapacitet var att sänka chassit för att öka lastvolymen. Denna reduktion av frigång satte oljetråget för nära marken vilket orsakade, de oönskade konsekvenserna, stötar och skrapningar under körtid. För att lösa det här problemet etablerades ett examensarbete av High Capacity Transport avdelningen hos ÅF tillsammans med Volvo Trucks med målet att konstruera ett mer tåligt oljetråg.

Genomförandet inkluderade flertalet produktutvecklingsverktyg såsom en kundundersökning för att etablera oljetrågets krav, en intern- och extern marknadsundersökning för att samla information om det existerande oljetråget samt inspiration inför konceptgenereringsprocessen. De koncepten utvärderades och betygsattes senare baserat på de tidigare ställda kraven och detta resulterade i ett omkonstruerat oljetråg som, med vidare bekräftelse, kan vara en fungerade lösning till problemet.

List of Figures

List of Tables

Table of Contents

1. Introduction

1.1 Background

Truck drivers and the haulage contractors they work for are highly dependent on their vehicles continued performance. This is especially true for the logging industry were the FH16 truck's is widely used for transport of low value goods in great quantities. The transports are over shorter distances but harder terrain which is the norm. One of the difficulties of this terrain is the presence of debris, such as larger rocks, which damages the oil pan of the truck. Also, during the shift from winter to spring, dirt roads lose their hardened nature due to thaw (Trafikverket, 2019) creating a ridge in the middle of the road (Alzubaidi, 1999) which scrapes the bottom of the oil pan. The scrapes from the roads ridge and impacts from debris on the road creates cracks, scratches and in some cases holes, see figure 1 and 2.

Figure 1 - Broken D16 oil pan, hole.

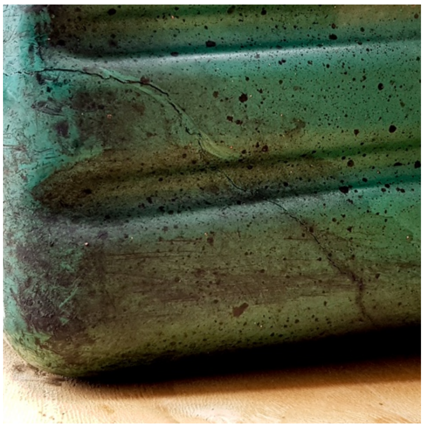


Figure 2 - Broken D16 oil pan, crack.

In worst case, these issues could cause a total engine failure due to the loss of oil. This issue exists from two ends, the first being that the road that is provided by the lumbering companies for the haulage companies is of insufficient quality, the second being that the oil pan is of insufficient quality for the terrain it is to sustain in. The issue that Volvo Group can solve is the second one.

Volvo has tried to ease the symptoms by adding a steel skid plate, see Figure 5 and blueprint in appendix A, underneath the oil pan to protect it, but the main problem is still unresolved. As of now, the oil pan, see Figure 3 and blueprint in appendix B, is the largest weak point in the design of the D16 engine as it is a supporting component and is causing mayor issues. This is because it's made from a plastic SMC, sheet molding compound, reinforced with glasfiber while the oil pan for the D13 engine for this terrain, see Figure 4 and blueprint in appendix C, is made from deep drawn sheet steel. The plastic oil pan does have advantages due to its low manufacturing cost as well as its lower weight.

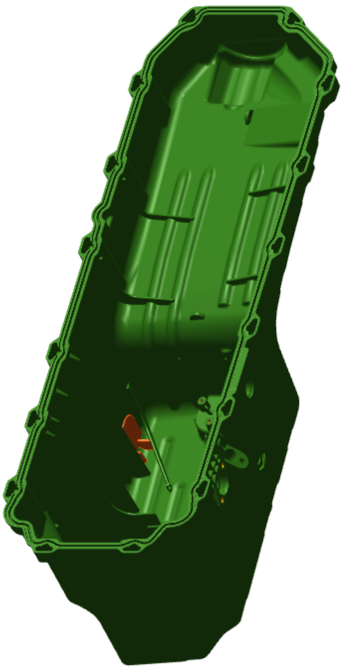


Figure 3 - D16 Plastic oil pan, reproduced with permission from Volvo group.

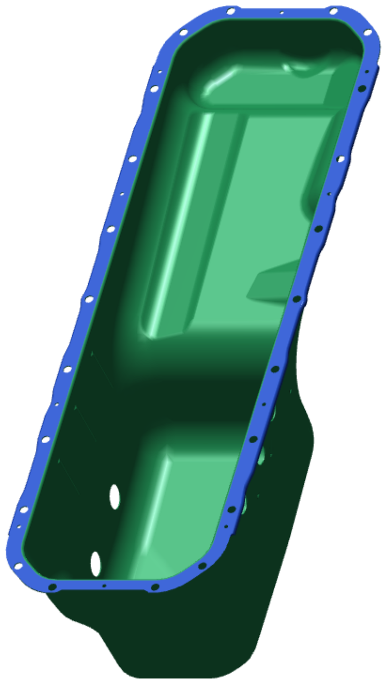


Figure 4 - D13 Deep drawn steel oil pan, reproduced with permission from Volvo group.

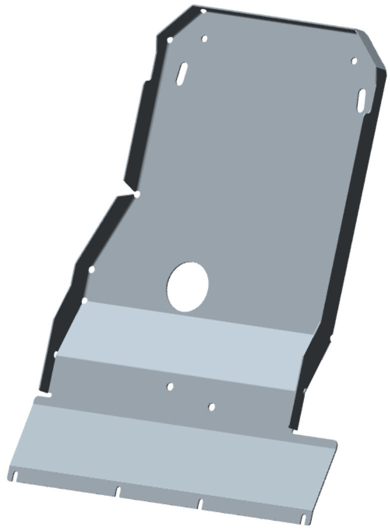


Figure 5 – D16 Protective skid plate, reproduced with permission from Volvo group.

Raising the clearance of the truck would be one option, but as Sweden has an upper clearance of 4.5 meters (Trafikverket, 2011) this would mean that the volume of load would be less. Also, raising the clearance would raise the center of gravity compromising on the capability of the truck to stay firmly on the road.

Another solution would be to reposition the oil pan to a less exposed area of the engine compartment but for that to be a viable option major redesigns of the entire truck would be necessary.

The goal of this degree project is to design an alternative oil pan that would not require mayor redesign of existing components nor lower the clearance, and which could stand up to the harsh demands of the environment the trucks are enduring.

1.2 Purpose

The purpose of this project is to analyze the cause of failure in the product due to accidents and use the various methods of product development to solve those issues. After the analysis, different concepts will be generated and through concept evaluation methods the optimal solution will be chosen for continued development.

A completed project would entail a suggestion for a functional redesigned oil pan which would be compatible with the existing skid plate. The skid plate would only be used in harsher environments to complement the added protection of a tougher oil pan.

1.3 Limitations

The project will focus on the design of the oil pan to generate a more durable product to reduce the number of failures.

Consideration of adjacent components will be taken to limit the project to the oil pan with only minor modifications to surrounding components.

Due to the project's timeframe, only light cost calculations will be produced as well as a light manufacturing method analysis. No physical prototype will be produced, only a virtual prototype.

1.4 Problem statement

Main question:
How should an oil pan with better durability be designed?

Subquestions:
How is today's oil pan designed?
Is it the design or simply the material choice that is the cause of failure?
What is the new oil pan allowed to cost to manufacture?

2. Technical background

This chapter contains information that is needed to fully understand the report.

2.1 The HCT project

HCT stands for High Capacity Transport and is a project located under the platform CLOSER. CLOSER is dedicated to making the transport sector more efficient by offering a neutral platform of communication for universities, research institutes, businesses and various levels of the government (CLOSER, n.d.).

The HCT project officially started 2007, see interview with HCT profile Lennart Cider in appendix D, although there were other projects under other names already in the process earlier. They were all combined into the HCT project with different companies, municipalities, research institutes and governments involved (CLOSER, n.d.).

The concept surrounding this part of the HCT project is concerning the length and weight restrictions currently in place for trucks. The current calculations for a products CO_2-emissions from transport can be reduced if the truck was allowed to carry more product per shipment and thereby reducing the transport emissions for the individual product. This has been achieved by increasing the volume that the truck is able to carry through, among other things, reducing the clearance of the truck. This is what causes the increased wear and damage to the oil pan as it is closer to the road. Both great and modest modifications have been made to the different test vehicles for the project to increase maneuverability and safety so that the longer as well as heavier truck does not perform worse than the trucks driving under existing laws.

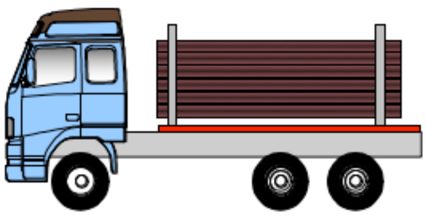


Figure 6 – Principal truck with normal clearance.

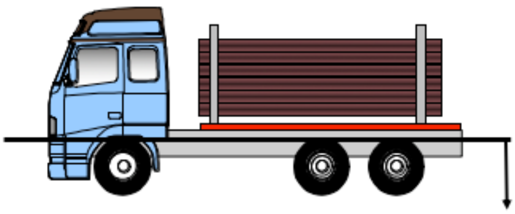


Figure 7 - Principal truck with reduced clearance.

The government's involvement is crucial for these types of projects as it is the authority which grants test vehicles the right to be driven on the current roads. It is also the sole authority when it comes to incorporating new regulations concerning the transport industry.

2.2 Driving conditions

Volvos trucks drive in different kinds of terrain that Volvo grades smooth, rough and very rough, see terrain specification in appendix E. The truck's design varies depending on the terrain (Volvo Lastvagnar Sverige, n.d.). The trucks that drives in smooth terrain for example, asphalt roads, has a lower clearance over the road than the trucks that drives in very rough terrain, gravel and forest road.

2.3 Product specifications

The product specifications below describe the oil pan and the compatible protection skid plate that is standard for the trucks driving in very rough conditions.

2.3.1 The D16 engine

The D16 engine, see Figure 8, is currently the largest engine that Volvo Trucks offers for commercial haulage companies. It exists with several different specifications ranging from 550 hp to 750 hp (Volvo Lastvagnar Sverige, n.d.).

The engine utilized mostly in the HCT project is the D16K750 with 750 hp and is the biggest of the engines.

Figure 8 - The D16K750 engine, reproduced with permission from Volvo group.

2.3.2 The oil pan

The oil pan is a container and is, in the case of the D16 engine, located directly underneath the truck's engine, see Figure 8 above. The oil pan's main purpose is to provide the engine with oil for lubrication and cooling (Hellsten & Pettersson, 2018). Inside the oil pan is an oil sensor, see Figure 9 notation 1 below. It measures the temperature of the oil and the oil level. The oil sensor is logging information continuously so that the driver can be notified if needed, see questionnaire with mechanics in appendix F. You will also find a tap hole inside the oil pan which is located on the bottom for oil changes, see Figure 9 notation 2 below.

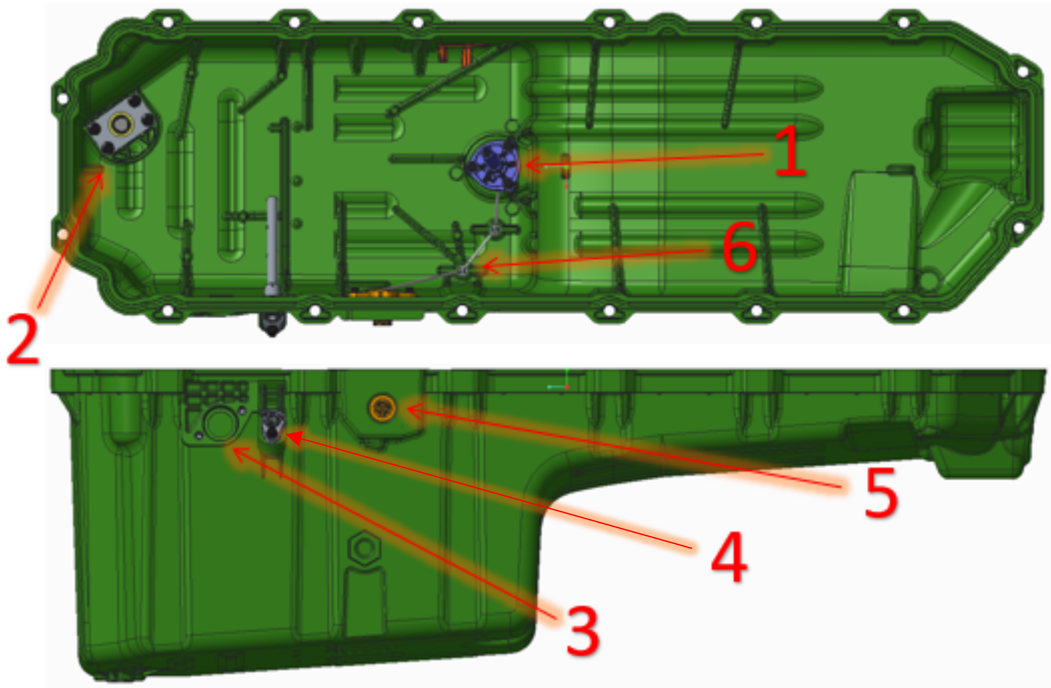


Figure 9 - D16 oil pan with details, reproduced with permission from Volvo group.

On the right side of the oil pan there are three entries, one for refill of oil, one for a manual oil measuring stick and the last one is an output for a cable, which has two mounts, one on either side, see Figure 9 notation 3, 4 and 5 respectively. The cable is connected to the oil sensor inside the oil pan, see Figure 9 notation 6, and is then fed through the output so that information from the oil sensor is sent to the driver.

Fixed to the engine is a suction tube that goes inside the oil pan and down to the bottom. The tube is connected to a pump which is mechanically driven, the faster the engine goes the faster the pump pumps up the oil as the pump is driven by a gear transmission. At the end of the suction tube is an oil filter that is designed as a very basic metal mesh.

Inside the oil pan there is a max input of oil which is limited by the refill hole but, as the engine is running, about a third of the oil is circulating the engine, so the oil pan is never completely full. Therefore, the suction tube needs to be so close to the base of the oil pan as possible, to avoid a temporarily stop of oil flow to the engine which could cause engine failure.

2.3.3 The skid plate

Because of the uneven road conditions when driving in very rough terrain, see terrain specification in appendix E, the oil pain, that now exists, is complimented with a skid plate, see Figure 5, to protect the oil pan from direct impacts and scrapes. This skid plate is not applicable for the trucks that drive in smooth terrain due to the lower clearance, if mounted it will cause impacts to the oil pan with every road bump in the way. The skid plate is mounted to the chassis and can be assumed to compliment all oil pans in very rough terrain even after this projects redesign of the oil pan.

One issue that has come with the skid plate is that gravel finds its way between the oil pan and the skid plate. Because the engine itself is not rigidly mounted and moves up to 2 cm in height, the small gravel starts to wear out the oil pan. The gravel comes into the space through a hole in the skid plate that is used to change the oil in the oil pan, see figure below. A lid has been added to the design but has not reached production yet.

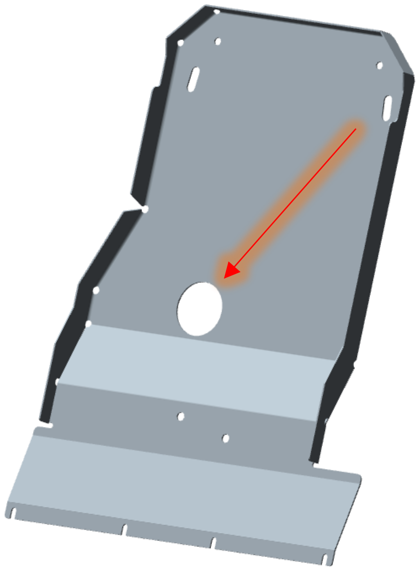


Figure 5 - Skidplate with added indication, reproduced with permission from Volvo group.

The mechanics are supposed to remove the whole skid plate when changing oil in order to also remove the small gravel that has gotten stuck since the last oil change. This is not implemented because of the extra time consumption that occurs when disassembling and assembling the skid plate. Right now, very few trucks drive with the skid plate due to the wear of the oil pan from the small gravel.

2.4 CES EduPack 2018™

In this project, an analysis to determine the choice of a material and manufacturing process was included. To get closely comparable values, a comprehensive database of information regarding different materials and manufacturing processes was used, in this case CES Edu Pack 2018™.

CES EduPack™ provides a comprehensive database because it depicts many commercial engineering materials which ensures the user that almost all possibilities for any application has been suggested. Also, CES EduPack™ has a strict database design where each material is only represented once with its properties ranging because of different manufacturer and different batches (CES EduPack software, 2018). References is given for each sheet of data to enable the user to further investigate the information given by CES EduPack™.

CES EduPack™ consist of different databases for the user to choose from depending on the user's educational level. There is Introductory – Level 1 and 2, as well as Advanced – Level 3. For this project, level 2 was used as it is the highest level used previously during the education. CES EduPack™ is continually developed based on feedback from the global user community.

3. Methodology

The following chapter presents the different stages of the degree project was performed in chronological order.

3.1 Research

Before the research part of the project could begin a list of contacts was established. In the following subheadings you will read about the process for the literature search, benchmarking and the customer needs analysis.

3.1.1 Literature search

The literature search was performed to obtain a greater understanding of the product and its uses but also to see if any degree projects, or bachelor theses, had been done in the specific or adjacent areas before that could be utilized in this degree project.

Research was also done on Volvo trucks intranet to better understand the position and implementation of the oil pan and the different versions used for both the FH13 and FH16 trucks. Included in this part was an overview of Volvo group and its affiliates to achieve a greater understanding of which companies that could be used for expertise and advice.

3.1.2 Benchmarking

The benchmarking was divided into internal and external benchmarking. The internal benchmarking aimed to establish if Volvo trucks had any solutions for some other truck models or older models. This involved talking to experienced engineers and mechanics.

The external benchmarking consisted of two parts were the first one was to meet with the team of engineers, at Volvo Trucks, that performs benchmarking on products on the open market. The second part was to talk to other companies to see if they had the same or similar problems with either clearance or subpar quality in their oil pans.

3.1.3 Customer needs analysis

A customer needs analysis was performed to establish the current thoughts about and problems with the existing oil pan. In the first stage of the customer needs analysis, contacts where sorted into groups before developing the questions. These groups were created to ease the process of establishing questionnaires, so that each individual was asked similar questions to give comparable results.

The questions where based mostly to answer the degree projects main question, "*How should an oil pan with better durability be designed?"*, which can be answered by the response to the question, *how does the oil pan break today*? With that in mind, phone interviews with drivers and owners of haulage contractors where held.

Interviews were also held with the supervisor from ÅF and the client from Volvo as well as mechanics with experience of the oil pan. Finally, meetings with the department responsible for the oil pan and the geometry architect engineer responsible for the surrounding components were held.

It was important that both the company and the users could express their concerns to arrive at a better solution.

The last stage involved summarizing the answers and, in some cases, individuals were contacted again for further questions that had arisen on the way.

3.2 Specification of requirements

From the research involving literature search, benchmarking and customer needs analysis a specification of requirements was developed. It contains criteria that were gained partly from customer's opinions regarding the development of the oil pan but also from raised issues with the oil pan. Criteria were also gained from the product description which explains the functions of the oil pan and therefore also gives what the developed oil pan must be able to do.

After all criteria were stated they were specified, in a column, as either a demand (D) or a wish (W). Each wish was rated in a scale from 1-5 were 5 indicates the highest priority. The ranking each wish gained was based on the customer analysis and a demand always has the ranking 5. Columns that contains the authority of standard, whom confirms the criteria for each criterion, and method of verification, which shows what mean to use to verify if the criterion is fulfilled or not, were also added.

3.3 Development of concepts

In the following text the different stages that were involved in the development of the concepts are presented.

3.3.1 Functional analysis – Black-box

A functional analysis was performed to build a perception of and to easier understand what the oil pans functions are. A functional analysis can look different depending on the chosen method and in this project a black-box analysis was chosen. It depicts a product's, one or several, main functions and its subfunctions.

To work out the main function and subfunctions for the oil pan the product description, see page 5, was the main source. From that description the oils pathway in, through and out of the oil pan was drawn up and after that different functions could be sorted out. The figure of the oil's pathway combined with the subfunctions later became the black-box image of the oil pan.

3.3.2 Brainstorming

When the functions of the oil pan were determined, the generating of concepts could begin. This was divided into two parts where the solutions were developed first and then combined into concepts. The process of the two parts are described below.

3.3.2.1 Brainstorming solutions

The first step of generating solutions began with a silent brainstorming. For about 15-20 min, each group member sat down and sketched on different and simple solutions that would solve the main issue. After the time was up a discussion began about the solutions at hand and from that discussions more solutions were developed. The solutions that were developed consisted of smaller changes to the oil pan. Each solution sought to solve the main issue presented in the introduction; *How should an oil pan with better durability be designed?*

3.3.2.2 Solutions to concepts

When no further progress could be made regarding the solutions the next step started, combining solutions to concepts. All possible combinations were listed and described then presented to the tutors and other affected employees, this to see if a discussion would generate more concepts. After that the concepts generating process came to an effective end.

3.4 Evaluation of concepts

This chapter contains the process of evaluating concepts which includes, among other processes, several different matrices. With the matrices, the concepts will be evaluated and those concepts that fulfills the different criteria continues to be developed and the others will be eliminated. In the end, this process will leave a final choice of concept.

3.4.1 Elimination matrix

The elimination matrix evaluates each concept by comparing them to the demand criteria in the specification of requirements. When compared, each concept is marked with either a (+), (-) or (?) to indicate that it fulfills, doesn't fulfill or that more research is needed to determine if it fulfills the specified criterion or not.

Any concept that ends up with a single (-) will be eliminated and not undergo any further evaluation. If a concept has both (+) and (?) it will still move forward in the process as it doesn't fail any demands but needs more research.

3.4.2 Material- and manufacturing analysis

After the elimination matrix, more research was needed regarding some criteria. Most of those criteria that needed further research were connected to the material- and manufacturing choice. In the following chapter the process of choosing a material and manufacturing process for the oil pan is presented. This involved both research and interviews with engineers in the affected branches.

3.4.2.1 Material analysis

First, a screening of all large material groups was done based on several criteria from the specification of requirements. From the initial larger screening, a few materials continued to a second screening which evaluated the materials against each other based on selected material properties that effected criterion, connected to the choice of material, from the specification of requirements.

To begin, the values of all the materials properties were listed in a table. From that table, each column of a material property was evaluated were the materials received a grade from 1-10 where 10 indicated that it had the best material property. If several materials had the same value on a material property, they received the same grade.

After all material property columns had been evaluated, the individual material grades were summed up as a total score. That highest score later gave the materials a rank from 1-10 where the best rank was 1.

A review of the result followed to ensure that the materials that were ranked highly not only scored high on criteria of low priority according to the criteria ranking from the specification of requirements. To verify the material choice further, interviews were made with different engineers with expertise in the area which concluded the material analysis.

3.4.2.2 Manufacturing analysis

To determine the manufacturing process from the material chosen in the previous chapter various processes were looked at. The manufacturing process had to provide the desired properties for the application for which the oil pan will be used as well as being financially viable. Through discussions with experts of relevant fields as well as researching different manufacturing processes a choice of a manufacturing process could be made.

3.4.2.3 Verification from expert

After determining the material and manufacturing process, an expert within Volvo group was consulted to confirm the validity of both.

3.4.3 Pugh's selection matrix – Concept screening

After the material and manufacturing processes had been found, the concept screening continued with Pugh's selection matrix.

The matrix contains all wishes from the specification of requirements as well as the demands that are possible to overachieve. The wishes were marked with their weighting from the specification of requirements while the demands were given a weighting of five. This weighting was not used in the concept screening but rather in the review of the results from it.

The criteria were listed against an index of choice and the concepts that were considered against it was marked as either better (+), worse (-) or equal (0) in terms of the considered criterion. This yielded a sum of better, worse and equal notations that later were summed up as a net worth. The net worth was used to create a rating between the concepts and the ones that got a net worth below zero were eliminated.

The results were then examined to evaluate if any of the criteria were worth more since the net worth don't always represent the concept fully. The concepts were also reviewed to see if any changes could be made to the concept so that the criterion where a concept was listed as a worse solution could be turned to a better or equal solution. In this way the concept could possibly continue through the evaluation process.

Based on the net worth and the examination of the concepts they continued to a second screening. The only difference in this matrix was the use of the winning concept from the first screening as the index.

To get a quantitative evaluation of the remaining concepts the evaluation continued with Kesselring's selection matrix.

3.4.4 Kesselring's selection matrix – Concept scoring

The last evaluation matrix used was the Kesselring's selection matrix. To build the Kesselring's selection matrix, the first step was to choose which criteria to use.

When all criteria were established, they had to be weighed against each other to determine the importance of each criterion. This was performed in a grading matrix were two criteria were compared against each other at a time. When compared, it was determined if one of the criteria were more important than the other or if they were equally important.

The superior criteria received a value 1 and the other a value 0, if equal, they were both given the value 0.5. When all criteria had been compared with each other, their values were summed up to a total, the total was then converted into percent and then again converted to a weighted value that varied in a scale from 1-5.

After the criteria weighting, the criteria, with their weighted values, and the concepts were inserted to the Kesselring's selection matrix where each concept was graded, with a value between 1 and 5, against each criterion. That grade was then multiplied with the criterion's weighted value to give the concept a score for each criterion, those scores were then summed up to give a total concept score.

In the Kesselring's selection matrix, there is also a column that shows an ideal case whit the highest grade and therefore the highest scores for each criterion and highest concept score. That ideal case concept score was used to convert the other concept scores into percentages and finally the concepts were ranked. When the evaluation with the Kesselring's selection matrix was over, a review of the result was made to verify the validity of the ranking and finally determine the choice of concept.

3.5 Virtual prototype

After the final concept had been chosen it was drawn up in 3D using Creo. The measurements were based on the dimensions of the original D16 oil pan.

4. Results

In this chapter the results of the different parts in the methodology chapter are presented in chronological order.

4.1 Research

Here follow the results from the research conducted during the degree project. The contacts that were established before the research part could begin often appeared by chance which prolonged the research part, the customer needs analysis and the final completion of the specification of requirements. After a period, the contacts were established easier due to developed experience regarding the subject *who to ask for what*.

4.1.1 Literature search

The literature search yielded some information on the oil pan and its usage in engines, this information is presented in the chapter theoretical background, see page 4. No degree projects on oil pans specifically were found but in adjacent areas a few were found regarding report structure, due to similar projects, and manufacturing processes.

4.1.2 Benchmarking

As previously mentioned, the benchmarking was divided into internal and external benchmarking and the results are presented below.

4.1.2.1 Internal benchmarking

The internal benchmarking yielded a few different solutions that already existed within Volvo group but as either discontinued oil pans and oil pans fitted to different models or markets. The oil pans found were an oil pan fitted for the American VN16 truck in cast aluminum, see Figure 10 and blueprint in appendix G, the deep drawn sheet steel oil pan for the D13 engine, see Figure 4 and blueprint in appendix C, and a cast aluminum oil pan for the bus engine 15X, see Figure 11 and blueprint in appendix H.

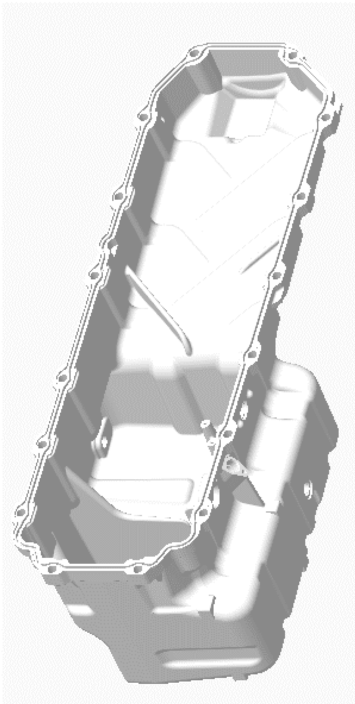


Figure 10 - American VN16 oil pan, reproduced with permission from Volvo group.

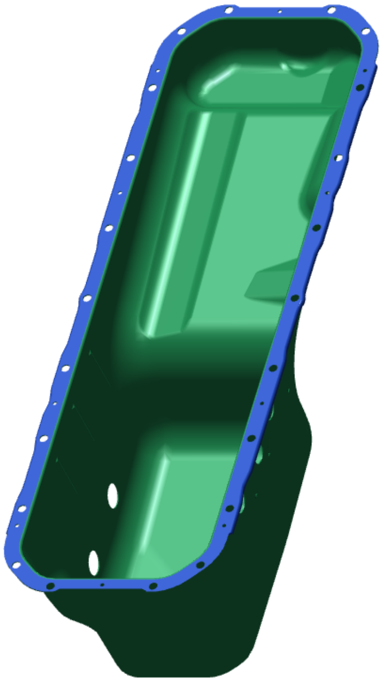


Figure 4 - D13 Deep drawn steel oil pan, reproduced with permission from Volvo group.

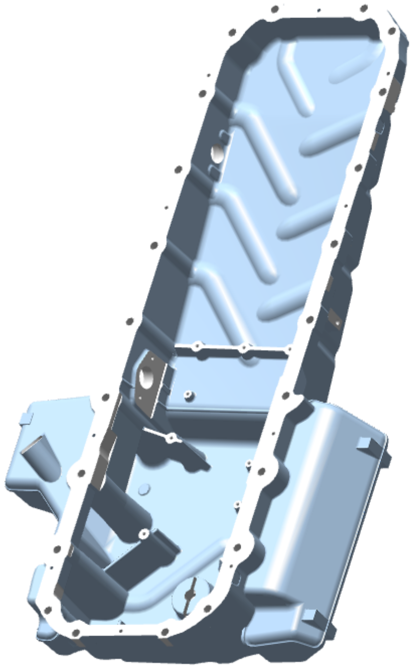


Figure 11 - Volvo bus oil pan for 15X, reproduced with permission from Volvo group.

Both the American oil pan and the 15X oil pan has bulges on the sides to expand the inner volume. The American together with the oil pan for the 15X engine also confirms that cast aluminum is a viable option for the design. The metal oil pan for the D13 confirms that deep drawing is a viable manufacturing method. This information was utilized later in the development of concepts and material and manufacturing analysis.

4.1.2.2 External benchmarking

The external benchmarking was divided into two parts, one was meeting with the team of engineers that perform benchmarking on products on the open market. This presented difficulties as the team explicitly expressed the lack of time to put towards this project.

The second part was contacting other companies to see if they had had the same or similar problems. Scania together with Mercedes-Benz, were less than eager to answer any questions related to specific problems and solutions to those problems. Hence, no further information was gained from the external benchmarking.

4.1.3 Customer needs analysis

Bellow follows the summarized information from all the interviews and meetings held with each group of interest. The questions asked at and information gained from the interviews and meetings can be found in whole in appendix D, F, I and K.

4.1.3.1 Supervisors and staff from ÅF & Volvo

Meetings and interviews were held with the supervisor from ÅF, Emil Pettersson, and the client from Volvo, Lena Larsson, as well as one engineer of interest from Volvo, see questionnaire in appendix D. This was to gain a starting view of the issues with the oil pan and the HCT project.

The issue is, as mentioned before, that the oil pan is not durable enough for the terrain condition very rough that some trucks from Volvo are used in today. The issue arose when the chassis of the trucks were brought down, bringing the engine and the oil pan closer to the ground. This came as a consequence from the HCT project since they aimed to gain more loading volume on the truck.

There is a department at Volvo trucks called Powertrain that are responsible for, and currently are working on developing a new oil pan and this degree project is to serve as support for that project. The solution that the supervisor from ÅF and the client Volvo sought was a new, more durable oil pan.

4.1.3.2 Mechanics at Volvo

Two mechanics, Patrik Oscarsson and Tomas Gatenberg, see questionnaire in appendix F, were contacted. One works with service of trucks in one of Volvo trucks workshops and one works at Volvo trucks engine lab. The information that the product specifications for the oil pan and skid plate bases of were gained from the mechanics mentioned.

An alternative oil pan that is used in the US was suggested as a solution, see Figure 10 and blueprint in appendix G. A smaller geometrical analysis with a D16 engine were made with support by Tomas Gatenberg as preparation before meeting with the geometrical architect responsible for the D16 engine.

4.1.3.3 Component engineer at Volvo Trucks

Meetings were held with the department responsible for the component, represented by Mattias Blondell, see questionnaire in appendix I. From the meetings held, a survey was requested by Blondell to establish how the oil pans break and how big the issue is today.

Blondell also shared the progress the department had made regarding the oil pan and what they plan to change with the design. Some facts about the existing oil pans for both the D13 and D16 engine, were also gained from the meetings and demands for the future D16 oil pan, see the specification of requirements in appendix J.

4.1.3.4 Geometry architecture engineer

A geometry architect engineer, Antonio La Sala, see questionnaire in appendix I, was meet with to discuss what boundaries the new oil pan must follow to not disturb the surrounding components. Several off-limit areas were shown in a virtual model of the oil pan, see Figure 12, with surrounding components of interest, while also looking at opportunities for the redesign of the oil pan with focus on the opportunity to incorporate bulges.

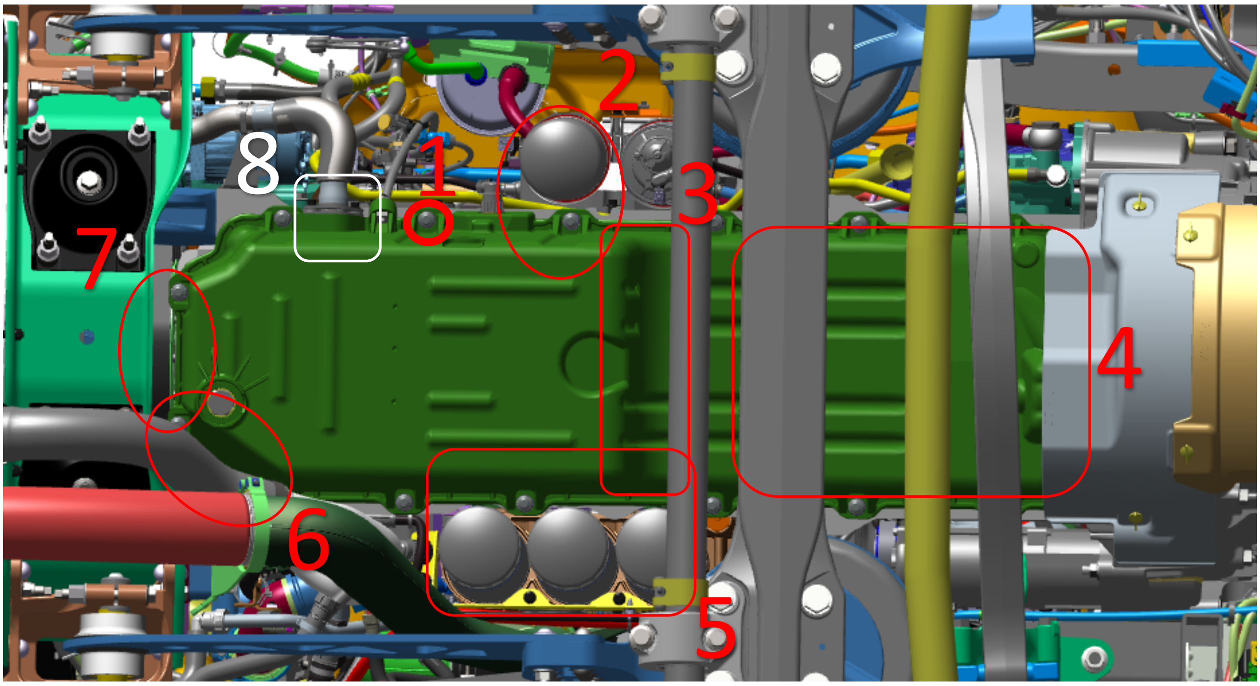


Figure 12 - Illustration of the oil pans position with off-limit areas, reproduced with permission from Volvo group.

The areas marked in red are the off-limit areas and the white area can be utilized for bulges. Area 1, which depicts the attachment points, were not suitable for bulges because the screws has to be vertically assembled. The same reason stands for the cylindrical containers in areas 2 and 5, the fuel filter and oil filters respectively. In area 3, scuffmarks have been found but the cause of these marks is still unclear. Scuffmarks has also been found in area 4 which comes from the front axle. In this area, further clearance is actually needed in the future. Increased space is also needed in area 6 in the future due to the nearby tube which makes the area not suitable for bulges.

The small space that exist in area 7 is also not suitable for bulges as the space that exist is a minimum and cannot be decreased. The small space left that could contain bulges is in area 8, directly under the hole for refill of oil. This would later show not to be defendable in a cost perspective as Antonio La Sala also suggested during the meeting.

4.1.3.5 Haulage contractors & drivers

Five different haulage companies were contacted and interviewed about their experiences with and thoughts about the D16 and D13 oil pan, see questionnaire in appendix K. The individuals that were interviewed were either managers with driving experience or only drivers. One of the haulage companies also operates a workshop.

The issues raised about the oil pans mostly regarded the D16 oil pan. One had experienced damage on the D13 oil pan in the past. However, the workshop still receives customers with damaged D13 oil pans, meaning it is still a current issue. Most of the damage take the form of cracks on the oil pans exterior surface and in very few cases holes. It takes 1-3 days from the moment when the damage is discovered until the truck has a new oil pan again.

The cracks occur during the fall or spring seasons of the year when the forest roads thaw and creates ridges in the middle of the road. Those ridges are sometimes high enough that they scrape the bottom of the oil pan which creates the cracks. In some cases, stone and debris are torn up from the ground during thaw and later frozen stuck in a way that will impact the oil pan and creates holes.

It also happens that the road will collapse underneath a trucks deck due to erosion of the road from movement of water, which is high during thaw (The Independent, 2014) and in that way impact the oil pan and create damage. In most cases when the damage occurs, the drivers either hears or feels it and stops immediately to examine the oil pan. When arriving to the loading area, the drivers also examines the oil pan for damage.

To aid the durability of the oil pan, they have only received the skid plate which no contractor used for long. The skid plate only created more damage to the oil pan due to the debris that got stuck in between the components.

There are some precautions that the contractors make to avoid damage. All drivers are to keep a continuous sight of the ground when driving on risky roads, forest roads, and to all possibly means avoid debris and ridges. Some trucks have air suspensions with different levels, depending on the road conditions, that they use. However, this is a rather expensive add-on and not standard in the trucks.

During thaw and rainy weather conditions, all drivers and managers must determine the safety of the road before starting the ride, since there is no were to turn back until the loading area. They must also refuse to drive during bad road conditions when faced with the lumbering company. A good dialogue with the lumbering company is also a precaution since they are the ones responsible for the forest roads conditions.

The solutions that the haulage contractors have suggested is to raise the clearance of the oil pan, change the material of the oil pan to a more durable one and add air suspensions for all trucks with different levels depending on the road condition. One even mentioned that the raised clearance could be obtained by reducing the oil pans volume. Most contractors also stated that the oil pans are too expensive and too fragile considering their cost. The cost of replacing the oil pan can vary from [redacted] and [redacted] without the engineering cost, see questionnaire in appendix K. The haulage company that also operates a workshop bills their customers [redacted] to replace an oil pan.

4.2 Specification of requirements

After all research was completed 20 different criteria was found and are presented below. For the full specification of requirements table, see appendix J. The specification of requirements was later utilized in the elimination-, Pugh's selection- and Kesselring's selection matrix.

Criterion 1 – *Hold specified amount of oil*

After a meeting with Powertrain representative Mattias Blondell, see questionnaire in appendix I, from the department that developed the original oil pan for the D16 engine, the demand was put up that the oil pan must be able to hold 42, or more, liters of oil. As they are already in the process of increasing the internal volume of the oil pan and therefore does not wish it to be reduced.

Criterion 2 – *Weight*

During a conversation with a mechanic, Patrik Oscarsson, the question of how much impact the weight of the oil pan has on the ease of removing and mounting was posed. He said that it does have an impact but not a large one. That is why it was weighted at a relatively low number.

Criterion 3 – *Resistance to oxidation*
The D16 oil pan is today made from a SMC plastic and is therefore not in need of any additional rust protection. However, if it was made from another material such as steel or iron, protection is a must.

Criterion 4 – *Removable*
For the oil pan to be replaced or removed for maintenance of the engine it must be removable.

Criterion 5 – *Easily removable*
This would enable the mechanics to save time while replacing or performing maintenance on the engine. Since the current oil pan is quite easy to remove as it is, this wish was not weighted too highly.

Criterion 6 – *Oil change compatible*
The main function of the oil pan is to store oil. The oil serves various purposes while in circulation, one of which is to serve as a dilutant for soot from the engine (Hellsten & Pettersson, 2018). The oil must therefore be changed from time to time to keep up performance of the engine.

Criterion 7 & 8 – *Oilmeter connection inlet & outlet (Inside & outside)*
As mentioned in chapter two *Technical background*, see page 5, the oil levels are monitored through the use of an oil meter. During meetings with mechanics, Patrik Oscarsson and Tomas Gatenberg, see questionnaire in appendix F, it was explained that the oil meter is mounted on the bottom inside the oil pan and a cable carries the information through a hole in the side. This hole has mounts on both the inside and outside for sealingrings so that the oil does not leak out and impurities can't get in.

Criterion 9 – *Tolerance of max/min interior pressure*
During a meeting with a mechanic, Tomas Gatenberg, see questionnaire in appendix F, it was revealed that there is a safety mechanism from which the screws attaching the oil pan to the engineblock are designed after. If the oil and air inside the oil pan exceeds operating pressure, the springs on the screws are supposed to compress and release the back part of the oil pan from the engine block releasing the excess pressure. The pressure given by both Powertrain and Gatenberg were guesses and they do not confirm each other. The oil pan must be able to hold this pressure without sustaining damage.

Criterion 10 – *Durable*
The thesis, see appendix L, presented from ÅF describing the project included the words "The task is to develop a durable oil pan […]" which in itself describes why this is presented as a demand in the specification of requirements. Also, the customer needs analysis, see page 14, concluded that the customers wish for the same thing as the lack of durability causes them unplanned stops and in turn loss of capital.

Criterion 11 – *Utilize existing attachmentpoints*
This demand was presented by the project supervisor at ÅF, Emil Pettersson, and the client at Volvo trucks, Lena Larsson, so that the finished redesigned oil pan would be as close as possible to a working concept. This would allow for a physical prototype to be built and utilized in one of their testveichles.

Criterion 12 – *Height*
As previously mentioned, the thesis for the project asks for a more durable oil pan. The main issue is that the oil pan hits debris and scrapes the road while in rough conditions. The customer needs analysis, see page 14, therefore confirms that one solution to the problem would be to raise the clearance.

Criterion 13 – *Defendable manufacturing cost*
This demand was presented from the client at Volvo trucks, Lena Larsson, because if the new oil pan was to be more expensive than the already existing oil pan it had to be more durable and/or have other features that compensate for the higher price point.

To get approximate numbers of what a defendable manufacturingcost for the oil pan would be the numbers provided by Powertrain, see questionnaire in appendix I, were extrapolated based on the difference between the plastic D13 and D16 oil pans. This gives an increase of 33% with the change to the bigger engine. The cost of the 15X oil pan, see Figure 11 and blueprints in appendix H, was provide by Emil Pettersson. Together with the information provided by Powertrain and Emil Pettersson it was possible to extrapolate the approximate value of what an oil pan from aluminum and one from steel would cost, assuming that the manufacturing processes stay the same. This gave an approximate value for both a cast aluminum oil pan and a deep drawn steel oil pan for the D16 engine. The end goal would eventually be to offer this tougher oil pan as an add-on to customers who need it.

Criterion 14 – *Cheap manufacturing cost*
Connecting to the previous criterion; the oil pan should be cheaper than the extrapolated value as it does not only make it possible to make a physical prototype, it would also give incentive to mass-produce it.

Criterion 15 – *Wear-resistant attachment points*
During the meeting with a mechanic, Patrik Oscarsson, see questionnaire in appendix F, a problem with the older version of the D16 oil pan from plastic was brought up. If a mechanic was to tighten the attachment screws or the oil plug a bit too tight, they would dig into the plastic during runtime due to vibrations from the engine running through the screws.

Criterion 16 – *Isolated redesign*
Due to the time limitations of the project presented in the introduction the product development will be limited to the oil pan with only minor modifications to surrounding components. This is why this criterion is presented as a demand instead of a wish.

Criterion 17 – *Uncomplicated solution*
Establishing a new partnership with a company and fine-tuning a manufacturing process takes time and costs a lot of money (Purchasing and negotiation training, 2010). By using the existing chain of subcontractors with previous experience of the oil pan money can be saved and the time to receive inventory can be reduced.

Criterion 18 & 19 – *Maximum width and length*
During a meeting with Powertrain, represented by Mattias Blondell, see questionnaire in appendix I, the demand that the maximum width and length has the previous measurements was presented. This was due to the complex design architecture of the truck.

Criterion 20 – *Measuring stick inlet*
The oil pan has two measuring methods for oil levels. One is the sensor previously mentioned and the second one is the old-fashioned oil metering stick. This is for redundancy so that if one fails, the second one still works. This method requires a secondary inlet in the oil pan that must be present on a new and future oil pans.

4.3 Development of concepts

Below follows the result of the different stages that were involved in the development of concepts.

4.3.1 Functional analysis - Black box

With the oil pans product specification, see page 5, the functional analysis determined one main function which was first described as *to provide oil for lubrication and cooling to the engine* and later reduced to *hold oil*. With that main function, the subfunctions *refill of oil*, *draining of oil* and *measurement of oil* came.

The oil pans system boundaries are shown in the black-box, see Figure 13 as the largest square which depicts the oil pans main function *hold oil*. To easier understand how the oil pan provides the oil to the engine the oils pathway in, through and out of the oil pan was also visualized within the black box. The subfunctions could be depicted in the black-box image directly.

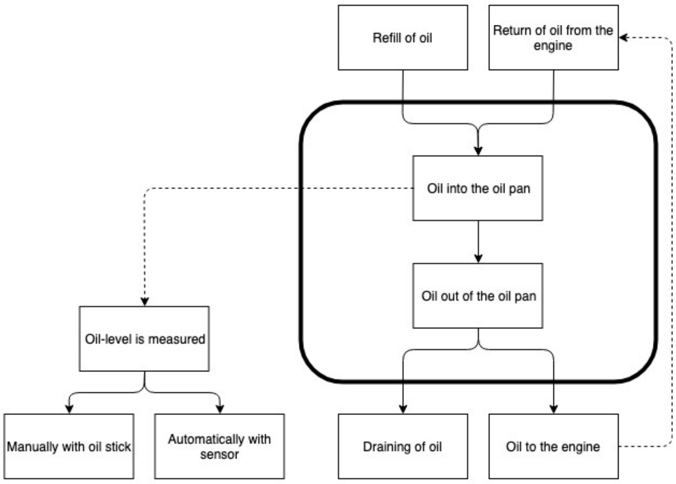


Figure 13 - Black-box illustration.

4.3.2 Brainstorming

The results from the process of generating solutions and concepts are presented below.

4.3.2.1 Brainstorming solutions

After the brainstorming was completed three solutions was presented. The solution presented did not take into consideration a specific material or manufacturing process.

Solution 1

Solution one, see Figure 14, is to reduce the inner volume with a larger percentage and utilize the won volume to raise the clearance. This would increase the service intervals for the drivers but reduce the number of unscheduled stops.

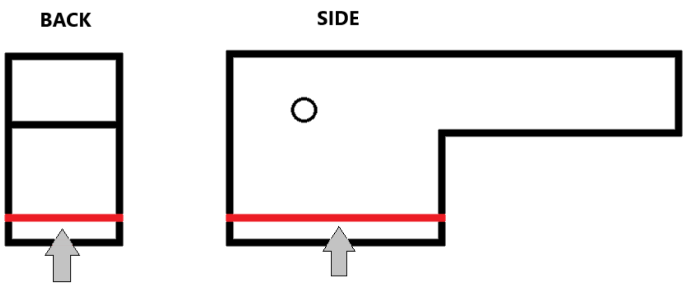


Figure 14 - Solution one.

Solution 2

Solution two, see Figure 15, is to alter the position of the refill hole on the oil pan upwards as this is allowed according to the geometry architect engineer, see questionnaire in appendix I. This would allow the service technicians to refill the oil pan with a larger volume. However, the won volume would be utilized to raise the clearance without compromising on the previous internal volume of 42 liters.

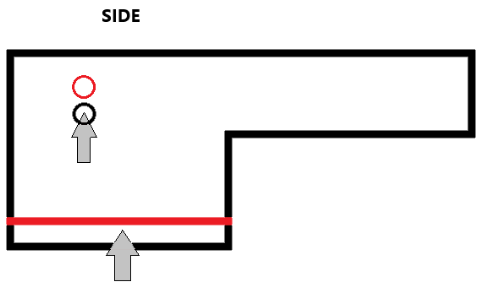


Figure 15 - Solution two.

Solution 3

Solution three, see Figure 16, is to extend the lower parts of the oil pan to the sides effectively creating bulges were extra oil would be held increasing the inner and outer volume of the oil pan. The won volume would be utilized to increase the clearance of the oil pan without compromising on the previous internal volume of 42 liters.

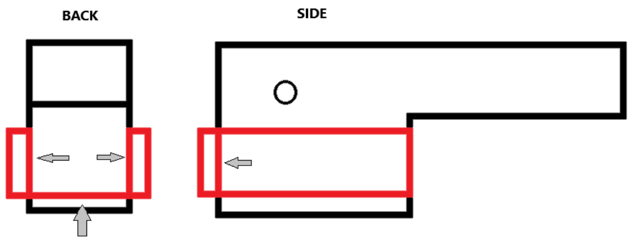


Figure 16 - Solution three.

4.3.2.2 Solutions to concepts

After all solutions had been generated, they were combined into concepts where one or more solutions were present, as seen in table 1 below. This yielded 7 different concepts which are presented below. The three different oil pans from the internal benchmarking, or versions of them, were also added and are presented below as concepts 8 to 10.

Table 1 - Concept generating table.

CONCEPT GENERATING TABLE							
CONCEPTS / SOLUTIONS	1	2	3	4	5	6	7
1	X			X	X		X
2		X		X		X	X
3			X		X	X	X

Concept 1 – *Solution 1*

Concept one utilizes a single solution, solution one, which entails that the oil pan in its general features remains the same, but the volume of oil would be cut, and the clearance be raised.

Concept 2 – *Solution 2*

Concept two utilizes a single solution, solution two, which entails that the oil pan in its general features remains the same, but the oil refill hole would be raised upwards allowing the oil pan to be filled with a larger volume of oil. The larger volume would then be used to raise the clearance.

Concept 3 – *Solution 3*
Concept three utilizes a single solution, solution three, which entails that the oil pan in its general features remains the same, but bulges according to the allowed volume presented in the customer needs analysis, see page 15, would be added to increase the inner volume. The increased volume would be utilized to increase the clearance.

Concept 4 – *Solution 1 & 2*
Concept four utilizes two different solutions, solution one and two, which entails that the volume would be cut and the oil pan has its refill hole raised. These two new properties would be utilized to raise the clearance.

Concept 5 – *Solution 1 & 3*
Concept five utilizes two different solutions, solution one and three, which entails that the volume would be cut and bulges would be added according to the allowed volume presented in the customer needs analysis, see page 15. These two new properties would be utilized to raise the clearance.

Concept 6 – *Solution 2 & 3*
Concept six utilizes two different solutions, solution two and three, which entails that the oil pan has its refill hole raised and bulges according to the allowed volume presented in the customer needs analysis, see page 15. These two new properties would be utilized to raise the clearance.

Concept 7 – *Solution 1, 2 & 3*
Concept seven utilizes all three solutions, solution one, two and three, which entails that the volume would be cut, the oil pan has its refill hole raised as well as having bulges according to the allowed volume presented in the customer needs analysis, see page 15.These three new properties would be utilized to raise the clearance.

Concept 8 – *D13 Steel oil pan*
Concept eight is the deep drawn steel oil pan for the D13 engine. The concept is considered an extrapolated version of the original oil pan to fit the D16 engine.

Concept 9 – *D13 Aluminum oil pan*
Concept nine is a casted aluminum oil pan based on the design of the D13 deep drawn steel oil pan but with design features of the 15X oil pan, without the bulges.

Concept 10 – *American D16 oil pan*
Concept eight is the casted aluminum oil pan for the American D16 engine.

4.4 Evaluation of concepts

This chapter contains the result from the process of evaluating concepts.

4.4.1 Elimination matrix

Table 2 - The elimination matrix

Elimination matrix for Oil pan																	
Requirements / Concept	1. Hold specified amount of oil	3. Resistance to oxidation	4. Removable	6. Oil change compatible	7. Oilmeter connection inlet (Case)	8. Oilmeter connection outlet (Case)	9. Tolerance of max/min interior pressure	10. Durable	11. Utilize existing attachmentpoints	13. Defendable manufacturing cost	15. Wear-restistant attachmentspoints	16. Isolated redesign	18. Maximum width	19. Maximum length	20. Measuring stick inlet	Comment	Decision
1	-	?	+	+	+	+	?	?	+	?	?	+	+	+	+	*Eliminated*	-
2	+	?	+	+	+	+	?	?	+	?	?	+	+	+	+	*Need further data*	?
3	+	?	+	+	+	+	?	?	+	?	?	+	-	+	+	*Eliminated*	-
4	-	?	+	+	+	+	?	?	+	?	?	+	+	+	+	*Eliminated*	-
5	-	?	+	+	+	+	?	?	+	?	?	+	-	+	+	*Eliminated*	-
6	+	?	+	+	+	+	?	?	+	?	?	+	-	+	+	*Eliminated*	-
7	-	?	+	+	+	+	?	?	+	?	?	+	-	+	+	*Eliminated*	-
8	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	*Approved for further evaluation*	+
9	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	*Approved for further evaluation*	+
10	+	+	+	+	+	+	+	+	+	+	+	-	-	-	+	*Eliminated*	-

Eliminationcriteria:
[+] Yes
[-] No
[?] More information is required

Decision:
[+] Follow up on solution
[-] Eliminate solution
[?] Search for more information

The elimination matrix, see Table 2, eliminated most concepts due to their physical design as can be seen for concept 1, 3, 4, 5, 6, 7 and 10. It was either because that the concept had decreased in the volume which affected the amount of oil or that the concept had changed width with exception for concept 10 which also failed in length and isolated design.

The concepts that remained after the elimination matrix, see Table 2, were concept 2, 8 and 9 where concept 2 needed further data in the form of material and manufacturing choice. The evaluations of concepts could only continue after a material- and manufacturing choice had been made.

4.4.2 Material- and manufacturing analysis

The results of the material- and manufacturing analysis are presented in this chapter.

4.4.2.1 Material analysis

First screening

From the large material tree found on level 2 in CES EduPack^{TM}, several material families were screened out based on common sense. The materials cataloged in CES EduPack^{TM} are categorized according to the following families; *Ceramics and glasses*, *Polymers and elastomers, Metals and alloys* and *Hybrids: Composites, foams and natural materials*. The criteria of common sense are for example cost, durability, scarcity and capability for plastic deformation.

The family *Ceramics and glasses* was eliminated due to their brittle nature (CES EduPack software, 2018).

Polymers and elastomers were eliminated as it is the same family used in the old D16 oil pan made from plastic. If a new oil pan is to be developed it should be more rugged and durable than the previous one. Elastomers are also not a suitable family for this application due to their high elastic deformational properties as well as low integral structure (CES EduPack software, 2018). On top of this information, polymers are a vast and complicated subject as there are near infinite variations within a single subcategory.

Hybrids: Composites, foams, natural materials was a trickier family as it entails a large number of combinations. First, all polymer hybrids were excluded for the same reason as previously mentioned. Second, all foams were excluded because of their porosity which is not ideal in this application. Third, all natural materials such as wood were excluded due to their porosity and their high elastic deformation capabilities. Left were metalcomposities and the only listed material in CES EduPack™ database were Aluminum/silicon carbide composite. This material was also excluded due its high price point (CES EduPack software, 2018).

The last family *Metals and alloys* was divided into ferrous and non-ferrous metals. The materials excluded from non-ferrous due to material cost were materials such as copper, gold and titanium. Other metals were excluded due to their reactiveness, such as sodium and potassium (CES EduPack software, 2018). The materials left were both from the ferrous and non-ferrous subfamilies which went on to the second screening.

Second screening

After the first screening, 10 materials were left for further evaluations. They were listed in a table, see Table 3, with their values of certain material properties taken from CES EduPack™ (CES EduPack software, 2018). The choice of which material properties that would be evaluated were based on which criteria from the specification of requirements that would be affected by a material's properties.

Table 3 - Material analysis matrix, complete with values (CES EduPack software, 2018)

Material analysis - Values							
Criterion	Cost (4)	Weight (2)	Durability (5)	Durability (5)	Oxidation (5)	Durability (5)	Durability (5)
Material property	Price	Density	Shear strength	Hardness (Vicker's)	Resistance	Stiffness (Young's modulus)	Yield strength
Unit	**SEK/kg**	**(kg/m^3)*1e^3**	**MPa**	**HV**	**Lim-Acc-Exc**	**GPa**	**MPa**
Cast Al	17,5	2,9	350	150	Acceptable	89	330
Cast Iron, grey	2,52	7,25	448	310	Limited	138	440
Cast Iron, duct	2,52	7,25	830	320	Limited	110	680
Low carbon steel	5,7	7,9	580	173	Limited	215	395
Medium carbon steel	5,8	7,9	1200	565	Limited	216	900
High carbon steel	5,7	7,9	1640	650	Limited	215	1160
Stainless stell	48,4	8,1	2240	570	Excellent	210	1000
Low alloy steel	6,19	7,9	1760	693	Limited	217	1500
Age hardening Al	17,3	2,9	620	150	Acceptable	80	610
Non-age hardening Al	17,4	2,9	360	100	Acceptable	72	286

Criteria that would be affected by a material's properties are as shown in Table 3 the materials cost, weight, durability and resistance to oxidation. The material properties that followed from these criteria were the price, density, shear strength, hardness (according to Vicker's), resistance from oxidation, stiffness according to Young's modulus and yield strength.

When the values for the different materials properties were evaluated against each other they were replaced by a grade from 1-10 where 10 is the highest grade, see Table 4 below. For some material properties, a low value did not correspond to receiving a low grade. The price and density are properties which are desirable with a low value since it would lower the cost and weight of the product which are wishes seen in the specification of requirements, see appendix J.

Table 4 - Material analysis matrix scores

Material analysis - Scoring									
Criterion	Cost (4)	Weight (2)	Durability (5)	Durability (5)	Oxidation (5)	Durability (5)	Durability (5)	Score	Rank
Material property / Material	Price	Density	Shear strength	Hardness (Vicker's)	Resistance	Stiffness (Young's modulus)	Yield strength		
Cast Al	4	10	1	3	9	4	2	33	9
Cast Iron, grey	10	9	3	5	8	6	4	45	6
Cast Iron, duct	10	9	6	6	8	5	6	50	5
Low carbon steel	9	8	4	4	8	8	3	44	7
Medium carbon steel	8	8	7	7	8	9	7	54	3
High carbon steel	9	8	8	9	8	8	9	59	2
Stainless steel	3	7	10	8	10	7	8	53	4
Low alloy steel	7	8	9	10	8	10	10	62	1
Age hardening Al	6	10	5	3	9	3	5	41	8
Non-age hardening Al	5	10	2	2	9	2	1	31	10

The material properties that had high values and received a higher grade for that were shear strength, hardness, stiffness and yield strength. The reason that high values for named material properties are considered better for the oil pan is to obtain the most durable design in theory.

A high value for hardness is favorably due to the vibrations from the engine that will travel through the screw connections during runtime and for resistance against wear from gravel that ends up in between the oil pan and the skid plate. The oil pan will have to endure shear stress during poor driving conditions that occurs on the forest roads, where it scrapes along the road. Therefore, a high value for the shear stress is also desirable.

The stiffness according to Young's modulus and the yield strength are connected and a high value is also sought after for those material properties. A high value for the yield strength to have elastic deformation for strong forces applied on the oil pan but also a high value for the stiffness to avoid to large elastic deformations.

For the resistance from oxidation there were no values to base the grade on, instead CES EduPack™ rated the material's resistance from oxidation as limited, acceptable or excellent. The resistance presented was without any further protection or treatment. For the oil pan it is favorable to have a material with as good a resistance as possible to minimize the cost of oxidation treatment. As seen in Table 4, the highest grade 10 was given to the material with a resistance from oxidation rated as excellent, grade 9 to those rated acceptable and 8 for limited.

All the grades that each material received for the different properties was then summed up to a total score and as an end ranked 1-10 based on their score where one was the winning material. The low alloy steel became the winning material according to the ranks, see Table 4.

Review

When reviewing the low alloy steel's grades, its values vary from 7-10 for the different properties meaning it is not the best performing material for all properties. To conclude that the low alloy steel still is the best choice it will be evaluated against the best performing material in the categories where the low alloys steel is not the highest graded material.

The low alloy steel has a grade 7 for the cost, see Table 4, and if compared with the best performing in that category, which is the cast iron grey and ductile, you can see that they also perform better than the low alloy steel in weight and has the same performance in resistance to oxidation. However, they lack in all the durability categories almost by half which are all ranked 5 from the specification of requirement compared to the cost and weight that are ranked 4 and 2 respectively. The low alloy steel is a more favorable material even with a higher cost and weight.

For the weight category, the best performing materials are the aluminum alloys. They also perform better in resistance to oxidation but have poor values in the durability categories and are also more expensive than low alloy steel. Therefore, the low alloy steel is still a more favorable material due to the low priority of the weight and that the resistance to oxidation can be increased with treatment.

Regarding the last two categories that the low alloy steel did not perform best in, shear strength and resistance to oxidation, it is the stainless steel that is graded best for those. However, for the other durability categories, it ranks lower than the low alloy steel and it has the highest cost of all the considered materials and therefore the low alloy steel is the more favorably material choice again.

As the evaluation above and Table 4 suggests, the final choice of material is low alloy steel. This material will be applied to all concepts without a specified material that passed through the elimination matrix.

4.4.2.2 Manufacturing analysis

After the material analysis and the choice of low allow steel, different manufacturing processes were examined. The manufacturing processes that were most prominent and widely used were additive manufacturing, milling, casting and deep drawing.

Additive manufacturing

Additive manufacturing, or 3D-printing, is an up and coming field within manufacturing processes due to its flexibility (Rexed & Skogh, 2018). It is ideal for concept confirmation through physical prototyping (On Demand Rapid Prototyping overview, n.d.), but it takes time. The 3D-printed oil pan presented in the degree project as an example for the report's thesis *"The potentials within additive manufacturing at Volvo Penta"* by Linus Skogh and Filippa Rexed, would take three to four weeks to produce, process and ship a done product of this nature (Rexed & Skogh, 2018).

The cost of the one unit previously mentioned would also be around 30 000 SEK, well above what is financially defendable for this degree project. Additive manufacturing is an expensive manufacturing process for a number of reasons including the slow speed of which the material is processed, the need for specialized staff and the limitations of materials that can be used (Pearson, 2018).

Milling

Milling, or subtractive manufacturing, is just as additive manufacturing a manufacturing process ideal for physical prototyping (Carter, 2017) but it's much faster. This is because removing material is mostly a question of how fast the routerbit can spin without tearing itself or the material. It would however not be faster per unit than deep drawing.

The manufacturing process is, however, just as additive manufacturing, and an expensive choice due to the large loss of material. Due to the design of an oil pan, the largest part of the material would be cut making it an unnecessarily expensive process and this makes it an expensive process (Additive Manufacturing & Subtractive Manufacturing | Pros & Cons, Applications, n.d.).

Casting

The advantages of casting are many. The geometries can be close to limited only by imagination, the weight of a piece can be from a few grams to hundreds of tons and it is the best choice from a financial standpoint since the cost will not differ with the amount of produced parts (Svensson & Svensson, 2004). However, the disadvantages are also many as there are many kinds of molds.

For low alloy steel one-time sand molds are best suited (Svensson & Svensson, 2004) which gives the cost no impact considering the size of the series. Instead every unit has a fixed price.

When casting, the surface finish is very rough when exiting the mold due to the use of sand molds (Prakash, 2017). This is not an issue on the outside of this application but on the inside, it might cause higher friction between the oil pan and the oil. This would reduce the flow speeds close to the oil pan creating deadzones were the oil is stationary (White, 2016). The oil is supposed to work as a coolant and a dilution medium for impurities (Hellsten & Pettersson, 2018) but if a percent of the oil is stationary these functions will not be achieved.

The precision for which dimension can be designed when sandcasting is lower than any of the mention manufacturing processes (Svensson & Svensson, 2004). In order to achieve desired design properties a larger margin must be added in terms of the thickness of the finished product. This would change the clearance of the oil pan.

The cost of casting is increased correlating to the melting temperature of the material used according to the castingexperts that were consulted, see questionnaire in appendix M. As the chosen material is the low allow steel, the melting temperature is between 1400°C and 1500°C (CES EduPack software, 2018) while aluminum on top of its cheaper material cost has a melting temperature of between 470°C and 670°C (CES EduPack software, 2018) which would make it much cheaper.

Deepdrawing

Deepdrawing has about as many drawbacks as it has advantages. This is due to its high initial cost for machines, the large stampingtools, educating staff etc. (Daugherty, 2016). Luckily there are companies that have all mentioned tools like for example the company that manufactures the D13 Steel oil pan, [redacted]. All that is needed is the development- and production cost of the inserts for the stamping tools. It is still a large expense but one that is reduced with the production of series, in contrast with casting in expendable molds.

Disadvantages of deepdrawing a part is mostly in the development stage and consists of, but not limited to; tearing due to overstretching or unintentionally using anisotropic material (Hågeryd, Björklund, & Lenner, 2002). If a galvanized material is used, shedding, due to stretching the material, can be an issue in aesthetic applications as it can create marks in the finished product (Adnan, 2009).

The precision of the manufacturing process is very high due to the small margins and high pressure. The material used can be very thin up to about 6 mm (Hågeryd, Björklund, & Lenner, 2002). The process also curates the material through strain hardening when it is plastically deformed (Hågeryd, Björklund, & Lenner, 2002).

Choice of manufacturing process

Additive manufacturing is as mentioned a slow and expensive process therefore it is not viable for this application. Milling, or subtractive manufacturing, suffers from the same disadvantages and cannot be applied.

In the case of casting, it would be expensive as the melting temperature of the chosen material is high. The lack of precision with casting would entail that the thickness be oversized which would mean a heavier oil pan and that the clearance is diminished.

In the specification of requirements, the different wishes were all prioritized with a grade and the one that scored the highest was clearance, second was cheap manufacturing cost. The conclusion is that deep drawing would be the best suited manufacturing process as it provides a marginally higher clearance for the oil pan. Its validity was also confirmed during the internal benchmarking.

4.4.2.3 Verification from expert

After the material analysis was completed and the manufacturing process was chosen, an expert in the field of deep drawing was consulted to verify the validity of the conclusion, see questionnaire in appendix M. She verified that the material chosen was ideal for the process and that the specific steel grades [redacted] would be ideal for deep drawing. The material properties were found in an internal database, Tech Volvo, along with other information about the materials.

4.4.3 Pugh's selection matrix – Concept screening

For the first iteration of the Pugh's selection matrix, the original D16 plastic oil pan was used as an index. This was to confirm that the concepts were better in one or several criteria. All the concepts that continued from the elimination matrix were compared to the index on the criteria; 1, 2, 3, 5, 10, 12, 14, 15, and 17 from specification of requirements, see appendix J. These were all the wishes as well as the demands that were beneficial if overachieved.

As criterion 1, *hold specified amount of oil*, is a demand from the specification of requirements, it was assumed that the different concepts without a finalized design would be designed to hold the specified volume. Criterion 2, *weight*, is connected to the finalized design of the product. Instead of comparing the finalized weights, densities were regarded.

Criterion 3, *resistance of oxidation*, was evaluated under the assumption that the oil pans that required additional rust protection had been treated. Criterion 5, *easily removable*, is connected to the finalized design and is not evaluated. However, it is interconnected with criteria 11, *utilizing existing attachment points.* Considering that the existing oil pan uses 16 screws to connect to the engineblock, see blueprint in appendix B, and the old attachment points should be utilized, there isn't much possibility to make the oil pan more easily removable.

Criterion 10, *durable*, is connected to both the design, the manufacturing process chosen and the material used. The materials durability is also a combination of various material constants. The comparison only took the material into account. For criterion 12, height was considered. Here the D16 plastic served as a reference level while concept 8 and 9 are considered to have the same, or close to the clearance to the D16 plastic.

Criterion 14, *cheap manufacturing cost*, is hard to compare as no exact numbers have been provided nor any quotes from manufacturers. Instead, the extrapolated values from the specification of requirements was used, see page 17. Criterion 15, *wear-resistant attachmentpoints*, is connected to the material properties and is therefore compared with data from the material analysis. For criterion 17, *uncomplicated solution*, existing products materials and manufacturing processes were looked at to see if there were existing manufacturers that could be utilized to not have to create an entirely new production chain.

As seen in Table 5 below, the index got a net worth of 0 but so did concept 2 and 9. Concept 2, as well as 9, did however get the same number of plusses as minuses. It was concluded that this was due to the change of material from plastic to low alloy steel.

After concept 8, *altered D13 steel*, scored lower than 0 it was reviewed to see if changes could be made to the concept to make it score higher. It was concluded that height could be influenced by utilizing solution 2, moving the refill hole upwards but that would make it too similar to concept 2. Hence it was eliminated. Concept 9, *altered D13 aluminum*, was reviewed to see if any features could be altered to give it a higher score. It was determined that utilizing solution 2, moving the refill hole upwards, would give it a higher score on criterion 12, *height*. This effectively developed concept 9 into 9.1.

Table 5 - Pugh's selection matrix, first iteration

Pugh's selection matrix for Oil pan - Iteration 1				
Criteria: [+] Better solution [-] Worse solution [0] Equal solution **Criteria**	**D16 Plastic**	**Concept 2**	**Concept 8**	**Concept 9**
1. Hold specified amount of oil (5)	0	0	0	0
2. Weight (2)	0	-	-	-
3. Resistance to oxidation (5)	0	-	-	0
5. Easily removable (2)	0	0	0	0
10. Durable (5)	0	+	+	+
12. Height (5)	0	+	0	0
14. Cheap manufacturing cost (4)	0	-	-	-
15. Wear-resistant attachmentpoints (5)	0	+	+	+
17. Uncomplicated solution (3)	0	0	0	0
Number of +	0	3	2	2
Number of -	0	3	3	2
Net worth	0	0	-1	0
Ranking	1	1	2	1
Further development	YES	YES	NO	YES

Table 6 - Pugh's selection matrix, second iteration

Pugh's selection matrix for Oil pan - Iteration 2			
Criteria: [+] Better solution [-] Worse solution [0] Equal solution **Criteria**	**Concept 2**	**D16 Plastic**	**Concept 9.1**
1. Hold specified amount of oil (5)	0	0	0
2. Weight (2)	0	+	+
3. Resistance to oxidation (5)	0	+	+
5. Easily removable (2)	0	0	0
10. Durable (5)	0	-	-
12. Height (5)	0	-	0
14. Cheap manufacturing cost (4)	0	+	0
15. Wear-resistant attachmentpoints (5)	0	-	-
17. Uncomplicated solution (3)	0	0	0
Number of +	0	3	2
Number of -	0	3	2
Net worth	0	0	0
Ranking	1	1	1
Further development	YES	YES	YES

Going into the second iteration of Pugh's for more conclusive results, see Table 6, concept two was chosen as the index due to the superior durability. In the second iteration of Pugh's all the concepts received the same net worth but both concept 9.1 and D16 plastic scored worse on durability and wear-resistant attachment points. Concept two did however score worse on both weight and resistance to oxidation.

The decision was to put all remaining concepts through to the Kesselring's selection matrix for a quantitative comparison of the concepts.

4.4.4 Kesselring's selection matrix – Concept scoring

Almost all criteria that were used during Pugh's selection matrix were reused, the criteria where concepts performed equally on were not reused. The criteria grading sheet, which gave each criterion a weighted value to build the Kesselring's matrix, can be seen below in Table 7. Determination of which criterion that were more important than the other was based on the weighting from the specification of requirements. The two criteria that received a weight of 0 were changed to 1 as they still carry importance.

Table 7 - Kesselring's weighting generating matrix

Criteria	2	3	5	10	12	14	15	17	Sum	Sum[%]	Given value
2	-	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,50	0,02	0
3	1	-	1,0	0,0	0,0	1,0	0,5	1,0	4,50	0,16	3
5	0,5	0,0	-	0,0	0,0	0,0	0,0	0,0	0,50	0,02	0
10	1,0	1,0	1,0	-	0,5	1,0	1,0	1,0	6,50	0,23	5
12	1	1,0	1,0	0,5	-	1,0	1,0	1,0	6,50	0,23	5
14	1	0,0	1,0	0,0	0,0	-	0,5	0,5	3,00	0,11	2
15	1	0,5	1,0	0,0	0,0	0,5	-	1,0	4,00	0,14	3
17	1	0,0	1,0	0,0	0,0	0,5	0,0	-	2,50	0,09	2
							Tot:		**28**	**1**	

While grading the concepts in the Kesselring's selection matrix, see Table 8 below, special considerations and comparisons needed to be made since not all criteria had specific values to grade after. These considerations and comparisons are explained below for each criterion.

When regarding the criterion *weight* it has been assumed that the D16 plastic oil pan is the lightest and for the other two concepts their density was considered which made aluminum lighter than and low alloy steel. The weight was also taken into regard when grading for the criterion *easily removable* as a component that weighs less is easier to move around.

The criterion *height* regarded to approximately how much each concept has raised the clearance, no specific values exist yet, but good assumptions can be made. No concept received the highest grade however because of several redesigns that would yield an even higher clearance but could not be made during this project but are still relevant for the future.

For the criterion *resistance to oxidation* the materials of the concepts were looked at. Since oxidation is not an issue for the D16 plastic oil pan it received the highest grade and aluminum not far behind due to its behavior to stop oxidation from spreading.

More criteria grades that were partly influenced by the material of the oil pan was *durable* and *wear-resistance attachment points* which regarded the strength of the material as mentioned previously. *Cheap manufacturing cost* and *uncomplicated solution* regarded the cost of the materials and how much the existing line of manufacturing and distribution could be used. No exact values exist for the cost here either, but extrapolated values from the specification of requirements, see page 17, could be gained for the concept which gave an approximation on how to grade the concepts.

Table 8 - Kesselring's selection matrix

Kesselring selection matrix for Oil pan									
Criteria	Weighting	Grade	Ideal	Grade	Concept 2	Grade	D16 Plastic	Grade	Concept 9.1
2. Weight	1	5	5	2	2	5	5	3	3
3. Resistance to oxidation	3	5	15	2	6	5	15	4	12
5. Easily removable	1	5	5	4	4	5	5	4	4
10. Durable	5	5	25	5	25	1	5	3	15
12. Height	5	5	25	4	20	1	5	4	20
14. Cheap manufacturing cost	2	5	10	2	4	5	10	2	4
15. Wear-resistant attachmentpoints	3	5	15	5	15	1	3	2	6
17. Uncomplicated solution	2	5	10	3	6	5	10	3	6

Score	110		82		58		70
Percentage	100%		75%		53%		64%
Ranking	-		1		3		2

The results from the Kesselring's selection matrix gave concept 2 as the winning concept and when reviewing the grades, the same conclusion is made since the Kesselring's matrix already takes into regard the importance of each criterion. From here on, development of the virtual prototype, which is concept 2, will follow.

4.5 Virtual prototype

This degree projects end product, see Figure 17, that came from concept 2 gave an oil pan with the measurements of the D16 plastic oil pans blueprints, see appendix B, to make sure not to exceed the allowed space in width and length, as the stated demand from the specification of requirements, see appendix J. The details, however, were designed after the D13 steel oil pan since the final product also will be manufactured in steel and the D13 steel oil pan is an approved and working design today.

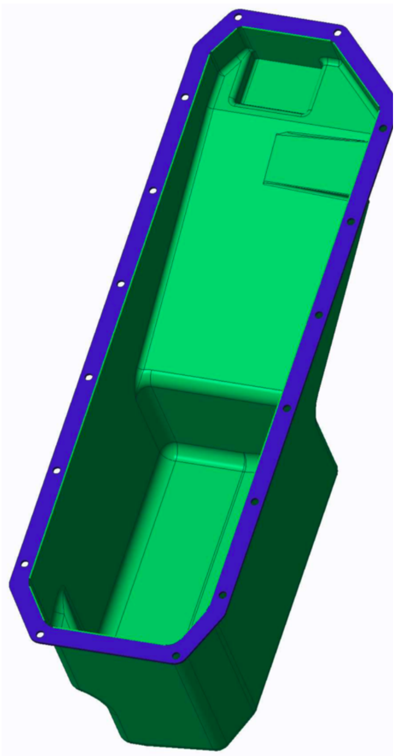


Figure 17 - Prototype oil pan.

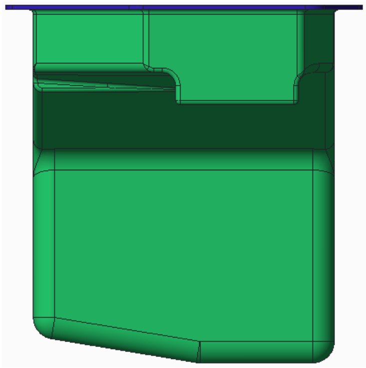


Figure 18 - Prototype oil pan, rearview.

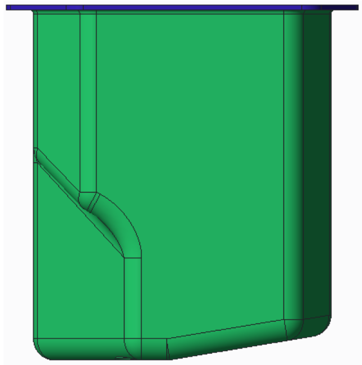


Figure 19 - Prototype oil pan, frontview.

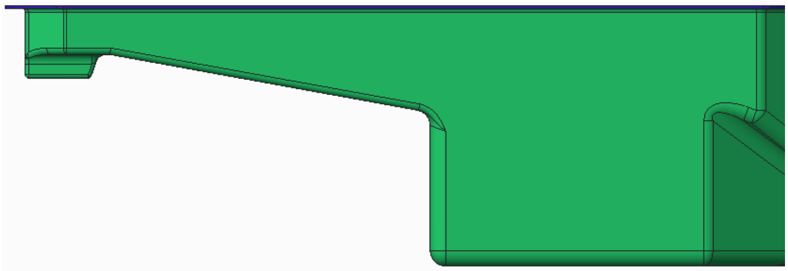


Figure 20 - Prototype oil pan, right side.

As concept 2 suggested, the oil pans refill hole for oil was moved to gain volume and then later use that gained volume to increase the clearance of the oil pan from the ground, see Figure 21 and 20. Since the refill hole is located in the region were the oil pan is almost twice as long as the bottom part, the height gained in the long part will be almost double in the bottom. When examining the D16 oil pan, the refill hole should be able to be moved up to 4 cm in height which would give about a 7-8 cm increase of clearance from the ground.

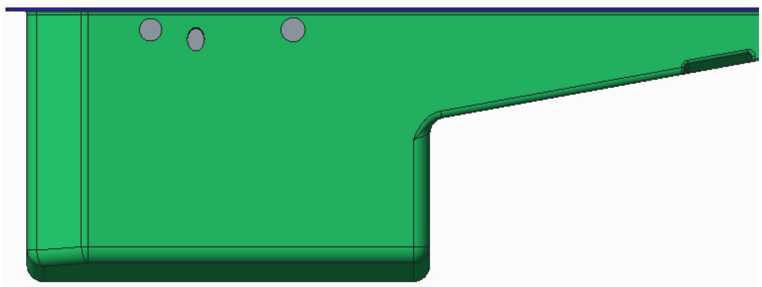


Figure 21 - Prototype oil pan, left side.

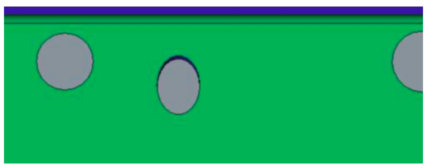


Figure 22 - Prototype oil pan, left side - section.

With this increase of clearance some changes will be needed for surrounding components. The suction tube that pumps up the oil to the engine will have to be shorter since its original design keeps it very close to the bottom of the D16 oil pan. The manual oil measuring stick will also need to be shorter and probably rescaled after the new dimensions of the oil pan and finally the cable connected from the oil sensor to the output of the oil pan will also need to be shorter.

5. Discussion

The task of this degree projects was to develop a durable oil pan for trucks driving in rough terrain. This task led the project to investigate the questions *"how should an oil pan with better durability be designed?"* and "*how does the oil pan break today?"* These questions gave the final solution for the oil pan, with a new more durable material and an increased clearance, but it also raised new questions.

As mentioned previously, the HCT project aims to reduce products CO_2-emissons from transports which ended with the risen issues of the oil pans due to the lowered clearance. This issue first started with the D13 oil pan, continued with the D16 and both is still an issue today. The questions that arose from this was if the reduced CO_2-emisson of the shipped cargo is large enough to not only compensate but also be large enough to make the increased usage of oil pans, which will produce more CO_2-emissions during production, negligible or not?

Another question of interest is why a plastic oil pan was developed for the specified road conditions with the D16 engine when the issue of clearance already existed with the D13 oil pan, which has a higher clearance than the D16. As mentioned previously, Powertrain requested a survey on how the oil pan breaks today which implies that the contact to customers is highly minimized for the department and therefore, they had no knowledge of how the existing problem occurs or a chance to solve it. Maybe this is a fault that exists when working in a large company?

Among all the solutions that were sorted out, the solution that decreases the amount of oil in the oil pan is one example where a customer's priority hasn't reached the developer. It has been said amongst haulage contractors that a decreased amount of oil would not be such a severe issue if it raises the clearance of the oil pan. The intervals for oil change would, of course, increase with the decreased amount of oil but a planned stop is better than an unplanned stop. A raised clearance would also, if high enough, save the haulage companies the money they would spend to purchase new oil pans.

Several oil pans with bulges exist today, as presented in the research earlier, in trucks and buses produced by Volvo Group but none of them has made their way to the D16 engine in Sweden. The geometrical analysis did show a small area were bulges could exist, but more areas are needed for the application to be defendable. This would, as said before, involve the movement and the redesign of several components in the undercarriage which succeeded the timeframe of this degree project. However, it is still of interest to ask why not more resources has been put in to make these redesigns for the trucks? Compared to other customer groups, the haulage contractors that drive in very rough terrain is a smaller one which makes them not as profitable as others, however, the loss of that customer group could be even more, less profitable.

When looking into how the oil pan breaks, it turned out that the oil pans bottom scrapes ridges on the road and impacts stone or debris during thaw and when the road collapses. If the fact that enough care of the road would erase most of the situations where the oil pan gets damaged is disregarded, is the environment only to be blamed for the damage or could human error be the cause? In the case of human error, even a steel oil pan would take damage if entering a road of bad conditions, not as much as a plastic one but still significant.

Some drivers still enter these roads of bad conditions and as expressed among the haulage contractors, some companies simply can't refuse deliveries due to the financial strain it would cause for them. This action puts the logging industry in a superior position and the choice to disregard the conditions of the road because if one refuses to drive, someone else will take the job.

A different view that some haulage contractors presented was that, sometimes, the refusal that haulage companies makes to drive may not be because of bad road conditions at all but is a way for them to avoid non economical trips. Suddenly, a perfectly fine road when only going 1-2 km in can be undrivable when going 5-6 km in. These issues, between the haulage contractors and logging industries, is not something that regards Volvo trucks directly or for Volvo trucks to solve, however, it is a subject worth discussion due to its influence it has on the cause of damage for the oil pan.

The amount of time spent to map people of interest and reach them was a factor that hit the project and consumed more time than whished for. This caused the elimination of testing the oil pans durability in a virtual simulation which would have been interesting to compare with the existing D16 oil pan durability.

However, an assumption that the redesigned oil pan is superior to the D16 oil pan can be made since steel is a more durable material than plastic SMC. The questions if the steel oil pan will hold the forces applied during drift, however, is unanswered but, as mentioned, the assumption that it will perform better than the plastic SMC oil pan can be made with great confidence.

To round-off the discussion, the purpose for this degree project was met and a redesign of the oil pan, with a new more durable material and an increased clearance, was developed.

Since the developed concept is to serve as a recommendation for a larger project at Powertrain, it is not sure that the redesigns suggested will be in the final product. However, the project’s results are still relevant due to the facts gained from the research and customer needs analysis that Powertrain lacks and will need when continuing the development of the oil pan.

6. Conclusion

This chapter aims to conclusively answer questions regarding the validity of the project as well as presenting the experience gained from this project. Lastly, recommendations for further development will be presented.

6.1 Result and validity of project

The oil pan developed throughout the project was connected to both Volvo Group and the end user. From the customer needs analysis, the customer's requirements were mapped out and the specification of requirements was generated. The most important parts of the entire project were the customer needs analysis and the brainstorming. The customer needs analysis brought up what mechanics, Volvo Group and customer's thought of the issue and allowed a fairly accurate description of the issues with the oil pan. The brainstorming allowed for out of the box thinking which is of tremendous importance in product development.

The project resulted in an oil pan, with further confirmation, could be used by Volvo Trucks as an alternative to the plastic oil pan for very rough conditions in conjunction with the existing skid plate.

6.2 Experience

Tremendous experience has been gained from this project, not only from the existing tools of product development but also from the non-existing. Previous product development project have been pretty straight forward and with teachers present at every turn, so the tools presented were the ones used. For this project the tools were implemented into a real scenario proving that it isn't always straight forward, instead tools were modified or completely redesigned to fit the needs of the project.

The limitations for what the project was to entail was from the beginning non-existent and limitations had to be created. It gave a true sense of what can be done in a certain amount of time.

6.3 Recommendations for further development

For the oil pan developed in this degree project to be utilized in an application it needs to be analyzed in manors excluded from this project due to either time limitations or lack of expertise. The project has been focused on developing the geometry of the oil pan and mapping the different needs of both producer and consumer.

Strength analysis

The oil pan needs to be fully analyzed in terms of impact resistance and wear resistance. This is to confirm the oil pans increased durability as well as that the design is the best choice.

Thermal analysis

The oil pans material has great properties regarding leading away heat from the oil when it exits the engine, but it needs to be confirmed through a thermal analysis. This to ensure that the oil does not get either too hot or too cold.

Sound and vibrations

With the harsher and harsher demands of sound generating from vehicles in cities by government and the EU, the oil pan must be tested for sounds and vibrations. This is to ensure that the oil pan does not add to the noise produced by the truck.

Manufacturing process

The process of deepdrawing is complicated and heavily relies on the experience of engineers. To fully develop the manufacturing process for this part, research must be done and tests must be conducted. The surface finish must also be considered to allow the oil to flow freely.

To ensure a smooth and cheap process good relations with manufacturers must be existing.

References

Trafikverket. (2019). *Tjällossning, tjälskador och potthål*. Retrieved 05 15, 2019, from Trafikverket.se: https://www.trafikverket.se/resa-och-trafik/underhall-av-vag-och-jarnvag/Sa-skoter-vi-vagar/Underhall-av-belagda-vagar-/tjallossning-tjalskador-och-potthal/

Alzubaidi, H. (1999). *Drift och underhåll av grusvägar: litteraturstudie.* Retrieved 05 13, 2019, from Väg- och transportforskningsinstitutet: https://www.vti.se/sv/Publikationer/Publikation/drift-och-underhall-av-grusvagar_673240

Trafikverket. (2011). *Dispenstransporter - en handbok.* (T. Holmstrand, Ed.) Retrieved 05 10, 2019, from Trafikverket.se: https://trafikverket.ineko.se/Files/sv-SE/11368/RelatedFiles/2011_057_dispenstrasnporter_en_handbok.pdf

Hågeryd, L., Björklund, S., & Lenner, M. (2002). *Modern Produktionsteknik: Del 1.* Stockholm: Liber AB.

Johannesson, H., Persson, J.-G., & Pettersson, D. (2013). *Produktutveckling.* Stockholm: Liber AB.

The Independent. (2014, 02 18). (J. Vincent, Ed.) Retrieved 04 22, 2019, from https://www.independent.co.uk/news/science/sinkholes-what-are-they-how-do-they-form-and-why-are-we-seeing-so-many-9136235.html

The Independent. (2014, 02 18). (J. Vincent, Ed.) *What are sinkholes, how do they form and why are we seeing so many?* Retrieved 04 22, 2019, from https://www.independent.co.uk/news/science/sinkholes-what-are-they-how-do-they-form-and-why-are-we-seeing-so-many-9136235.html

CLOSER. (n.d.). *About CLOSER*. Retrieved 01 25, 2019, from https://closer.lindholmen.se/en/about-closer

Purchasing and negotiation training. (2010, 06 28). *What it costs to obtain a new supplier.* (H. Hough, Ed.) Retrieved 04 13, 2019, from Purchasing and negotiation training: http://purchasingnegotiationtraining.com/purchasing/what-it-costs-to-obtain-a-new-supplier/

CES EduPack software. (2018). Cambridge, UK: Granta Design Limited. Retrieved from www.grantadesign.com

Hellsten, A., & Pettersson, O. (2018). *Reducing Time-To-Pressure in Oil System of Combustion Engine with Oil Cooler: Investigation of bypassing the oil cooler in an internal combustion engine.* Bachelor Thesis, Chalmers University of Technology, Department of Mechanics and Maritime Sciences, Gothenburg. Retrieved from http://publications.lib.chalmers.se/records/fulltext/255114/255114.pdf

Rexed, F., & Skogh, L. (2018). *Möjligheter inom additiv tillverkning på Volvo Penta: The potentials within additive manufacturing at Volvo Penta.* Degree project, Chalmers University of Technology, Department of Industrial and Material Sciences, Gothenburg. Retrieved 05 02, 2019, from http://studentarbeten.chalmers.se/publication/256052-mojligheter-inom-additiv-tillverkning-pa-volvo-penta

Pearson, A. (2018, 01 24). 10 Disadvantages of 3D Printing Technology. *3DINSIDER*. Retrieved 05 02, 2019, from https://3dinsider.com/3d-printing-disadvantages/

On Demand Rapid Prototyping overview. (n.d.). Retrieved 05 03, 2019, from 3D SYSTEMS: https://www.3dsystems.com/on-demand-manufacturing/fast-turn-prototyping

Carter, S. (2017, 02 16). *RAPID PROTOTYPING: SUBTRACTIVE VS. ADDITIVE*. Retrieved 05 10, 2019, from Datron: https://www.datron.com/blog/rapid-prototyping-subtractive-additive/

Additive Manufacturing & Subtractive Manufacturing | Pros & Cons, Applications. (n.d.). Retrieved 05 04, 2019, from Minaprem: http://www.minaprem.com/machining/introduction/additive-manufacturing-subtractive-manufacturing-pros-cons-applications/

Svensson, I., & Svensson, I. (2004). Gjuteriteknisk handbok. Retrieved 04 24, 2019, from http://gjuterihandboken.se/

Prakash, S. J. (2017, 12 02). Pros & Cons of Sand Casting. *Engineering Product Design*. Retrieved 05 15, 2019, from https://engineeringproductdesign.com/advantages-disadvantages-sand-casting/

Daugherty, R. (2016, 01 26). *How Deep Drawn Can Reduce Your Manufacturing Costs*. Retrieved 04 22, 2019, from Accurate Forming: https://www.accurateforming.com/blog/how-deep-drawn-manufacturing-can-reduce-your-manufacturing-costs

Adnan, Z. (2009). *Deep drawing mechanism, parameters, defects and recent results: state of the art.* Applied Science University, Deparment of Mechanical and Industrial engineering, Amman. Retrieved 05 14, 2019, from https://iopscience.iop.org/article/10.1088/1757-899X/146/1/012009/meta

White, F. M. (2016). *Fluid Mechanics* (8th ed.). New York: McGraw-Hill Education.

Volvo Lastvagnar Sverige. (n.d.). Retrieved 03 15, 2019, from Volvo Lastvagnar Sverige: https://www.volvotrucks.se/sv-se/home.html

Appendix A

[redacted]

Appendix B

[redacted]

Appendix C

[redacted]

Appendix D

[redacted]

- *Volvo har vägförhållandegrader som är indelade i smooth, rough, very rough och crosscountry. Lastbilarna som kör med oljesumpen som ska förbättras kör i very rough vägförhållanden.*

[redacted]

[redacted]

[redacted]

Från skadan som skapar läckaget, hur lång tid tar det innan felet märks av?

- ***Beror på hur alvarlig skadan är, alt från direkt till några dagar senare***

Hur länge är fordonet funktionsdugligt efter skada?

- ***Antingen stop direkt eller flera månader om oljan fylls på efter hand***

Vid reparation, blir detaljen som ny och har fortfarande samma förväntade livslängd?

- ***Olika beroende på hur allvarlig skada är***

Behövs speciella verktyg eller material för reparationen?

- ***Nej standard verktyg som finns i normal verkstad räcker***

Vid utbyte, finns detaljen att tillgå och hur långt tid tar det att få delen?

- ***Beror på tillgång men bör gå på någon dag/några dagar, sumpen är en standard komponent***

Vid utbyte, vad händer med den trasiga detaljen?

- ***Kan lagas eller så slängs/återvinns sumpen beroende på hur alvarlig skadan är***

Vid läckage I oljesumpen – vad är den vanligaste ställtiden(reparationstiden) för fordonet?

- ***Byte tar cirka 2 timmar medans lagning tar cirka 3 timmar***

Lennart Cider (HCT)

Hur startade HCT projektet?

- ***April 2007 startade projektet, Lennart och Lena kom in i projektet för att det fanns ett behov att utveckla/effektivisera lastbilarna hos Volvo***

Vilka är involverade i HCT projektet?

- ***Det finns väldigt många aktörer inom HCT projektet och alla har sina drivkrafter inom olika områden. Dessa områden skulle kunna sorteras ner till:***
  LASTBILAR (Volvo, Parator, Wabco, SSAB, EXTE….)
  VÄGAR (Trafikverket, REV - Riksföreningen enskilda vägar, Kommuner…)
  PRODUCENTER/TILLVERKARE (SCA, Storaenso,….)
  TRANSPORT (DB Schenker, DHL…)

Hur är staten/regeringen inblandad i HCT projektet?

- ***De styr via sina myndigheter såsom Trafikverket, Transportsstyrelsen, Riksdagens trafikutskott (VD Anders Åkesson, kan prata med, hälsa från Lennart, viktig spelare i HCT)***

[redacted]

[redacted]

[redacted]

Appendix E

Volvo Trucks. Driving Progress

FAKTABLAD

Vägförhållanden

Smooth road conditions.

Rough road conditions.

Very rough.

Vägförhållanden

Lastvagnen är optimerad för att passa den typ av vägar där den kommer att användas. Genom att utnyttja parametern Vägförhållanden (Road Conditions) underlättas specifikationen av ramtjocklek, hjulupphängning och andra egenskaper.

Smooth road conditions (RC-SMOOT)

För fjärrtrafik på välunderhållna och mindre välunderhållna vägar.

Rough road conditions (RC-ROUGH)

För körning på dåligt underhållna vägar och hårdpackad sand eller grus samt andra ytor av god eller dålig kvalitet.

Dessa fordon är robusta och byggda för långvarigt bruk under svåra förhållanden.

Very rough (RC-VROUG)

Vägförhållandena anses vara Very Rough när mer än 5 % av den totala körsträckan försiggår på mycket dåliga vägar eller i terräng.

VOLVO

Volvo Truck Corporation
www.volvotrucks.com

2012-09-06 SWE Version 01

Appendix F

Questionnaire – Mechanics from Volvo

Bellow follows interviews and meetings with mechanics Volvo in chronological order.

Frågeformulär - Mekaniker från Volvo

Nedan följer intervjuer och möten med mekaniker från Volvo i kronologisk ordning.

Patrik Oscarsson (mekaniker YB)

Gå igenom oljesumpens funktioner och delsystem.

- *Inuti oljesumpen så finns det olja som via en pump, pumpas upp till motorn, oljan passerar genom ett filter innan det kommer upp till motorn. Det finns en oljetryckssensor/oljemängdssensor som sitter kopplad till motorn i sumpen, det finns också hål för påfyllning samt tömning av olja och en utgång med en mätsticka för manuell mätning av oljenivån*

Vilka slags skador är det som sker på oljesumpen?

- *Har mest erfarenhet från stålsumpar där det skett korrosionsskador (rostskador) men detta sker mest i slutet av hela lastbilens livscykel så är inget allvarligt fel. På plastsumpen är det nog mest hål rakt igenom och sprickor men sprickor ät nog inte lika vanligt*

Vilka skador går att reparera och vilka går inte att reparera på oljesumpen?

- *Man lagar nog helst inte plastsumpar utan man byter ut dem. Plåtsumpar går däremot att laga på olika sätt och i omgångar, allt beror på hur allvarlig skadan är. Inbuktningar skulle man t ex kunna trycka ut igen men det går bara att göra så många gånger innan man utmattat materialet i ett specifikt område så pass mycket att det går hål. Sprickor skulle man säkerligen kunna svetsa*

Hur lång tid tar det att reparera/byta ut en skadad oljesump?

- *Väldigt osäker, gissade på samma som Emil P sa. Se Emils frågor. Det han kan säga med säkerhet är att det tar längre tid att byta ut oljesump på en lastbil med luftfjädring än bladfjädring då det är mer saker i vägen vid luftfjädring*

Finns det något mer som ni skulle vilja ändra med oljesumpen?

- *Man skulle kunna ha en oljesump med liknande utseende som några av Volvos bussar där oljesumpen sitter bredvid motorn och är en torrsump istället, då har man en oljetank bredvid och en pump som pumpar in oljan i motorn*
- *Silen som går från botten i sumpen upp till motorn skulle kanske kunna vara kortare så sumpen skulle kunna bli mindre och därmed öka avståndet mellan mark och oljesump*

Vilka andra problem förekommer med oljesumpen?

- *Utmattning vid avtappningshålet pga av för hårt åtskruvad avtappningsplugg*

- *Utmattning vid skruvfästena pga vibrationer*

Ytterligare diskussion med Patrick gav följande information

- *Fick kontaktinformation till en Christer Nordin som är ansvarig för konkurrentanalyser, se kontaktinfo i kontaktformulär*
- *Ska återkomma med kontaktinformation till en verkstadsgubbe där dem tagit av sumpen så man kan se motorns undersida samt de komponenter som kopplar ihop motorn och sumpen*

Tomas Gatenberg (Mekaniker motorlabbet)

Gå igenom oljesumpens funktioner och delsystem.

- *Gått igenom väldigt noga, se skriven produktspecifikation*

Hur fungerar oljesensorn i lastbilarna, visar den oljetryck eller oljemängd? När får föraren varning om minskad oljemängd/oljetryck?

- *Oljesensor visar temperatur och oljenivå. Informationen lagras kontinuerligt så den ska kunna skicka varningar när som till föraren samt att motorn hinner reglera sig och sätta igång eventuella säkerhetssystem*

Vilka slags förändringar hade du vilja göra med oljesumpen?

- *Om något skulle ändras så ska de var att öka volymen på sumpen för att öka serviceintervallen, just nu servas lastbilarna var 10 000 mil. Man ska absolut inte ändra konstruktionen på det sättet att volymen minskas på sumpen. Finns lösningar på sumpar där man gjort den platt som en svamp men bredare istället så samma volym erhålls, finns i USA och kallas privåsump.*
- *Man skulle kanske kunna vrida på dagen sump och montera den omvänt, man kan enkelt montera om sugröret för det finns redan fästen för det på alla motorer*

Ytterligare diskussion med Thomas gav följande information

- *Kolla på aluminiumsumpen som finns idag (VN16), på en amerikansk lastbil finns en sump som är exakt som D16 i Sverige, möjligtvis lite bredare, som man skulle kunna använda direkt. Den sitter bara omvänt på den amerikanska men den ska gå att montera direkt på den svenska lastbilen*
- *Det finns ett säkerhetssystem som är kopplat till oljesumpen och det är fjäderskruvförbanden. Om ett övertryck byggs upp i motorn (blubay) och sumpen så vill man släppa ut det trycket på den kalla sidan av motorn vilket är nere vid sumpen på den bakre delen (smala delen av sumpen i vårt fall). Så fjädrarna är dimensionerade på det sättet att när trycket överskrider sitt max (Tomas gissar på cirka 0,5–0,6 bar) så släpper sumpen från motorn i det nämnda fästet och trycket släpps ut, sen stängs det igen.*
- *På aluminium och plast har du en gummitätning som sitter i ett spår i sumpen, det är inte detsamma på en plåtsump. Där är det en bred tätning istället som har små "gummipluggar" som*

ska dras igenom hål som finns längs överkanten på sumpen, detta för att tätningen ska kunna centreras

- ***De kolvarna som roterar vid förbränning/expansion som sitter på vevaxeln nuddar ej oljan***
- ***Fick med en 2D ritning på den aluminiumsumpen vi såg idag, det va en D16***

Tomas Gatenberg (Mekaniker motorlabbet)

Förberedande möte inför mötet med geometriansvarig Antonio La Sala

Oscar & Mona frågor/kommentarer

- ***Vilka begränsningar finns det för utbuktningar hos oljetråget pga andra komponenter?***
- ***Vilka begränsningar finns det för utbuktningar hos oljetråget pga monteringskrav (krav på utrymme vid montering?***

Tomas Gatenberg frågor/kommentarer

- ***Oljefilter, bränslefilter, vattenavskiljarfilter för bränsle, fäste till ladd luftrör från turbo och främre motorfäste är komponenter som kan störas av utbuktningarna***
- ***Man behöver kunna slå hål på oljefiltren underifrån och skruva av dem men det ska finnas plats att montera av dem trots utbuktningar. Oljefiltren sitter cirka 80 mm från motorblocket och gängan är 20 mm***

Övrigt/slutsats från mötet

- ***Specifikationer för oljemängder finns i separat mapp***
- ***Se bilder på komponenter i separat mapp***

Appendix G

[redacted]

Appendix H

[redacted]

Appendix I

Questionnaire – Component & geometry engineers at Volvo

Bellow follows interviews and meetings with component & geometry engineers at Volvo in chronological order.

Frågeformulär - Komponent och geometriingenjörer hos Volvo

Nedan följer intervjuer och möten med komponent och geometriingenjörer hos Volvo i kronologisk ordning.

Mattias Blondell & Magnus Nilsson (Komponentansvarig respektive Project managing engineer)

Mona & Oscar frågor/kommentarer

- *Frågor som ställdes kom från frågeformulär #1*

Mattias & Magnus frågor/kommentarer

- *Vi har en låg kunskap om hur själva skadorna uppstår och frågar därmed om en genomgående undersökning hos samtliga kunder för att bygga upp statistik kring hur vanligt problemet med oljesumparna är*
- *De på Powertrain som arbetar med oljesumpen vill försöka tillverka den i aluminium men har frågetecken kring materialval pga de problem som uppstått kring oljesumpen. Därav önskas en undersökning om hur sumpen går sönder*

Övrigt/slutsats från mötet

[redacted]

Frågeformulär #1 - Mattias Blondell & Magnus Nilsson

Hur tillverkas oljesumpen för D13/D16 i de olika materialen som används idag?

[redacted]

Har Volvo några krav/önskemål på vilken tillverkningsmetod som den framtida oljesumpen för D16 ska tillverkas på?

- *Det finns inga krav på tillverkningsmetoden. Detta på grund av blandade faktorer*
    1. *Volvo tillverkar dem inte själva vilket innebär att de inte har investerat i stora maskiner eller verktyg utan det står leverantören för*

2. *I dagsläget sitter det tre olika sumpar på D13 utan att orsaka några problem då samtliga sumpar anpassats för perfekt passform*

- *Det enda Volvo önskar är en mer robust sump som klarar av sina utmaningar*

Har Volvo några krav/önskemål på vilket material den framtida oljesumpen för D16 ska tillverkas i?

- *Samma svar som tidigare fråga. Volvo har inga krav utöver relativt självklara som till exempel att den inte får göras i miljöfarliga material. De flesta material vi kommer röra oss runt är helt okej men undvik radioaktiva saker*

Har några stresstester utförts på oljesumparna i D13 och D16? Om ja, hur fungerar dessa tester och vad har man fått för resultat?

- -

Har några simuleringar (FEM) gjorts på sumparna i D13 och D16? Vem har gjort dessa och kan vi komma i kontakt med dessa?

- *Ja det har det gjorts men vi saknar ett namn på vem som har gjort den*

Finns det några riktvärden på max/min oljetryck i oljesumpen?

- *Oljetrycket i oljan i sumpen är väldigt nära atmosfärstryck, däremot så har den oljeblandade luften som är ovanför sumpen trycksatt. Sumpen ska släppa på kall-sidan vid cirka 25–35 kPa alltså 0.25-0.35 ATM vilket är relativt lite. Men det verkar skruvförbanden ta hand om*

Finns det några riktvärden på oljesumpens dimensioner, storlek och vikt?

- *I nuläget säger Mattias, antagligen för att han inte vet, att de yttre dimensionerna får vara i enlighet med den existerande oljesumpens yttre dimensioner*

Finns det ett volymminimum som oljesumpen får ha i storlek? Alltså hur lite får maxvolymen vara på mängd olja i oljesumpen?

- -

Finns det någon produktspecifikation/kravspecifikation för D13 samt D16 i de olika materialen som vi kan få?

- *Vi fick ritningar men inga kravspecifikationer*

Finns det några skaderapporter gällande oljesumpen som vi kan få?

- *Protus, men det bedömer Mattias vara värdelöst*

Finns det några andra problem med oljesumpen än det som uppstår när den kolliderar med ting på vägen?

- *Nej*

Har ni haft kontakt med andra företag med liknande problem med oljesumpen som ni har och bytt information mellan varandra? Isåfall, kan vi få ta del av den informationen?

- *Nej*

Vad för slags förbättringar har gjorts för att minimera skadorna på oljesumpen i dagsläget utöver hasplåten?

- *Inga*

Är det Volvo trucks som tillverkar samtliga sumpar eller är det ett externt företag?

Om externt företag:

Uteslutande externa företag vad kostar det att tillverka D13 samt D16 oljesumpen i de olika materialen idag?

- ***De siffrorna saknas för det är externa företag***

Uteslutande externa företag vad kostar det att köpa in D13 samt D16 oljesumpen i de olika materialen idag?

[redacted]

Om Volvo trucks:

Vad kostar det att tillverka D13 samt D16 oljesumpen i de olika materialen idag?

- -

Gentemot vad oljesumparna kostar idag ide olika materialen, hur mycket mer får en nykonstruktion kosta? Alltså, vad är takkostnaden?

- -

Finns det något mer som ni skulle vilja ändra med oljesumpen idag?

- ***Nej***

Frågeformulär #2 - Mattias Blondell & Magnus Nilsson

Max- och min volym på olja i oljesumpen när den nyligen är påfylld, alltså hur många liter? Har fått siffror från Tomas Gatenberg enligt bild nedan, stämmer dessa?

[redacted]

- -

D13 sumpen får en ökning på 33 %, [redacted], i kostnad när det går från plast till stål. Är det rimligt att anta att D16 sumpen borde få en prisökning på 33%, [redacted], också?

- -

Hur mycket extra kostar en D13 oljesump i plåt jämfört med en i plast?

- D13 sumpen får en ökning på 33 % [redacted], i kostnad när det går från plast till stål

Vid en tidigare mejlkonversation ska en kravspecifikation för D13 plastsump ha bifogats men det gjordes ej, kan vi få denna?

- -

Enligt Thomas Gatenberg (Mekaniker motorlabbet) ska oljesumpen släppa på den kalla sidan vid övertryck i motorn och sump. Vi har fått en gissad siffra från Thomas men skulle gärna vilja ha en exakt siffra på det trycket

- -

Har några simuleringar gjort i FEM för någon av oljesumparna och skulle vi i så fall kunna få tillgång till dessa eller namn på den som utfört dem?

- -

Antonio La Sala (Geometriansvarig)

Mötet med Antonio La Sala handlade om att se vilka möjligheter det finns med konceptens konstruktion.

Oscar & Mona frågor/kommentarer

- ***Visade upp koncept där utbuktningar har lagts till och påfyllningshålet har flyttats samt den amerikanska sumpen***
- ***Vilka begränsningar finns det för utbuktningar hos oljetråget pga andra komponenter?***
- ***Vilka begränsningar finns det för utbuktningar hos oljetråget pga monteringskrav, alltså krav på utrymme vid montering?***
- ***Slutligen, vem har sista ordet gällande dimensionerna på oljetråget konstruktion? Antonio, Mattias eller någon annan?***

Antonio La Sala frågor/kommentarer

- ***De områden på sumpen som är helt off limit är den smalare bakre delen som ligger kring framaxeln, man har redan upptäckt skrapningar på sänket närmast framaxeln som indikerar att mer utrymme antagligen kommer behövas. På den bredare delen längst fram på sumpen finns en inbuktning på ena hörnet som antagligen kommer ökas ännu mer pga rör som slår i***
- ***De områden på sumpen som gör det komplicerat för utbuktningar är infästningar, oljefiltren och bränslefiltren. På vissa lastbilar även CVV-röret där luft kommer ut***
- ***De områden där det kan finnas space att utnyttja är en bit längst fram på sumpen vid sänket och på motsatt hörn bredvid samt under påfyllningshålet***
- ***Vissa områden kan komma att ändras via Powertrain såsom längre oljefilter och annorlunda oljesensor***
- ***Man behöver också ta vara på motorrörelse under körning men det är en roterande rörelse***
- ***GTO (Group trucks operation) samt Volvo Penta med flera använder i vissa fall samma oljesump men har andra geometriska krav vilket man kanske behöver ta hänsyn till***

Övrigt/slutsats från mötet

- ***Påfyllningshålets slang/rör är flexibel så geometriska förändringar till dess plats är möjligt. Det finns kringliggande komponenter som skulle störas enormt av utbuktningar vid av/på-montering i fabriker. De få utrymme som är kvar kommer inte ge en tillräckligt stor förändring på frigång för att***

rättfärdiga en så pass komplicerad lösning med ändrad tillverkningsprocess. Så länge sumpen håller motorns infästningspunkters dimensioner i längd och bredd så ska det inte vara några problem vid montering av motorn

[redacted]

Appendix J

Critiera number	Criteria	Value	Authority of standard (AOS)	Demand = D Wish = W	Method of verification
1	Hold specified amount of oil	42 liters at refill maximum capacity	Mattias Blondell	D	Measurement in Creo
2	Weight	Component should be as light as possible	Mattias Blondell	W(2)	Comparison with existing oil pan
3	Resistance to oxidation	Rustprevention must be considered	Emil Petterson	D	Verbal confirmation from AOS
4	Removable	Solution must be able to be installed and removed without removing surrounding components	Tomas Gatenberg	D	Verbal confirmation from AOS
5	Easily removable	Solution that is installed and removed easily	Tomas Gatenberg	W(2)	Verbal confirmation from AOS
6	Oil change compatible	Must have drafthole for oilchange as well as a refillhole	Tomas Gatenberg	D	Verbal confirmation from AOS
7	Oilmeter connection inlet (Inside)	For sensorconnection	Emil Petterson	D	Verbal confirmation from AOS
8	Oilmeter connection outlet (Outside)	For sensorconnection	Emil Petterson	D	Verbal confirmation from AOS
9	Tolerance of max/min interior pressure	The oil pan should not sustain damage if the safetymechanism for exceeding internal pressure is triggered	Emil Petterson	D	Calculations in Creo
10	Durable	The oil pan should stand up to the harsh enviroments wear and tear better than todays solution	Emil Petterson	D	Experimental simulations in Creo
11	Utilize existing attachmentpoints	The oil pan must match the existing attachmentpoints	Emil Petterson	D	Assembly in Creo
12	Height	The height should be reduced if possible to increase the clearence	Emil Petterson	W(5)	Measurement in Creo
13	Defendable manufacturing cost	The manufacturing cost should be defendable with regard to added features or improved properites	Lena Larsson	D	Costcalculations
14	Cheap manufacturing cost	The manufacturing cost should be as low as possible	Lena Larsson	W(4)	Comparison with existing oil pans for D13 & D16
15	Wear-restistant attachmentpoints	The attachmentpoints to the engineblock should be better protected from the screws eating into the oil pan than todays solution	Emil Petterson	D	Verbal confirmation from AOS
16	Isolated redesign	Solution that requires no redesign of surrounding components exluding the suctiontube	Emil Petterson	D	Verbal confirmation from AOS
17	Uncomplicated solution	Solution that utilizes the existing line of manufacturing and distribution as much as possible	Emil Petterson	W(3)	Verbal confirmation from AOS
18	Maximum width	Solution can not be wider than the existing solution	Emil Petterson	D	Measurement in Creo
19	Maximum length	Solution can not be longer than the existing solution	Emil Petterson	D	Measurement in Creo
20	Measuring stick inlet	For manually measuring oil	Emil Petterson	D	Verbal confirmation from AOS

Appendix K

Questionnaire – Haulage contractors & drivers

Below follows interviews and meetings with customers from haulage contractors, previous and current truckdrivers chronological order.

Frågeformulär - Åkerier & Förare

Nedan följer intervjuer och möten med åkeriägare, före detta samt nuvarande lastbilsförare i kronologisk ordning.

Marina Thyberg (Thybergs Åkeri)

Hur fungerar oljesensorn i lastbilarna, visar den oljetryck eller oljemängd? När får föraren varning om minskad oljemängd/oljetryck?

- ***Oljesensorn varnar föraren när oljemängden börjar bli för låg. Så om det blir ett hål och oljan börjar läcka ut varnas föraren väldigt snabbt men om det är en mindre spricka kan det ta en längre tid då oljan inte rinner ut så snabbt. Då märker oftast föraren ett oljeläckage när man kliver ur lastbilen***

Kör ni några 13-liters lastbilar från Volvo med plast samt plåtsump?

- ***Kör D13 i plast, visste inte att det fanns i plåt***

Har ni haft några problem med sumparna på 13-liters?

- ***Inte alls i samma mängd, det är nästintill bara sumpen på 16-liters som går sönder***

Hur länge har ni haft problem med sumparna på 16-liters?

- ***Sedan 2012 vilket var året då dem köpte in lastbilarna med plastsump***

Vad för slags problem har det varit med sumparna?

- ***Sumparna har spruckit pga direkt kontakt med mark eller saker ovanför mark, detta har varit när de kör i skogar. Vid minsta lila stöt så blidas en sprickbildning direkt. Har också blivit hål***

Har ni någonsin fått motorhaveri pga. trasig sump (oljeläckage)?

- ***Nej vi har aldrig fått motorhaveri pga oljeläckage men det är för att vi har så observanta förare som reagerar och stannar och undersöker sumpen så fort en varning ges att oljemängden går ner. Om de kör på något så stannar de också och undersöker sumpen. De har varit fall där de behövts bärgas till verkstad för att de inte räcker med att fylla på oljan och köra själv till verkstaden***

Vad händer före, under och efter skada?

- *Om föraren noterar att hindret på vägen som inte går att undvika eller förflytta så försöker de köra vidare och hoppas på det bästa. Om de känner av att det slår i så går de ut och undersöker sumpen med en gång. Det finns inte utrymme att vända förens lastplatsen*

Hur arbetar ni för att förbygga skador vid riskfyllda vägar?

- *Vid välkända vägar som har riskfylld väglag för sumpen så skickar åkeriet andra lastbilar, med normalhöjd som inte ingår i HCT – projektet*

Hur upptäcker ni skadorna?

- *Antingen märker föraren det direkt genom att de känner slaget mot sumpen, hör knappast att de kör på hinder. Om det blir småsprickor så märker de oljeläckaget när de kliver ut ur lastbilen för av/på lastning eller så upptäcks skadan för att oljesensorn varnar föraren om låg oljenivå*

Har ni skidplate (hasplåt) under era sumpar på era 16-liters?

- *Ja vi har haft hasplåt under sumparna men inte längre, vi tog bort dem för det gav mer problem än nytta*

Har det blivit bättre eller sämre med skidplate?

- *Det blev sämre med hasplåten för det fastnade småsten mellan sumpen och hasplåten som låg och nötade mot sumpen. Vi var tvungna att vara vaksamma på detta och skruva loss hasplåten emellan åt för att ta bort småstenen*

I vilka slags terränger kör ni i (längst?)?

- *Vi kör ju rundvirkesbilar så vi kör längst 2 till 3 km i skogen. Resterande sträckor kör vi på större vägar (asfalt)*

Vid vilka tillfällen/områden går sumpen sönder mest?

- *Skogsvägar*

Hur lång stopptid får ni ungefär vid skadad sump (upptäcker skada->körduglig lastbil)?

- *De går som snabbast 1 dag och som längst 3 dagar innan vi kör igen. Det som tar tid är att verkstäderna inte har reservsumpar på lager utan måste beställa dem. Om det bara skulle var att köra in och byta så tar det bara några timmar*

Vad skulle vara ideallösningen för er?

- *Ett material som tål smällar, alltså som bara bucklas till vid kollision istället för att spricka eller gå hål direkt*

- *Om man kan lösa så sumpen inte går under drivaxeln utan satt ovanför så skulle det inte vara någon risk för kollision*

Finns det något mer ni skulle vilja ändra med sumpen?

- *Nej*

Vilka slags kostnader får ni stå för vid skada på sumpen?

- *Det blir kostnader pga av stillestånd, vi får också betala för en ny sump som ligger på cirka* [redacted] *per sump samt verkstadskostnader. Volvo ersätter/kompenserar inte för något*

Ytterligare diskussion med Marina gav följande information

- *De kör lastbilarna från 74 tons-projektet som har medium chassi, detta innebär att de var låga till att börja med och har blivit ännu lägre pga ytterligare sänkning som bidraget till problemet med sumparna. De kommer ej köpa in fler medium chassin tills en lösning med sumparna har skett*
- *När lastbilsförarna kör den 2 - 3 km sträckan ute på skogsvägarna eller riskfyllda vägar generellt så har de ibland försökt höja med luftfjädringen för att undvika kollision. Detta orsakar dock problematik med styrning och viktfördelning som är en säkerhetsfråga*
- *Om det dyker upp sten eller liknade på vägen som inte går att kringgå så försöker förarna flytta på objekten men ibland kan de vara berghällar som sticker upp och de kan de inte hacka bort*

Christer Nilsson (Holger-Nilssons Åkeri)

Kör ni några 13-liters lastbilar från Volvo med plast samt plåtsump?

- *Kör D13 fortfarande i plast*

Har ni haft några problem med sumparna på 13-liters?

- *Nej*

Hur länge har ni haft problem med sumparna på 16-liters?

- *Körde första D16 inom HCT-projektet 2008 som var bladfjädrade så där började problemen. Kör inte HCT-lastbilar längre. Har kört/kör provbil för HCT Volvo trucks*

Vad för slags problem har det varit med sumparna?

- *Det har varit enbart sprickbildningar, inga hål, som har uppstått för att sumpen stöper/skrapar i vägen pga av tjällossning. Detta sker framförallt på våran och hösten, så under vintern är det aldrig problem och på sommaren är det lite problem bara*
- *Sprickbildningarna har också uppstått när framaxeln skrapar i och grus/sten flyger över och träffar framsidan på sumpen. Vi har kört sönder cirka 4–5 sumpar*

- ***Det är oftast skador på framsidan***

Har ni någonsin fått motorhaveri pga. trasig sump (oljeläckage)?

- ***Nej***

Hur arbetar ni för att förbygga skador vid riskfyllda vägar?

- ***Om vi vet med oss att den väg vi ska köra ut på är riskfylld för det varit kraftigt regnväder så kör vi helt enkelt inte förens vi eller andra hinner grusa vägen. Men om vi redan påbörjat körningen så finns det inget alternativ än att köra igenom och hoppas vi tar oss fram. Vi kör på olika vägar hela tiden så kan ej förutspå problemvägar***

Hur upptäcker ni skadorna?

- ***Vi hör när det skrapar i och då går vi ut och undersöker direkt***
- ***Det går aldrig så långt att oljesensorn hinner varna för låg oljenivå***

Vad händer under och efter skada?

- ***Om vi kan köra vidare så gör vi det, alla skador som skett har vi kunnat reparera tillfälligt med plast-inpaddning. Det är som ett jättegummi som man täcker över hålet med***

Har ni skidplate (hasplåt) under era sumpar på era 16-liters?

- ***Haft hasplåten på provbilen***

Har det blivit bättre eller sämre med skidplate?

- ***Sämre, har den inte längre***

I vilka slags terränger kör ni i (längst?)?

- ***Mest grusvägar vi kör på, en liten bit är skogsvägar***

Vid vilka tillfällen/områden går sumpen sönder mest?

- ***Skogsvägar för att skogstraktorn drar sönder vägen efter tjällossning***

Hur lång stopptid får ni ungefär vid skadad sump (upptäcker skada->körduglig lastbil)?

- ***Om man hinner beställa en oljesump innan 16 på en vardag så får verkstaden oftast in den till nästa dag och kan fixa bilen så 1–2 dygn innan den är körduglig igen. Har kunnat lagat provisoriskt tills verkstaden får in en ny sump***

Vad skulle vara ideallösningen för er?

- ***Att höja upp sumpen, göra den mindre eller plattare. Just nu servar de sin bil vid 4000 mil vilket de kommer upp på 2 månader. Om det intervallet skulle ökas pga minskad oljemängd tills säg 1 månad så hade inte det varit något större problem***

Finns det något mer ni skulle vilja ändra med sumpen?

- ***Ibland drar folk i oljepluggen för hårt så plasten går sönder. Mänskligt fel såklart, bara en observation***

Vilka slags kostnader får ni stå för vid skada på sumpen?

- [redacted] ***för själva sumpen plus stillestånd och verkstadskostnader***

Ytterligare diskussion med Christer gav följande information

- -

Torbjörn Bennedsved (åkeriägare, kört förr, verkstad)

Kör ni några 13-liters lastbilar från Volvo med plast samt plåtsump?

- ***Kör D13 i plast (64-ton)***

Har ni haft några problem med sumparna på 13-liters?

- ***Nej***

Hur länge har ni haft problem med sumparna på 16-liters?

- ***Ser inte problemen med sumparna som ett större problem för bara blivit en skada en gång. Men har många kunder till vår verkstad som kommer in ofta och är tvungna och byta, dess kunder kör D13 plastsumpar (notera att de då är vanlig frigång!!). Problemen började för kunderna för 4–5 år sedan***

Vad för slags problem har det varit med sumparna?

- ***Vi har skrapat i sumpen en gång bara, gav en 7–8 cm lång spricka som var hårfin i tjockleken. Våra kunder får problem oftast vid tjällossning och det är enbart sprickor de kommit in med, aldrig hål***

Har ni någonsin fått motorhaveri pga. trasig sump (oljeläckage)?

- ***Nej***

Vad händer under och efter skada?

- *Vi har bara skadat vår sump en gång och då va de oljeblöta precis vid sprickan som vår mekaniker upptäckte vid veckounderhållet, en grej som ingår i HCT projektet är att skicka data om lastbilen vilket inkluderar veckounderhåll. Alltså märkte inte vår förare av skadan*
- *Man kan lappa ihop sprickor provisoriskt med plast-inpaddning tills man byter ut sumpen hos en verkstad*

Hur arbetar ni för att förbygga skador vid riskfyllda vägar?

- *Vi höjer lastbilarna till max vid dåligt väglag, skogsläge för fjädringen, och enligt mig så kan man som en erfaren förare förutspå att om början av skogsvägen är dålig så kommer resten vara det också. Om det är för dåligt väglag så kör vi helt enkelt inte. Se vidare diskussion kring detta ämnet längre ner*

Hur upptäcker ni skadorna?

- *Vi upptäckte pga vår veckokoll med mekanikern. Sen gör vi en daglig check där vi manuellt kollar oljenivån på våra lastbilar det första vi gör på morgonen*

Har ni skidplate (hasplåt) under era sumpar på era 16-liters?

- *Har kört med hasplåt men gör det inte längre*

Har det blivit bättre eller sämre med skidplate?

- *Sämre, det kommer grus emellan och det tar för lång tid att ta bort hasplåten för att rensa gruset och tar för lång tid vid av/påfyllning av olja samt byte av oljefilter. Vi körde aldrig på något så va aldrig att hasplåten slog i något och fick en inbuckling*

I vilka slags terränger kör ni i (längst?)?

- *Mestadels är asfalt/byväg (grusväg) och väldigt liten del är skogsväg. Skillnaden mellan byvägen och skogsvägen är att man hyvlar och sköter byvägen konstant*

Vid vilka tillfällen/områden går sumpen sönder mest?

- *Skogsvägen*

Hur lång stopptid får ni ungefär vid skadad sump (upptäcker skada->körduglig lastbil)?

- *För våra kunder är 1–2 dygn. Om man kommer in tidigt på morgonen så hinner man få sumpen till eftermiddagen. Själva bytet tar inte mer än 3 h*

Vad skulle vara ideallösningen för er?

- *Det bästa hade varit att göra sumpen mer hållbar, annat material där inbuktningar sker istället för sprickor*

Finns det något mer ni skulle vilja ändra med sumpen?

- ***Man kan ju undra om sumpen som uppenbarligen inte håller för väglaget ska kosta så mycket att ersätta? Chassit är ju faktiskt ganska billigt (säg 2 000 000 kr) men reservdelar, reparationer och service är för dyrt. Volvo borde göra det billigare eller chassit dyrare och ha mer hållbara komponenter***

Vilka slags kostnader får ni stå för vid skada på sumpen?

- [redacted]

Ytterligare diskussion med Torbjörn gav följande information

- ***När det gäller väglaget på skogsvägarna så är det faktiskt skogsbolagen som ansvarar för att det ska hålla en viss standard/körklass. Detta står t om i kontrakten som åkerierna skriver med skogsbolagen. Alltså ska skogsbolagen beställa grus för att grusa vägarna, i många fall levererar de åkeriet som kör timret åt dem gruset. Men ofta är det så att dem inte sköter detta och man kommer ut till skogsvägen och det är alldeles för dålig.***
I vissa fall märker man det direkt och i andra fall kör man igenom skogsvägen, 0–3 km, och kommer till upphämtningsplatsen för timret men nekar att köra. Detta är dock något som inte alla förare har modet nog att göra men i vårt åkeri får förarna bra backning från mig i sådana fall. Då bryter dock skogsbolagen avtalet och beställer åkare från andra företag. Andra åkerier har inte ekonomin att neka sådana kunder/kontrakt, samtidigt har man knappast råd att köra sönder sina sumpar heller för det är så dyrt att byta

Per Höök (förare) (Kör Scania idag)

Kör ni några 13-liters lastbilar från Volvo med plast samt plåtsump?

- ***Nej***

Har ni haft några problem med sumparna på 13-liters?

- ***Nej***

Hur länge har ni haft problem med sumparna på 16-liters?

- ***Inte haft några problem på egna bilar. Körde sönder en sump på en provbil som vi körde åt Lena, den skrapade i ryggen på vägen och det blev en spricka***

Vad för slags problem har det varit med sumparna?

- ***Inte haft några problem med egna sumpar. Körde sönder en sump på Lenas provbil bara. Andra åkerier har problem med sina sumpar, att de går sönder***

Har ni någonsin fått motorhaveri pga. trasig sump (oljeläckage)?

- ***Nej***

Vad händer före, under och efter skada?

- ***Hört att andra gör sönder sina sumpar. Tror det händer för att vägen brister i stunden från ingenstans, vägen kan se bra ut alltså men går tyvärr sönder vid en punkt pga lastbilen***

Hur arbetar ni för att förbygga skador vid riskfyllda vägar?

- ***Vi håller hela tiden igång en bra dialog med de som sköter avverkningen (skogsbolagen) om skogsvägarna tillstånd. Om det behöver grusas någonstans så fixar dem det***
- ***Vi har också en funktion på vår lastbil där luftfjädringen kan ändra så bilen har 3 körlägen. Ett normalläge (asfaltskörning, standardfrigång), ett mellanläge, cirka 1 dm över normalläget) och ett högt läge (skogskörning, flera dm över normalläget)***
- ***Vi har också ett front skydd på lastbilen som egentligen är till för annat men har en extrafunktion som vår lägsta punkt. Så om det skrapar i eller stöter i så vet vi att vi ska höja bilen så inte sumpen eller annat som finns i underredet slår i***

Hur upptäcker ni skadorna?

- ***Man kan höra när det skrapar i***

Har ni skidplate (hasplåt) under era sumpar på era 16-liters?

- ***Vi hade hasplåt på den provbilen vi körde åt Lena, men inte på egna bilar***

Har det blivit bättre eller sämre med skidplate?

- ***Det gäller att ha koll på gruset som samlas mellan sump och hasplåt. Det är bättre med luftfjädringslägen än hasplåt***

I vilka slags terränger kör ni i (längst?)?

- ***Skogsvägen är den kortaste sträckan, för oss snittar den sträckan mellan 5–6 km***

Vad skulle vara ideallösningen för er?

- ***Luftfjädring som ger olika körlägen***

Ytterligare diskussion med Per gav följande information

- *Vägarna kan vara dåliga ibland men standardvägarna, det tillstånd dem är i som mest alltså, är jag nöjd med*
- *Många andra åkerier och förare klagar på att skogsbolagen/avverkarna inte fixar vägarna när det är för dålig. Per tror ibland att det kanske inte är skogsbolagen som är skurkarna utan det kan vara så att ett åkeri hämtat virke på en väg där de bara kör 200 m skogsväg. Sen när nästa hämtning ska ske några km in på samma väg, helt plötsligt är inte vägen tillräckligt bra. Detta är något åkerierna kan "skylla på" för att slippa köra oekonomiska turer. Längre och långsammare sträckor är mindre önskvärda än korta långsamma sträckor*

Anders Eklund (åkeriägare, kört förr)

Telefonintervju hölls med Anders Eklund där både Emil P och Lennart C satt med och diskuterade. Frågorna ställdes allt eftersom och var ej planerade men baserade sig på vad vi frågar tidigare åkerier och förare. Följande kommentarer kom från Ander Eklund.

- *Det är tjällossning just nu men förare avgjorde att vägen var tillräckligt körduglig och körde in på skogsvägen. De va flertal bilar som körde och den bilen som senare fick en söndrig sump körde sist då den tidigare brukar köra fast och de ville undvika stopp för resterande fordon.*

  Väl vid timmerplatsen (lastplatsen) noterar föraren att det läcker lite olja från under lastbilen och konstaterar att ett mindre hål har uppstått vid ena hörnet på framsidan av sumpen. Förfarna ska av rutin kontrollera sumpen vid timmerplatserna men följer inte alltid upp på detta. De avbryter pålastning och kör bilen till verkstad.

  Det som antagligen har hänt, enligt Anders, är att pga tjällossningen har föraren kört en sten som gjort hål på sumpen. Det kan ha förekommit skrapningar men föraren har varken hört eller känt något under bilfärden, det var ett väldigt litet hål så det var lite olja som läckt ut så oljesensorn har inte hunnit varna för låg oljemängd då oljemängden var okej. Det kan också ha varit så att ett av fordonen innan dragit upp i marken när det kört och blottat sen sten, detta är spekulationer. Dem körde utan hasplåtsskydd.

  Anders tycker frigången är alldeles för låg, den måste höjas. Detta problem har uppstått tidigare hos deras lastbilar. Han föreslår ändring på utseendet, kanske man kan göra bredare och minska oljan.

  Eftersöker också en applikation där man som förare kan höja lastbilen med luftfjädringen efter eget behov (över 4,5 m). Det ska dock också finnas en stark indikation för föraren i hytten att den kör i

för högt läge, detta i form av tex en stark blinkande orange lampa så man inte av misstag kör ut med för hög höjd på de allmänna vägarna.

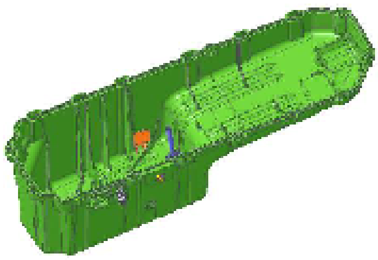
Appendix L

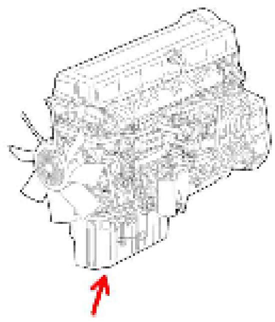
Bachelor Thesis Project at ÅF, Automotive R&D

1 Title: Development of a new oil pan for heavy duty truck engines

Background

The oil pan on heavy duty truck engines is mounted at an exposed position underneath the engine block. Trucks driving in harsh environments can easily damage the skid plate and oil pan, which can lead to oil leakage and therefore truck downtime.





2 Objective

The task is to develop a durable oil pan for trucks driving in rough terrain.

3 Methods

Perform a pre study to evaluate how to design the oil pan to be durable when driving in rough terrain. This can be done using litterateur, interview or benchmarking. Generate and evaluate concepts of how the oil pan can be designed. Investigate material selection and manufacturing processes.

4 Deliverables

A report including:

a) Benchmark study
b) A proposal for redesign of the oil pan

5 Contact

Per Axel Ohlsson, per-axel.ohlsson@afconsult.com **+46105050597**

Please submit your application at: www.afconsult.com/jobb

Bachelor Programs: Mechanical engineering, Product Development,

ÅF is an engineering and design company within the fields of energy, industry and infrastructure. We sustainable solutions for the next generation through talented people and technology. We are based Europe and our business and clients are found all over the world.

ÅF Making Future.

Appendix M

Questionnaire – Material & manufacturing engineers

Below follows interviews and meetings with material- and manufacturing engineers in chronological order.

Frågeformulär - Material- och tillverkningsingenjörer

Nedan följer intervjuer och möten med material- och tillverkningsingenjörer i kronologisk ordning.

Kenneth Eliasson (Gjutexpert)

Samtal med Kenneth för bland annat materialförslag vid gjuten oljesump

Vilka material gjuter ni i och vilka skulle passa att tillverka en oljesump av?

- ***I Skövde har vi hög tillverkning av gjutjärn och lite segjärn. De båda gjuts i runt 1400–1500 grader Celsius och går absolut att tillverka oljesumpar av***
- ***Aluminium skulle också gå att gjuta i, där går temperaturerna bara upp till 700–800 grader Celsius***

Skulle de gå att tillverka en oljesump i något slags stål?

- ***Vi tillverkar inte något i stål då våra ugnar inte klarar av de temperaturerna som krävs för att smälta stål. Temperaturen för att gjuta stål ligger nog kanske på cirka 1800–2000 grader Celsius***

Ytterligare diskussions med Kenneth gav följande information

- ***Skillnaden mellan att gjuta i aluminium jämfört med stål är att, förutom temperaturskillnaden, stål i sig är dyrare***

Anette Nilsson (plåtpressningsexpert)

Samtal med Anette för bland annat materialförslag vid en plåtpressad oljesump

Hur lämpar sig de tre olika materialen järn, stål och aluminium för plåtpressning? Är det någon av dem som är direkt olämplig? Om ja, varför?

- ***Jag har aldrig hört talas om eller jobbat med pressning i järn***
- ***Rekommenderar en plåt (stål) med hög formbarhet, VSCR 140 material eller VSCR 140 EF***
- ***Vi har hittills bara tagit fram ett fåtal verktyg för pressning i Aluminium. För att kontrollera om en artikel är tillverkningsbar i ett material brukar vi göra en FEM beräkning - formningssimulering. Det vi har sett är att särskild återfjädring är svårare att beräkna för aluminium***

Då sumpen kommer ta en del slag samt skrapningar under motorn mot mark så undrar vi om det är så att ni tror att aluminium, i ett pressat format, inte skulle klara av de potentiella deformationerna på grund av dess sköra natur?

- -

Är det någon av de olika materialen järn, stål och aluminium som är dyrare att pressa om materialkostnader förbises?

- ***Kostnaden för att ta fram pressverktyg kan bli större för aluminium i och med svårigheterna med att beräkna återfjädringen***

Vad vet du om materialkostnaderna för järn, plåt och aluminium?

- -

Ytterligare diskussions med Anette gav följande information

- ***Vid pressning av så få artiklar tänker jag att, för stål och aluminium, det skulle vara mest lämpligt att antingen Quintus-pressa eller göra ett dragverktyg för att forma artiklarna och sedan laserskära ut klippkant och hål. Om artikeln inte går att dra i ett steg, så skulle jag försöka använda samma stomme och ha utbytbara stål för en andra pressnings operation (restrike) - i samråd med leverantör***
- [redacted]