Development of a tipper body subframe
-a pre-study at SSAB

Master thesis work
Advanced level, 30 credits

Product and process development

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ABSTRACT

This thesis is performed on master level and covers an assignment given by the Value Added Services (VAS) department at SSAB (Oxelösund, Sweden). The thesis has been carried out by Mattias Hägglund during the fall of 2014 at Mälardalen University.

The transportation industry has over time developed to be more efficient and environmentally aware. Looking at the truck industry shows that the development is strong and constant, new solutions and improvements is being introduced every year. One result of this is reduced fuel consumption and/or increased loading capacity. In the mining industry for example, can a few hundred kilos extra payload make a big different at the end of the day.

This constant development seen in many fields is something that SSAB wants to take part in. By using product diversification can the VAS department reach new customers and secure sales of SSAB steel. Subframes, being a natural step from tipper bodies, are worth to consider as a possible project start-up. Combined with SSABs current tipper body program could a new subframe make its way to the market.

This project have adapted a new product development process in order to come up with a subframe design not yet physically tested, but theoretically superior to conventional subframes. Each development phase of this process is explained and executed in the report, giving the reader a detailed step-by-step overview.

The projects result builds on the knowledge attained from the course of the project and simulation results. With the use of a CAD-program and by applying FEM, have a number of concepts been analysed with regards to their strength and rigidity. The simulation results have made it possible to design a final solution where a number of demands and desired properties have been fulfilled.

The result from this thesis work have reduced the weight by 7%, increased rigidity about 20% and substantially improved the strength in comparison to a typical subframe. This shows that there are possibilities to improve on the current subframe design, and that there is cause for SSAB to make further research and development in the subject of tipper body subframes.

Keywords: SSAB, high strength steel, subframe, product development.
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Bengt Gustavsson at MDH has been key to the success with which the project has concluded. His guidance and support through the simulations have secured the result high quality.

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The author also wants to thank the persons and companies who took a moment to answer my questions and show me their production facilities. It gave valuable information later used in the development phase.

Finally, thanks to everybody at SSAB who have supported my work and happily answered my questions. You have all made me feel welcome and as part of the group from day one. It has been greatly appreciated.
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# ABBREVIATIONS

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AHSS</td>
<td>Advanced High Strength Steel</td>
</tr>
<tr>
<td>Alloy</td>
<td>Blend/mix of metals</td>
</tr>
<tr>
<td>CAD</td>
<td>Computer Aided Design</td>
</tr>
<tr>
<td>Dual Phase Steel</td>
<td>High strength steel that has a soft (ferrite) and a hard (martensite) microstructure, resulting in a desired combination of good ductility with high strength</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Deterioration of a material's strength caused by frequent change in the mechanical state of stress.</td>
</tr>
<tr>
<td>FEM</td>
<td>Finite Element Methods</td>
</tr>
<tr>
<td>HSS</td>
<td>High Strength Steel</td>
</tr>
<tr>
<td>IDT</td>
<td>School of Innovation, Design and Engineering</td>
</tr>
<tr>
<td>LYNC</td>
<td>Windows based communication program</td>
</tr>
<tr>
<td>MDH</td>
<td>MälardalensHögskola (Mälardalen University)</td>
</tr>
<tr>
<td>MC</td>
<td>Thermomechanically rolled (M) Cold formed steel (C)</td>
</tr>
<tr>
<td>NPD-process</td>
<td>New Product Development Process</td>
</tr>
<tr>
<td>RF</td>
<td>Reference Frame</td>
</tr>
<tr>
<td>Steel</td>
<td>Alloy of iron and carbon with a carbon content below 2.1%</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>Maximum force that can be applied without the material breaking</td>
</tr>
<tr>
<td>VAS</td>
<td>Value Added Services</td>
</tr>
<tr>
<td>UHSS</td>
<td>Ultra High Strength Steel</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>The maximum force that the steel can withstand without sustaining permanent deformation</td>
</tr>
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1 INTRODUCTION
Development of a tipper body subframe is a project commissioned by SSAB in Oxelösund. This introduction covers the background and aim of the project.

1.1 SSAB
The history of SSAB is long and interesting. Starting up as three separate steel-companies between 1878 and 1941, SSAB was created when they decided to combine into one company in 1978. From there, a number of acquisitions made SSAB grow all over the world, the latest, being that of the Finish steel manufacturer Ruukki. Today, SSAB is a strong actor on the steel market with its foundation in northern Europe. Product names as Weldox, Domex and Hardox are well known brands in the steel related industry and synonymous with high quality.

1.2 Project Background
Over the course of several years it is possible to see a strong development on trucks and flatbeds. During the 21 century truck companies have made great improvements on the truck body with the introduction and smarter use of high strength steel. Flatbeds have seen a similar development. New constructions and stronger materials have increased the strength and reduced the weight, saving money and emissions along the products lifespan.

However, in comparison to the two above mentioned products, the subframe has seen very low levels of development during its lifetime. There is a range of different manufacturers producing flatbeds with connecting subframe. These producers have their own subframe design, but they all share very similar traits and appearance, and have done so for a long time. A few people around the SSAB company have commented on this rather strange fact. With all the focus on improving the truck and flatbed, the subframe seem to have been left out. The thoughts on subframes expressed as; why change something that working fine?

This gives room for possible development and improvement. As SSAB is moving into the finishing stages of developing their own tipper body program, they see it as a natural step to study subframes. With the in-house expertise on the use and construction of steel products, an optimised design making use of the materials benefits, would give SSAB a product that could transform the way subframes are designed today. Additionally, SSABs high strength steel could give a weight reduction, leading to positive benefits like reduced fuel consumption and additional loading capacity.
1.3 Problem Formulation
Central part of designing a quality product is to have a good understanding of the problem. Everyone involved from developer to sales have a different view of what the customer wants. To find out what the customer really needs is crucial and should be allowed to take a lot of time (Ullman, 2010).
When constructing a truck with a tipper body, there is of course a lot to take into consideration. Weight should be minimized without a loss of function, strength and safety. The tipper body needs to be securely attached to the chassis but at the same time allow for some movement to maintain driver comfort. Another important aspect is the centre of gravity in the finished and loaded truck, which should be as low as possible.
All of these attributes are affected by the subframe and its design. Small changes or a complete redesign have to be carefully measured and tested. Breaking new ground in a field that has evolved through many years of trial and error is not, without difficulties.
SSAB has chosen to view this task as a product development pre-study project. In this conservative field, the problem (or opportunity) is described as a lack of innovation and development, opening up for a potentially, new product.

1.4 Project Aim
The aim of this project is to find out if there is enough room to commit to a new product project. SSAB is looking for a 10 percent improvement in strength, rigidity and weight, as well as a reduction in height. The hope is to get a good starting position to launch a project start-up around the possibility to produce an SSAB subframe.
Is it possible to use SSAB’s steel products and make an improved construction where the introduction of HSS is a central part? Can the design be improved with regards to weight, strength and stability? The aim is to be able to answer these kinds of questions, through research and development. This work is made in an effort to make “a stronger, lighter and more sustainable world” (SSAB’s vision).

1.5 Research Questions
Research questions should help guide a project without being too specific and restricting.
At the conclusion of this project, the report should have answered the following research questions:

RQ1: What are the rules and directives surrounding the construction of a subframe for tipper body trucks?
RQ2: How can high strength steel improve a subframe construction?
RQ3: How can SSAB develop a tipper body subframe with a 10 percent improvement regarding strength, rigidity and weight?
1.6 **Project Limitations**
In accordance with SSAB and MälardalenHögskola (MDH) have the following delimitations been chosen for this project.

1.6.1 **Time Frame**
This project is a master thesis for 30 credit points. Start date is the first of September 2014, end date is the 15 of January 2015 where an oral presentation is held at MDH.

1.6.2 **Vehicles and Equipment**
The developed subframe should fit on Scania chassis and meet their demands with regards to strength, durability, flexibility and more. Other truck brands will not be included in this first research and developing project.
Tipper body trucks will be the only truck configuration that this project will cover. Tankers, cranes or logging units for example will not be taken in consideration for design or construction of this subframe.

1.6.3 **Result**
The final result should consist of a detailed product description. The specific data should be presented and analysed in comparison to an existing subframe.
The projects must be described in a paper report covering all the phases of the new product development process.
2 RESEARCH METHOD

This chapter describes the method used during the course of this project.

2.1 Research Approach

This case study has been initiated on the behalf of SSAB’s department Value Added Services (VAS) located in Oxelösund. Material directly given from SSAB own research department Knowledge Service Center (KSC) have served as the information foundation of this study. At KSC, a vast bank of secondary data has been available tapping into material properties and previous research projects. In addition to SSABs own data and research material other sources has been used to widen the input of information. MDH’s library service (web and house based), Google Scholar and public libraries have been sources of secondary data.

Primary data have mostly been gathered from in house meetings, Scania’s bodybuilding department and interviews.

This project is divided into three parts. Each part covers different steps of the project, as seen in figure 1. Note that they are overlapping each other.

![Part One: Project definition -Theoretical framework](image1)

![Part Two: Empirical study -Results](image2)

![Part Three: Analysis -Conclusions and Recommendations](image3)

Figure 1. Project part 1-3

The product development process used in this project is an adapted version of Ullmans design process from the book *The Mechanical Design Process* (Ullman, 2010), combined with Ulrich and Eppingers development process from the book *Product Design and Development* (Ulrich and Eppinger, 2008). This new product development process is explained in detail in chapter 3.1.
2.1.1 Qualitative and Quantitative Data.

Quantity, also known as category questions, can seem like easy and straight forward questions. They require a simple short answer, often an exact number or approximation. Quantitative questions are often seen to have pre-selected alternatives answers. The wording of the questions is critical for the outcome and needs careful consideration (Bell, 2006).

Hox and Boeije (2005) describes quantitative data as data that can be described numerically in terms of objectives, variables, and their values, clearly connecting it to a degree of data volume. The large diversification of subframes made it clear from the start that quantitative questions will be hard to formulate. The result would be ill-founded in reality, where every company might give different answers. Not enough quantitative numbers would be acquired for future analysis. The use of quantitative data is therefore conservative in this report.

Some believed that quantitative data gives little but exact information. This is not true, as large amount of data is generated in a qualitative study. The aim here is to provide an understanding of the complexity of the research problem. This may include transcribed records of interviews, audiovisual material, a diary or chronological account, the researcher's reflective notes made during meetings, jotted notes and more detailed field notes of observational research (Hox and Boeije, 2005).

This project mainly builds on qualitative data gathered from several companies working direct or indirect with subframes and HSS. The methods used to collect qualitative data include ethnographic practices such as directly observing and interviewing working personnel. A large part of this project is to interpret the data and draw correct conclusions. The result will depend heavily on the thoroughness of the analysis of the qualitative data.

2.1.2 Primary and Secondary Data Gathering

When conducting research and development projects, there are two types of data. Primary and Secondary data are both of great importance to a project that wants to build on old, as well as new, information. Primary data is data specifically collected to answer the research problem at hand, using tools that best suits the research problem. Later, when this data is made available for others it becomes secondary data for them. Secondary data is described as data originally collected for a different purpose and reused for other research. (Hox and Boeije, 2005)

This project relies heavily on primary data for its result. The project uses secondary data to plan and structure the method and development process. There is for these tasks an abundance of secondary data available, surrounding the process and tools.

On the main subject of the project however, secondary data have been hard to come by. A few in-house projects are touching on the subject but none are taking the problem head on. This leaves primary data as a crucial and necessary part of this project. KSC on SSAB has provided secondary data in the form of reports from similar projects, material properties and more. The library along with internet search engines has also served as tools for secondary data collection. Primary data comes from company visits, interviews conducted with in-house personnel and external customers.
2.1.3 Structured, Semi- and Unstructured Interviews

The goal of any interview is to ask questions and get answers. This can seem easy enough but the method used in the interview has a big impact on the received answers. No matter how careful we phrase the question, the spoken or written word will always have a residue of ambiguity. Despite that, interviewing is one of the most powerful and common ways we use to understand one another (Fontana and Frey, 1994).

In a structured interview the respondent is asked a set of pre-established questions with a limited set of responses. There is generally little or no room for open end questions, this is to make sure the interview is running along smoothly. The method of recording the information follows a similar pre-decided coding scheme. Thus, all respondents are given the same set of questions, asked in a likewise manner, by an interviewer who repeat the same structure. In other words, there is very little flexibility in the way questions are asked or answers are given in the structured interview setting. (Fontana and Frey, 1994).

Surveys are an example of structured interviews which only provides a few pre-decided answers to choose from.

In comparison the unstructured interview method gives a greater span in its qualitative nature. Many qualitative researchers state a difference between unstructured interviews, also known as in depth interviews, and practical observations. Some do however mean that they go hand in hand saying that the information gathered from observations often come from informal interviewing in the field. What Fontana and Frey (1994) means, is that an unstructured interview can, and to some degree should evolve in the heat of the moment. Questions going both ways and followed up with yet more questions to give an in depth understanding of any given issue.

This project has used a mix of the two above mentioned structures. Together they form a Semi-structured interview method. It starts with pre-established questions to decide the topic and get the conversation started. Each question written in a more open manner and is therefore evolving the interview into a more unstructured form. This together with observations and follow up questions sets the interview method adapted in this project.

2.1.4 Literature Review

Every project, no matter the size, will require a large amount of reading. The work performed and the arguments made needs to be supported by other people’s previous writings. This may help with approach and method as well as building a better understanding of the topic. All of this is very important as it will help prepare for the production of the final report (Bell 2006).

It falls naturally that the bulk of any literature reading should come early in a project. Performing several tasks at the same time is not uncommon, reading literature being one of them. The worker should however guard against letting reading take up too much of his or her time. The amount of information available is huge and the ability to take out relevant parts from the mass will save much needed time. In the face of this Bell (2006) likes to remind us that we are only human and sometimes have to accept that we cannot do everything. People can only do the best they can and should not use more reading as an excuse to avoid getting down to the main task.
This project will mainly be based on information gathered from within the SSAB group and other companies with connection to the subframe and its use. The subject for this thesis work is one with low amount of conducted research. This makes the available literature directly connected to the topic very limited. The main part of the literature read in this project comes in the form of theoretical examples. No larger investigation have been done as far as this conducted research have been able to find.

2.2 Research and Source Criticism

Every project builds on gathered information. For the project to be trustworthy, needs the information that it builds upon also be trustworthy. Therefore cannot every piece of information found be taken as facts. It is easy to accept information that supports your claim and goal with little or no consideration, but without source criticism losses your work credibility itself.

Björklund and Paulsson (2012) states in their book Seminarieboken, *Att skriva, presentera och opponera*, that there are three ways to measure the credibility of a project. It is argued that in a scientific context Validity, Reliability and Objectivity needs to be present.

- Validity: the extent to which it actually measures what it is intended to measure.
- Reliability: the degree of reliability of the instrument, ie the extent to which one gets the same amount if you repeat the survey.
- Objectivity: the extent to which values influence the study.

The aim in every project should be to achieve as high validity, reliability and objectivity as possible. The amount of recourses spent on validating the information should however be in proportion to the conducted work (Björklund and Paulsson, 2012).

2.2.1 Interviews

Interviews are a good way of gathering primary data. This thesis builds much of its results on material from conducted interviews. Precautions have been made to ensure that they are done in such an objective way as possible. The interviews were semi-structured meaning that the interviewees could give as long or short answer as he or she wanted to, on a set of pre-decided questions. Notice has been made to ensure that the questions are formulated so that a certain answer is not benefiting more than others. For the interview to have a high degree of validity no questions can be left out over the risk of getting an unwanted answer.

Several interviewees have given similar answers to the same questions. This enforces the reliability of the information gathered for the project. If there is a desire to further strengthen the reliability the questions can be rephrased and given to the interviewee again (Björklund and Paulsson, 2012).
2.2.2 Literature
Ms Bell cites Mr Hart’s on the importance of literature review in her book; Doing Your Research Project as,

“In your written project you will be expected to show that you understand previous research on your topic. This amounts to showing that you have understood the main theories in the subject area and how they have been applied and developed, as well as the main criticisms that have been made of work on the topic.”

Critical review of the literature is essential for any larger project, it strengthens its trustworthiness. It should be remembered that the gathered and presented information should provide the reader with a clear picture, so that they are able to draw their own conclusions. More sources pointing the same way strengthen the reliability of the literature findings. (Bell, 2005)

On the subject of books, it should be noted if it is a monograph (same writer for the whole book) or anthologies (different writers for different chapters). Monographs are regarded as more reliable as a single writer carries the responsibility. Monographs based on peer-reviews can be seen as a sign of higher quality (Eriksson, 2009).

In this thesis work, a number of sources have been used for literature based knowledge. The primary data have mainly been attained reports from the KSC on SSAB. The amount of literature on the subject of subframes outside of SSAB is limited, therefore is the reliability also lower. With this situation all information has been taken in for study. Where up-to-date peer-reviewed material is preferable, the lack of information has led to the use of less reliable sources as well. The in-house material is, however, of higher reliability as it is tested and evaluated to some degree.
3 THEORETIC FRAMEWORK

This chapter presents the theoretical structure used during this thesis. Chapter 3.1 describes the two product development processes that together builds the process used in this project. This is then followed by an explanation on the theoretical knowledge and tools that is important to this project.

3.1 Refined New Product Development Process

For this project, an adapted NPD-process has been established and used. It builds upon a combination and reconstruction of Ullman's as well as Ulrich and Eppingers NPD-process. See appendices 1, for a summary of Ullman's and appendices 2, for Ulrich and Eppingers NPD-process.

This NPD-process consists of six phases as seen in figure 2.

![Figure 2. Project NPD-process](image)

**Define Problem**

In the beginning of a new project start-up is it important to define the main problems for the product. Define the opportunities with product portfolio and the product advantages. It is crucial to validate the possible value of the project before start-up begins. Defining the problem or problem construction has been suggested as one of the first steps in creative problem solving. Sometimes, it can be a good thing to have a loose definition of the problem as that gives more room for creative solutions (Blichfeldt and Eskerod, 2008).

**Planning**

Planning a product developing project can be the key to success. Time, people and resources need to be well distributed over the course of the project. The market and product strategy can help maximize probability of economic success. Management must decide the amount of control or freedom allowed in the project and how this will be monitored. With a clear goal and a good plan to get there the whole project will benefit immensely (Mansfield and Wagner, 1975).

**Research**

Gather information from competitors and make a wide research on suitable areas is often crucial for the product breakthrough. It is important to fulfill and satisfy the customer’s requirements. If this is successfully done, this will often give a great competitors advantage in both performance and cost (Iansiti, 1995).

**Conceptual Design**

This phase relies on a volume of creative thinking. Previous research and understanding of the problem increases the quality of the generated concepts.
Target values must at this stage be clearly defined for the products attributes. This will direct the work and creative thinking towards solutions corresponding to the demands. Different variants and the overall physical design of the product need to catch the buyer's interest and confident (Dahan and Srinivasan, 2000).

**Product Development**

The most promising concepts will move into this development phase. Working towards the concepts, optimum design is performed with the selected tools. This is then followed by a thorough evaluation and ending with elimination of the low performing concepts.

To maintain a strong competitive advantage, a firm needs to continuously redesign or create new products. In the product development stage it's important to find the products characteristics like physical features, materials, size, color and other qualities for the product (Kaul and Rao, 1995).

**Result**

Here are the results from the empirical study presented. Hard facts and soft values are explained with pictures and texts.

This project presents its simulation results as the result from the empirical study, followed by the projects final result in chapter 6.

### 3.2 Demand Specification

A *Demand Specification* is a document stating the demands that the final result should meet. It tells what properties and functions the product or service need to have in order to meet the customer needs. They can be given in the beginning or produced during the early stages of the project, often through collaboration between the project manager and the customer.

Demands can be product specific; size, material, functions, quality and more. The demands can also be for suppliers; Time frame, dispatch volumes, documentation among many (expowera.se2014.10.08).

This projects demand specification can be found in appendices 3.

### 3.3 Gantt Schedule

A *Gantt Schedule* is a project planning tool well suited for most projects. The schedule is a type of flow diagram where different parts and activities are easily monitored and followed up upon. On the vertical axis are all the activities listed. The horizontal shows time and progress.

The main benefit with a gantt schedule is the availability to all involved personnel. Current tasks are viewable and easy to plan for, as well as any delays can be seen and corrected for. Follow up work is made simple by the gantt schedule, the planned outcome and the achieved outcome can be seen and evaluated.

This project uses a gantt schedule to plan and distribute time over all the projects activities. See appendices 4 for completed gantt schedule.

(smartbiz.nu 2014.09.15)
3.4 High Strength Steel
There is a large variety of different types of steel. The difference is its strength and elongation properties. Figure 3 shows that low strength steel also called mild steel stretches from a lower tensile point of 100MPa to around 300MPa. Steel products considered to be High Strength Steel (HSS) starts its lower tensile strength close to 300MPa.

![Figure 3. Steel formability and strength. (Globalspec webpage)](image)

Considering figure 3, we can see that with higher strength comes a smaller elongation. A reduced elongation factor means that the ability to stretch the material without it breaking or permanently deform is decreased. A correlation between elongation and tensile strength is clearly showing.

SSAB has several steel products among the conventional HSS. An example is Domex which is a high strength low alloy steel. This is steel which has been alloyed with low levels of titanium or vanadium. Despite the fact that the content only counts for less than a percentage of the total weight it gives a substantial increase in strength.

When the strength of a material is further increased through chemical and deforming processes they can become Ultra High Strength Steel (UHSS). Among SSABs materials can HSS and UHSS sometimes be referred to as Advanced High Strength Steel (AHSS). Docol 1000 is one example of Dual Phase (DP) steel and contains approximately 30% ferrite and 70% martensite in its micro structure. Through a variety of processes like these, SSAB are able to produce several materials with unique properties (Bergström, 2009).

3.4.1 Steel Improvements
Used in the right way, HSS can give the user a diversity of improvements. Not only making thinner and lighter constructions, but also expand customers’ paybacks, develop knowledge and increase the innovative ability.
Innovative companies are constantly stretching the limits of what was previously thought possible. By combining different fields or branches new synergies are found where HSS has never been seen before (Design Handbook, page 1.8).

Considering the transportation industry an easy example will explain the benefits. Replacing the I-beams in the chassis from a S355 steel grade to a high end HSS will make a big difference. With the right knowledge, production costs can be cut. This benefits the producers and their customers. The figure 4 below shows the different cost positions before and after implementation of HSS.

![Figure 4. Cost positions. (Trailer Design Guide)](image)

Stronger material means less material with maintained strength in the construction. Thinner plates lead to smaller costs for cutting, increased bendability, which in turn means a lower need for welding. The benefits are many and obvious in comparison.

For the end user, further benefits are attained. The maximum weight of a truck and its load is limited by law. Reduced weight will therefore allow for larger payload and/or lowered fuel consumption as a result, having a direct effect on profitability. (Trailer Design Guide / SSAB)

### 3.5 Scania Rules and Directives

A large part of the information guiding this project comes from Scania and the rules and directives that they provide. Their experience on the subject and documentation on how to achieve a reliable product is central in this project. If the result does not comply with the demands from Scania, their product guarantee cannot be assured. Such a product will have a difficult time of ever making it to the market. These directives will be explained later in this report.

For complete and up to date information on demands regarding subframes and its components see Scanias Body Builder Webpage. (bodybuilderhomepage.scania.com 2014.10.10)
3.6 Creative Tools
There are plenty of creative tools to be used in a product development process. To stimulate creativity during a project process you can use tools like Brainstorming, Brainwriting (Österlin, 2003) and Storyboards (Lelie, 2005). These tools can be used to collect and create new ideas, solve problems in a product development process and help generate new solutions.

During the course of the concept generating phase the main approach was the classical brainstorming method. This was then followed by two more, breakdown method and Value Engineering method. They help to find other ways of solving the key problem. By breaking down and looking at different parts of the product separately new creative solutions can be obtained.

For more and closer information on the different methods and how to use them, see Creative Minds webpage (creatingminds.org 2014.10.26).

3.7 Simulated Driven Construction
Engineering design is today performed with the help of computer programs, so called Computer Aided Design (CAD). Used together with Computer Aided Engineering (CAE) they form the iterative process called Simulated Driven Construction (SDC). Constructing parts and products in a CAD program will later allow analytic simulations to be made with the help of Finite Element Method (FEM). The simulation can for example give important insight into product's visual appearance or its physical behavior under stress. SDC plays a vital role in this process, as the results of such analysis are often used as basic optimization parameters to improve the design of a given part or product (Dolšak and Novak, 2008).

3.7.1 Finite Element Method
The Finite Element Method (FEM) has become a universal method for solving differential equations. The key is its simplicity, allowing equations from several fields of science to be analysed and solved within a common framework. FEM can together with finite elements and mesh, be viewed as a machine that automates the discretization of differential equations, resulting in a system of discrete equations. It is an advanced computing application and allows engineers to interact with computers and their 3D constructions (Logg, 2007).

This project has been using Solidworks Simulation to simulate the different concepts. By using the displacement formulation of the finite element method Solidworks Simulation is able to calculate component displacements, strains, and stresses under external and internal loads. The geometry under analysis is discretized using triangular (2D), see figure 5, or tetrahedral (3D), and beam elements. The geometry can then be solved by either a direct sparse or iterative solver. These FEM calculations done by the computer program then gives information on the products physical properties (Nelson et al, 2010).
Figure 5. Triangular (2D) mesh
4 EMPIRIC STUDY

In this chapter, the execution of the NPD-process can be studied. It follows the process described in 3.1 and covers all the phases of this project.

4.1 Define Problem

The initiating phase in the product development process is to define the problem. SSAB experience that they lack knowledge on the area: subframe for tipper body trucks. They want to increase their knowledge in order to make rational and well based decisions on the subject in the future. In order to produce a successful result, an understanding of the basic problem is essential as described by Ullman (2010).

A subframe can appear to be a simple construction, it is however far more complex. What looks like simple steel profiles and crossbars have evolved over a long period of time. Countless failed and broken subframes have served as lessons for the manufacturers over the course of its history, its design adapting after each failure.

The problem with today’s subframes is that they are over dimensioned. An effort to transport more and heavier loads, have forced the subframe grow in size. According to Richard Södereng at Scania, have this development occurred without closer evaluation or analysis, resulting in stronger but heavier subframes. See appendices 5 for complete interview. In an effort to meet the demands have the size of the profiles and the number of reinforcements increased, as seen in figure 6 below.

Figure 6. Reinforced subframes (SSAB Database)

There is no product that breaks the familiar pattern. SSAB wants to know if this is because no one has attempted, or because the current design is in fact the best solution. SSAB is considering the possibility to expand their product portfolio with a subframe that challenges the conventional design.
4.1.1 Demand Specification
A demand specification has been produced. It defines the role for a subframe in the complete truck and flatbed assembly. These demands are set with the help of Scania body builder. The final result should cover the following demands.

General demands for a subframe
The subframe should:
1. Distribute the load evenly over the chassis frame
2. Provide clearance for wheels and other parts which project above the frame
3. Connect the bodywork to the chassis frame
4. Provide rigidity and reduce the stress in the rear overhang
5. Contributes to dampening chassis oscillations

Specific demands from SSAB
The subframe should:
6. Pass strength and stress simulation tests
7. Use HSS in a correct and optimized manner
8. Be adapted for use on Scania trucks
9. Be adopted for use with tipper body trucks

4.2 Project Planning
Throughout this project a Gantt-schedule has been the key tool for planning and follow-up work. The starting time and duration of each main task can be studied in the appendices 4 Gantt-schedule.

4.3 Research
This project has its foundation in a number of books, papers and previous projects, mainly done by SSAB and Scania. Careful investigation of this material has given a good understanding of the subject and task at hand. The secondary information found on this subject will here be presented along primary information produced during the course of this project.

4.3.1 Literature and Document Review
The knowhow regarding construction and calculations for this project is largely founded on SSAB’s books: Design Handbook and Design with WELDOX and HARDOX. These books are produced by SSAB and are based on many years of experience and research. The in-house technical reports from KSchave also served as a valuable source of information.
The Design handbook is an easy-to-use book for beginners as well as professional companies. It explains the benefits of high strength steel and how SSAB’s materials can help a customer improve life time, capacity and overall performance of their products. It presents profiles and plates, instability tests and its effects to name a few examples. Working through the concept generating and product development phase of the subframe, this book has given several tips on what can be done and how it should be done in the best way (SSAB design handbook 2012).

**Design with Weldox and Hardox**

Design with Weldox and Hardox is a manual dedicated to each of the in the title mentioned SSAB products. It explains the material properties, area of use, do's and don'ts as well as giving several examples of this. These examples will be of great help during the concept development phase.

**Knowledge Service Center**

Another source of valuable secondary information have been SSABs own department called Knowledge Service Center. They are working with customers who contact SSAB for support and advice on how to improve their products with HSS. The KSC will then conduct a case study on the subject leading to a result and recommendations for the company to proceed with. Two reports investigated in this project are “Upgrading of subframe for a tanker truck” and “Upgrade of subframe for a fire brigade truck”, both of which are describing the change from mild-steel to HSS, resulting in a weight reduction. These have been the best examples of previous attempts at redesigning the subframe. Their information has therefore been valuable to the project.

**4.3.2 Material Properties**

SSAB has a wide range of steel products. From the mild steel Domex 235 to the wear plate Hardox 600, can steel for almost every application be found. See full list of SSABs product program in appendices 6.

By consulting co-workers at SSAB, it soon became clear that it was only one steel material in question for this project, Domex. Domex is a high strength steel with all the qualities that a subframe requires. It is strong, bendable, weldable, and has low tolerances, it has also been successfully applied in several similar constructions. Domex construction steels are thermo-mechanically rolled in modern plants where the heating, rolling and cooling processes are carefully controlled. In figure 8 the different types of Domex steel are listed after their yield strength.

Supporting the choice of Domex as the best option for this project is its low price. Produced at high quantities with an effective production process provides a competitive price range. Domex steel grades between 460-900 also ground the name AHSS, see figure 7.
4.3.3 Reference Subframe (RF)

SSAB is currently working with a subframe recommended from Scania to complement their tipper bodies. This frame will be used as reference during the project. By comparing strength, weight and different measurements, the project results can be connected to a physical product. The final product or products should in other words match or exceed the attributes of this frame. The complete subframe can be seen below in figure 8.

The subframe uses U-profile beams with added web in areas subject to high stress. The cross members are also made from U-profiles welded in place. In order to make simulation tests and measurements on the frame, plates and additional parts have been removed. In figure 9a basic view of the subframe can be studied.
4.3.4 Field Study

Every year around the end of September, an entrepreneurial fair is held in the south of Sweden called *Entreprenad Expo*. The project was in its research phase at this moment, it was therefore decided that a field study would serve the project well. With the entrepreneurial fair, *Entreprenad Expo* as the main objective a few other stops was added along the way. Together with Mika Stensson, Area Technical Manager on Tech-support, the field study was undertaken over the course of three days.

The companies visited were *TranåsWagnfabriken, Norje* and *BalticumFrinab*. These companies have an extensive use of HSS in their production, some more than others. They are SSAB customers and use SSAB's steel to build their own products. Through semi-structured interviews with personnel at these companies and the entrepreneurial fair, important insight in production with HSS and subframes were attained.

Questions such as “Describe the difference between working with HSS and normal steel”, and “In your field, what are the benefits of reduced weight” were asked. The complete interviews and the received answers can be found in appendices 7, Company Questions and Answers.

With the valuable information learned from the field study, the project could move forward with clearer purpose.

4.3.5 Body Building Companies

When making a complete vehicle composing of a truck, tipper body and subframe, there is the matter of connecting them together. In general the truck is produced by one company and the tipper body by another. To connect the two, a subframe is needed which in turn can be produced by yet a third company. The work of putting all this together and making the complete product ready for the buyer is the job for a body building company.

It is these companies work to make sure that the requested flatbed fits on the truck, to mount a crane, hydraulics and more. This work often involves processing the metal construction by cutting, drilling and welding.

Figure 10, 11 and 12 are examples of body building companies that have been studied.

---

**Berger Fegen**

Figure 10. Berger Fegen, located in Fegen, Sweden (Berger Fegen webpage)

**Wagnfabriken**

Figure 11. Wagnfabriken, located in Tranås, Sweden (Wagnfabriken webpage)

**Zetterbergs**

Figure 12. Zetterbergs, located in Östervåla, Sweden (Zetterbergs webpage)
They perform body builder work on the customers’ demand, in general, following the rules and directives given from Scania or other truck companies.

Body building companies are the ones with the most experience working with the practical difficulties regarding subframes, therefore in possession of first-hand-knowledge important to this project.

4.3.6 Attachments

Studying several body building companies a few different attachment methods were found. Individual versions of the same solution were common place but the function stayed the same. General for all attachments, or brackets as some call them, are mounting distance set to 600-900mm by Scanias body building directives. In order to obtain a gradual increase in the bending resistance, the frame should be fitted with adapting flexible brackets at its front section, and rigid brackets at the rear.

For a full description of every type of attachment see appendices 8.

Rigid weld attachment

The welded support bracket is the strongest attachment method. Only a low amount of movement is allowed and the subframe connects strongly with the chassis of the truck. These support brackets have to be placed at the rear of many tipper body trucks, and should be of the same thickness as that of the side profiles. The number of attachments is decided by the selected tipper body. Lower levels of accepted oscillation, requires higher use of rigid attachments, like the ones shown in figure 13.

![Figure 13. Rigid weld attachments (Scania doc, Attachments and SSAB Database)](image-url)
Flexible attachment
In figure 14 below are two examples of flexible attachments. This attachment-method is longitudinally flexible. That means that it permits some movement horizontally along the frames length. The length and diameter of the screw decides the flexibility of the bracket.

![Flexible attachment](https://example.com/attachment.png)

Figure 14. Flexible attachments (Scania doc, Attachments and SSAB Database)

4.3.7 Stabiliser
Some subframe solutions contains something called a Stabiliser. It is a hinged par of profiles that stretches from the subframe up to the tipper body, as shown on figure 15. It is rigid in its construction and helps absorb lateral forces on the tipper body.

![Stabiliser](https://example.com/stabiliser.png)

Figure 15. Classical Stabiliser (SSAB Database)

Figure 16 shows a solution that incorporates the hydraulic cylinder into the stabiliser. A benefit of this is a decreased unloading time, making it well suited for truck-configurations where repetitive use is expected. This solution does however reduce the maximum loading weight of the tipper body.
4.3.8 General Directives for Subframe

When constructing a subframe there are directives and recommendations to follow. Some are explained in detail in Scania's Bodywork information documents and others are recommendations from body building companies. During the concept generating and product development phase it is important to keep these directives in mind. Concepts missing or going too far outside these directives will be hard to introduce on the market, and will only have limited success. This knowledge will help ensure that the product meets the body builder’s requirements.

- One of the subframes roles is to distribute the load evenly over the chassis frame. In order to do this in the best way, a subframe must have the same external width as the chassis frame and must follow its exterior lines.
- The subframe structure may in no circumstances restrict any movement of the tipper body or other moveable parts on the truck.
- Changes in the profile must be gradual in order to avoid high stress points.
- Where possible, the subframes cross members should be positioned over the cross members of the chassis.
- The subframe should it extend forward as far as possible for the load to distribute evenly.
- When connecting the subframe with the use of longitudinal screws is it regarded as a flexible connection. Scania recommend that the screw length, diameter and tightening torque is chosen with the designated truck in mind, or the purpose of the attachment may be lost.

For detailed information regarding the subframes design see Scania Bodywork document: Subframe Design.
For detailed information regarding subframe torsional classes see Scania’s Bodywork document: Selecting the Subframe and Attachment.
For detailed information regarding subframe reinforcements see Scania Bodywork document: Reinforcement.

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4.3.9 Centre of Gravity

There is a general agreement that a lower Centre of Gravity (CoG) is affecting the vehicles handling performance and stability. When a truck is fully loaded with 36 tons of payload a height difference of just a few centimetres could make a notable difference. An interview with Björn Jonsson, truck driver for the company DHL, strengthens these thoughts.

-When loading a truck you have to think of how you are positioning the load. Heavy goods should always be placed in the bottom and centre if possible. The way the truck behaves on the road is strongly affected by the position of the load and it’s CoG. This becomes apparent when you for example are driving through a roundabout.  

(Björn Jonsson, Truck driver, DHL 2014-10-13)

A calculation can be made for the effects of reducing the height of the subframe, which in turn affects the CoG for the payload. This is made in an attempt to scale the benefits of a lower CoG against possible drawbacks.

The values and calculation method is derived from a parallel project where a Scania truck and a new SSAB tipper body are tested. Figure 17 shows what is being calculated.

![Figure 17.CoG for loaded tipper body](image)

Value 1: 2362mm
Value 2: 922.5mm

\[
\tan A = \frac{1}{2} \\
A = \tan^{-1} \frac{2362}{922.5} = 68.66^\circ
\]

A reduction of the height by 50mm or 2.1% would then give:

\[
A = \tan^{-1} \frac{2312}{922.5} = 68.25^\circ
\]

By removing 50mm from the height of the subframe the angle is reduced by 0.41°. Drawbacks following the reduced height of the subframe should be investigated.
4.3.10 Tipping Stability
Unloading a tipper body is a critical moment. The CoG is being moved away from its secured position close to the ground. To avoid damage to the truck and its parts unloading has to be done in a correct manner. In the document *Roll Stability and Tipping Rollover Stability*, Scania explains what interacting factors affect the trucks stability during tipping with the following bullet points:

- Capacity of ground to support the load
- Position of centre of gravity
- Roll stiffness of the chassis
- Torsional rigidity of the bodywork
- Stabilising equipment (bogie blockings, empty rear air bellows and stabiliser)
- Practical handling during tipping

Generated subframe concepts should when possible, work towards the fulfilment of these factors.

Unloading a tipper body truck in a sideway hill have proven to be a task associated with damage and injury. As shown in figure 18 below, unloading at small angles can be dangerous as well. The risk of tipping over drastically increases with rising angle.

![Figure 18. Unloading at angle (National AG Safety Database)](image)

The best way to test and evaluate how a new construction handles these kinds of forces is through physical testing. Scania therefore provides precise information on how to conduct these tests, see Scania bodybuilding document *Roll stability and tipping rollover stability* for more information. The recommended angle to perform these tests is set to $5^\circ$, this will later be used during simulation as an angle of reference for the different concepts.

4.3.11 Effects of Reduced Weight
One of the goals of this project is to investigate if the weight of the subframe can be reduced. By reducing the weight several benefits are acquired. Regarding the truck and its lifetime effect, small improvements can provide large benefits. Using SSABs “Extreme Performance Calculator”, an easy-to-read result is given.

If, for example, the weight is reduced by 250 kg the lifetime benefits for the owning company and the environment is showed below in figure 19.
Figure 19. SSAB Extreme performance calculator

With increased amount of work performed by the truck the total savings can move up to 9000 Euros per year. During the vehicles life time, a total of 7 tons of CO₂ emissions can be avoided. This is a strong argument that can be used during sales of a subframe with reduced weight. Higher payload capacity and fuel savings are numbers that any businessman can understand, something that could defend a possible higher price.

4.3.12 Patent Research

When designing a new product for an international company checking patents on the current area of interest is important. During the concept generating phase of the project a patent research was therefore conducted. This was made in an attempt to find similar or crossing patents.

For this patent check two institutions were used. The Swedish Patent and Registration Office and the United States Patent and Trademark Office. On their respective web sides can a search engine be used to search for active and passive patents.

By searching in their data bases a number of hits could be found. “Subframe” and “Truck Subframe” along with their Swedish translations were used as the main search words. More than 400 hits were generated and examined for relevant material. Several interesting patents were found but none could however be said to hinder the project in any way. The assessment was made that no concept is in danger of breaking a patent and further development will be seen to avoid it as well.

It should however be remembered that this was only a first attempt to make sure there are no obvious patents in force. As MDH teacher Håkan Mattsson so elegantly put it, “that you cannot find it, does not mean it does not exist”. In the future should a wider examination be conducted, preferable with the help from a professional institution.
4.4 Conceptual Design

Conceptual design is about describing ideas and thoughts with the help of pictures and text. Taking the first steps towards a new product often starts with a sketch on a piece of paper. This project was no exception, ideas starting as sketches on a piece of paper.

During the research and information gathering phase has several different solutions been studied. Some are old and well tested, others are introducing small individual part-solutions. No one of these does however step out of “the box” and approach the problem with new unrestricted eyes. This concept generating phase aims to leave “the box”, in order to come up with new untested solutions.

4.4.1 Concept Generating Method

This project concept generating phase started with a *Brainstorming*. With the knowledge previously gathered, numerous solutions or part solutions were generated. Some left “the box” in its design and function and others were improvements on the conventional subframe design. When this no longer proved efficient a *Breakdown method* was applied. By looking at every part of the subframe individually, new part solutions could be generated. However, did this only work with the conventional subframe, limiting any major changes of the overall design. This was then followed by using the *Value Engineering* method. This method is working by identifying and prioritizing the different functions of a product. In the case of a subframe these were: distribute load, connect tipper body to truck and absorb oscillation for example.

As a final effort to produce more concepts and widen the base of alternatives an in house colleague was consulted. Bo Lindström, Senior Design Specialist at SSAB Oxelösund with many years of experiences could add several new ideas to the concept phase. Mr Lindström introduced a couple of previous projects that had some thoughts along the same lines and therefore in turn led to new concepts. He made introductions to additional companies working in surrounding industries, this gave yet more concepts to the project. See appendices 9 for complete concept catalog.

Satisfied with the concept solutions found, the next step became categorizing these into groups.
4.4.2 Concept Groups and Descriptions
All concepts are listed in one of the three concept groups, A, B and C.

Group A: Improvements
This group is made up of solutions which aim to improve on the common subframe design. Redesigning the profiles, cross members and attachments can give benefits in the terms of weight, height, strength and production. The introduction of HSS in the traditional subframe design brings possibilities for improvements worth investigating.
A combination of several part-concepts will together result in a complete “group A concept”. Figure 20 and 21 shows a few examples from group A.

![Figure 20. Profile concepts and attachment](image)

![Figure 21. 45 degree subframe concept](image)

Group B: Shaped Plate
With inspiration from the KSCs previously made reports, a number of concepts were generated with steel plate as its focus. All subframes today are built upon closed or open profiles running along the truck chassis. This concept group leaves “the box” by instead utilizing shaped plate. Where needed reinforcements can be added and holes made through the plate. All concepts adapting plates in its design are included in group B, see figure 22.
Group C: Support Construction
The third group of concepts approaches the problem differently. The current construction has to be very rigid in order to counter the forces that affect a tipper body during unloading. Because it does this in a very ineffective way, the size and strength of the subframe has to be unnecessarily large. There are today stabilisers between subframe and tipper body to make the tipper more resilient against lateral forces. If this function could be scaled to give a larger amount of support, this could make new and different subframe designs possible. This group examine if it is possible to reduce the subframe size or even partly remove it by giving better support and counter the forces involved in a more effective way. Figure 23 below shows a number of examples.

4.4.3 Concept Evaluation
To make effective use of time and SSABs resources a concept evaluation was made over Lync together with Jonas Gozzi at SSAB Borlänge. Mr Gozzi, Manager Market Development and R&D at SSAB has experience of working with trucks from previous projects. By making use of his experience an effective elimination could be made with minimal risk of removing concepts with still hidden potential.

In discussion with Mr Gozzi it was agreed that the most important thing a subframe has to do is to absorb oscillation forces. This follows the same line as the demand specification and Scania’s guidelines. Focus will therefore be on the concepts ability to counter these kinds of forces.
The most common design on SSABs tipper bodies was debated. They use strong top side profiles stretching down in the back to connect with the subframe. The rest is free hanging plate unfit for connection. NoSSAB subframe has any reinforcements on their underside. Concepts with bottom connecting equipment are therefore unrealistic as the tipper bodies would need to be adapted. Figure24 shows a SSAB free hanging tipper body.

![Figure 24. SSAB tipper body (SSAB Database)](image)

Many high-end truck manufacturers use a chassis frame that expands in the front, like Scania's trucks does. Concepts must therefore allow for this inflection point in their front most part or be un-affected in its design, see figure25.

![Figure 25. Chassis frame and inflection point](image)
Mr Gozzi strongly argues that closed profiles are preferable to open profiles. Support for this is found in the document *Trailer Design Guidelines* as shown in figure 26.

![Figure 26. Strength improvement for closed profiles and cross-tie (Trailer Design Guide)](image)

This should be remembered and used during construction of concepts. Shaped platedoes in the same way make better use of its material by not leaving any open profiles.

In appendices 9, the different concepts with explanations can be found. There, every decision is clarified with comments on the evaluation process done together with Mr Gozzi.

### 4.5 Product Development

During the product development process the concepts that have been evaluated and found to be of high quality will go through further development. Here, every concept will be systematically worked through and brought to its best possible state. This will be followed by another evaluation resulting with one final product solution.

#### 4.5.1 Construction and Simulation Boundaries

Before the construction started in Solidworksa meeting was held with Bo Lindström and Tomas Visurat SSAB. Putting down guidelines for simulation prior to construction will save time spent on re-doing and correcting designs to fit with the simulations. Knowing how the simulation should be conducted can have a large impact on how a part should be constructed in the best way. The result of a simulation is heavily influenced on what boundary conditions have been used. It is therefore crucial to be careful and consistent with the boundary conditions used for all the tested parts.
In order to make the result from the simulation useable some simplifications had to be made. This has been done to give equal and comparable values between the existing RF and the evaluated concepts.

It is not possible in this project to use a complete truck during simulation, restrictions has therefore been made at certain points. One restriction is the exclusion of a tipper body. Instead is a representing forced applied to the subframe. See appendices 10 for calculation.

During the meeting was it established that simulations has to be made together with the trucks chassis frame and subframe. Relying solely on a comparison of the existing subframe would not give reliable values as the “moment of inertia” changes differently for different designs on the subframe according to Mr. Lindström.

Testing the strength of a subframe is relevantly straight forward. Supports and loads are positioned at corresponding points in the different concepts. The result can be measured and analysed.

Regarding the ability to simulate oscillation forces on the subframe a different situation appears. To be able to make reliably simulations a number of restrictions had to be decided upon. See chapter 4.6, Simulation preparations.

These boundaries are important when constructing the subframe concepts for later simulation.

4.5.2 Concept Solution A1: Improved Subframe

Solution number one is from the concept group A. As shown in figure 27 it applies the commonly used closed rectangle profile seen at many competing companies. It has a low innovative height and need to be modified through other means like colour or idiom if it should be recognisable as a SSAB product.

It is a reliable solution and the production techniques are well known to the body builder companies. This makes it an economical product as needed material and production techniques are well known and available. It can move quickly onto the market as the design is trusted by the buyer, therefore inexpensive to promote as well.

Figure 27. Concept solution A1 improved subframe

The subframe uses 180x80x6 millimetre profiles and 100x80x6 millimetre cross members. Length follows the same measurements as the RF to avoid problems with surrounding equipment, as seen in figure 28.

The end part does differ from traditional products. Here the crossing plates are thin and flat, made from UHSS with very low flexibility. This should make the end section of the
subframerigid and good at countering oscillation forces. Simulation will show if these assumptions are correct.

Figure 28. Top view of concept A1

In figure 29 can every part be seen and the numbers required for one subframe. These are then welded together to make a complete subframe. The body builder companies can make minor adaptations and processing work to individualise the subframe to fit for the given purpose.

Figure 29. Concept A1 parts

4.5.3 Concept Solution B1: Shaped Plate
This solution utilizes a new technique by using shaped plate in the rear most part. Only few examples of similar solutions exist and they are still un-tested. Developing this product further will require extensive testing and marketing. This solution carries higher risk but can also give bigger rewards. The idiom can easily be recognised as an SSAB product as no other producer uses similar techniques.

This second solution is made up of shaped plate and is passing over to closed profiles towards the front. Cross members are made from closed profiles as well. Holes are cut to lighten the construction while maintaining high rigidity and strength. See figure 30.
The main body is composed of two identical plates welded together along the sides as showed in figure 31. Inside the body is strengthening plates welded to increase the rigidity even more. The flat sides makes it easy to attach to the chassis as well as other equipments.

In figure 32 can every main part be seen as the numbers required. These are then welded together to make a complete subframe.

4.5.4 Concept Solution B2: OctagonPlate
The second concept solution from group B makes extensive use of shaped plate. Nothing similar has been tested before as a subframe for tipper body trucks. See figure 33. This solution can be said to have a high innovative level. A lot has to be tested and measured to see that it can
hold up to the physical stress and forces needed. A unique design like this one comes with high uncertainty but can also give strong benefits compared to competitors.

Figure 33. Concept solution B2 octagon plate

The main body of the concept is composed of two identical halves put together in the rear as shown in figure 34. The end pipe for the tipper axel is welded onto the end of the shaped plate.

Figure 34. Octagon plate shape

In figure 35 are all the main parts of the concept listed. Cross members are cut to fit the shape of the pipes and then welded in place. Because the checked pipes are more rigid than normal profiles, have the last cross member been left out to compensate for this.

Figure 35. Concept B2 parts
4.5.5 Material
Through discussion and evaluation have the Domex 700 been selected for the three above mentioned concepts. It is cost effective and well suited for the task. It is already successfully used in a number of applications such as cranes, truck chassis and earth moving machines. By using Domex 700 in these applications have the total weight been decreased.

The chemical alloy, consists of low levels of carbon and manganese. This together with a clean structure, makes Domex Steels the most competitive alternative for cold formed and welded products.

Domex 700 has a yield strength of 700MPa and a tensile strength if 750-950MPa. It can be delivered in thicknesses from 2-10 millimetres in lengths of up to 13 metres. See appendices 11 for complete product information.

4.6 Simulation Preparation
In order to make further validations all concepts have undergone simulation testing. This allows for comparison of physical values between the different concepts. Torsional strength and weight is the two main properties of interest.

4.6.1 Delimitations
This study is a pre-study and should therefore not get too deep into detail in specifics. In order to make the simulation process adapted to the size and demand of the project, some limitations have been made. A FEM-analysis requires considerable amount of computer power, the three concepts and the chassis frame have therefore been simplified in order to help the process. Some of these actions have been described earlier in the report, others are now explained. The following simplifications and rationalizations has been made

- Surrounding equipment has been removed. Any parts not designed to add strength to the construction has been removed.
- Bolt holes have been removed. All small holes along the chassis frame and subframe are considered to have a limited effect on the overall structure.
- The flexible attachments in the front have been removed. Early simulations have shown that they have small to no, contributing effect on the products torsional strength.
- The stabiliser has been removed. The stabiliser is underperforming when used with a free-hanging tipper body, as there are no reinforcing profiles to connect it to. It has therefore been excluded from the simulations.
- The hydraulics has been excluded from the simulation. The hydraulic and the load resting on top of it are not adding any torsional forces on the subframe, because the load is carried on the rigid fixture in the front, representing the front wheels.

4.6.2 Payload
To be able to measure the forces that affect the truck and its subframe data had to be collected. With the help from Wear Specialist Dan Forsström an angle for tipper bodies unload point could be found for rock fill material. It was established that at a 35 degree angle will the payloads mass start moving out from the tipper body. At this point will the combined centre of
gravity be as high as it will ever be during the unloading process. See appendices 10 for detailed calculations.

This was then followed up by calculating the amount of weight going down in the rear pivot point and forward hydraulic cylinder. The weight pushing on the rear pivot point (26 356kg) would then be used in the simulation. However, this value had to be revised when the first simulation showed that large areas of the RF underwent plastic deformation. Results from simulations with large areas of plastic deformation cannot be trusted as the material starts to act non linear, something the program is unable to take into consideration. It was therefore decided together with Mr Lindström that lowering the weight to 15 000kg would represent a more realistic load for this simplified subframe.

4.6.3 AngleDuringUnloading

In the scenario at which a tipper body truck attempts to unload at a sideways angle lateral forces will appear. It was decided together with Bengt Gustavsson at MDH that 5° and 10°angles should be simulated. These values represent the combined angle that the ground, suspension and lateral movement of the tipper body adds up to.

4.6.4 Test Parameters

Each one of the three concepts will be tested in three different ways together with the RF. The first simulation is a typical beam strength test. The subframe is tested together with the chassis frame as they are pushed down 50mm in the centre. This will give information on stress levels in the subframe that can then be compared.

The two above mentioned sideways angles will be simulated. 5°is the by Scania recommended testing angle, 10°will therefore be an extreme test that goes further than the suggested angle of a physical test. The newly revised load of 15 000kg is positioned at the tipper body’s centre of gravity at unloading.

These three scenarios will be simulated and the result will be compared and analysed.

4.7 Simulation Results

Here, the three concepts will be presented and explained. All three concepts have benefits and drawbacks that can be valuable for continued work. The final result will later combine these benefits to form a complete and improved product.

A summary of the data from every concept can be viewed after the separate result descriptions. See chapter 4.7.5.

N.B. Areas in direct contact with the connection points and the force may show stress levels that are not representable. Colours on the chassis frame are not displayed correct, as its yield strength is 500MPa, not 355 or 700 as the scale shows.

These results are only to be viewed as approximations of the real construction properties.

4.7.1 Reference Frame

The RF is the subframe that SSAB currently use together with their tipper bodies. The performance of the different concepts will be compared against this subframe and its simulation results. That will make it possible to study the difference against an existing
subframe, securing that a concepts performing in a similar manner should do so physically as well.

Figure 36 below shows the RF as it is pushed down 50mm on one of the central chassis cross members. The stress is at its highest around the middle where red areas represent stress levels of over 355MPa. The maximum stress level verified from this scenario is 433MPa.

The subframe used as RF weighs 483kg when surrounding equipment is removed. In the 5° tipper scenario, does a 45mm displacement appear on its rear right side. At 10° is this displacement at 87mm. This data allows the three concepts to be compared, making it possible to scale their results.

4.7.2  Concept A1: Subframe Improvements

This concept with its lightened construction is an attempt to make a traditional subframe with the implemented use of HSS. By constructing this frame with HSS, the weight has been reduced while the subframes strength still meets the demands. In figure 37, 50mm, reaches a large area stress levels of 500MPa, with Domex 700 instead of S355 are these levels well within the limits.
With its 421kg, the A1 concept is the lightest of the concepts. Looking at stress shows that this concept performs well in the 5° tipping simulation. With closed profiles and a new thin-plate rear cross, makes concept A1 perform better than the RF. Lower levels of allowed stress can be seen in all three scenarios, indicating that the risk of plastic deformation is lower. However, the stiffness is lower than the RF. This becomes very clear when studying the maximum deflection on the frame, where concept A1 deflects 68% more than the RF at both 5° and 10° angle.

4.7.3 Concept B1: ShapedPlate
When concept B1 is affected by the 50mm displacement areas reaching about 350MPa stress levels appear in the centre of the subframe. The transition from shaped plate over to closed profiles is believed to have a negative effect on its strength, where local stress levels spike. The solution does however stay within the yield limit of Domex 700 in this scenario, as shown in figure 38.

![Figure 38. Concept B1 stress test](image)

Concept B1 is 18kg lighter than the RF. A small decrease in weight but a decrease none the less. In the 5° tipping scenario is a 35mm displacement measured. That is 10mm less and indicates towards a stiffer construction. Being one of the main demands, B1 counteract lateral forces better compared to the RF. At 10° is the displacement 78% of the RF as well, an important improvement in its rigidity.

4.7.4 Concept B2: Octagon Plate
The Octagon plate is the heaviest concept. Weighing 514kg makes it 31kg heavier than the RF. For the 50mm scenario does B2 perform in a similar way as concept B1 with stress levels of around 350MPa, see figure 39 below.
Looking at the 5° scenario for concept B2 shows considerable improvement in stiffness and ability to counter lateral forces. With only 33% of the original displacement, this concept can then be described as very rigid. At 10°is the displacement only 24mm or 28%, attesting to the fact that the octagon shape is well suited for the task.

4.7.5 Summary of Results

In table 1 below, can the collected data received from the simulation scenarios be studied. The row “50mm” measures the maximum stress level in the given subframe. The percentage described the occurring stress level compared to its material yield limit. Local stress points are excluded.

The row ”5°” shows the maximum displacement in the subframe at 5° angle. The percentage shows displacement compared to the RF.

The row “10°” shows the maximum displacement in the subframe at 10° angle. The percentage shows displacement compared to the RF.

<table>
<thead>
<tr>
<th></th>
<th>Reference Frame</th>
<th>Concept A1</th>
<th>Concept B1</th>
<th>Concept B2</th>
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<tbody>
<tr>
<td>Material</td>
<td>S355</td>
<td>Domex 700</td>
<td>Domex 700</td>
<td>Domex 700</td>
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<tr>
<td>Weight (kg)</td>
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<td>421 (87%)</td>
<td>465 (96%)</td>
<td>514 (106%)</td>
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<td>50mm (MPa)</td>
<td>433 (122%)</td>
<td>553 (79%)</td>
<td>353 (51%)</td>
<td>375 (54%)</td>
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<td>5° (mm) max displ</td>
<td>45</td>
<td>76 (168%)</td>
<td>35 (78%)</td>
<td>15 (33%)</td>
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<tr>
<td>10° (mm) max displ</td>
<td>87</td>
<td>146 (168%)</td>
<td>68 (78%)</td>
<td>24 (28%)</td>
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<tr>
<td>Height (mm)</td>
<td>200</td>
<td>180</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>
5 PROJECT RESULT

By using the information gathered from the research, conceptual design and product development phase have a final solution been produced. With the information attained from the simulations, and by reading the results from each simulation, benefits and drawbacks have been made visible. The final solution uses these benefits to make a stronger, stiffer and lighter subframe. This subframe is developed to highlight the possibilities available when designing a subframe. It is not a finished product ready for production. This frame is an early design-suggestion that proves the potential of a new subframe design, as was the aim of this pre-study. Figure 41 shows the final solution, given the product name: SSAB Octagon Subframe.

![Figure 40. Final solution SSAB Octagon subframe](image)

The SSAB Octagon Subframe is performing better in several tests. SSABs aim of a 10% improvement have in most cases been reached and exceeded, see table 2 below. Looking at the weight, only a 7% reduction was reached. Strength is however drastically improved, using merely 56% of the maximum yield limit in the material. Simulation tests at 5 and 10 degrees angle shows an improvement of 18% and 23% with regards to rigidity. The subframe is a total of 60 millimetres lower as well. Closer evaluation of the results can be found in chapter 6.2 Final Result Evaluation.

<table>
<thead>
<tr>
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<tr>
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</tr>
<tr>
<td>Height (mm)</td>
<td>200</td>
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Table 2. SSAB Octagon subframe compared to the RF
5.1 Size and Position
As explained in the report, there are many measurements taken from the RF. The new subframe is constructed to fit with Scania’s chassis, and therefore follows its exterior lines. In figure 41 below, some rough measurements can be seen.

![Figure 41. SSAB Octagon subframe measurements](image)

The decision on size and positions comes from the knowledge attained from the project simulations, making a rigid construction and keeping a low weight at the same time is about finding a balance between the two.

The octagon plate has in the rear been made wider than the truck’s chassis frame. This is done in order to make the forward profiles line up with the chassis exterior, and position the rear plates on top of the chassis frame.

Distance between the cross members is set to 1000mm, this puts the most forward positioned cross member close to the inflection point.

In figure 42 can the width and height of one octagon plate be studied. Two identical plates welded together make the main body of the subframe.

![Figure 42. Octagon plate measurement](image)

The complete product weighs a total of 447kg and measure only 140mm in height. This makes it a lighter and lower subframe than most designs existing today.

5.2 Parts and Assembly
This pre-study makes no detailed part-descriptions. There is still much work to be done on the separate parts, adapting them to each other and surrounding equipment.

SSAB Octagon Subframe consists of a number of parts as showed in figure 43. Assembling the subframe is done by welding. The plate and profiles are made from 6mm thick steel, see appendices 12 for Domex 700 profile product range. The end beam is made from thicker material since it is located in an area where stress is high.
Assembling the SSAB Octagon Subframe follows the same handcraft techniques being applied today. Rounded ends and holes can easily be cut by the body builder companies, as well as making smaller adaptations. It is however, still too early to make evaluations on time and costs involved with production. It is only stated that the final result is practically possible to produce. Figure 44 below shows a typical subframe. It is assembled in close connection with the dedicated truck, securing that measurements and adaptations are correct.

The SSAB Octagon Subframe can in a similar way be assembled and mounted on a truck. The figure 44 shows that there is room for a wider construction, something few subframe designs are making use off. Attachments are bent to fit the wider rear body and then screwed and welded into position as usual. Hydraulics and cabling can easily be wired through the octagon plate, granting protection at the same time.

5.3 Material
Most parts of the SSAB Octagon Subframe solution is constructed in Domex 700. There are several products today where Domex 700 is being successful applied to products with similardemands, serving asassurance that it is the right material for this construction. The bearings holding the tipper axle can to be produced from Weldox700, were the right size of material does not exist in Domex 700. The properties of both materials are considered to be well suited for the current design.
6  ANALYSIS AND EVALUATION
In this chapter will the product development process and result be analyzed and evaluated. How each phase has been carried through and contributed to the outcome. The demand specification and research questions will be answered after the result and its performance is analyzed.

6.1  Evaluation of Project Phases
The NPD-process used in this report was created and adapted with this specific project in mind. The six phases of this project will be analysed and evaluated, looking at how they have supported the development of a tipper body subframe. Figure 45 is a reminder of what the project's six phases are.

6.1.1  Define Problem
This project started up as a need to find out more regarding subframes for tipper body trucks. Coming to SSAB only a rough idea existed on what this project was meant to be about. Made apparent from Ullrich and Eppingers NPD-process not every project starts with a definition, instead going straight to the planning. Because SSAB did not have a clear purpose with the project the problem definition phase was very important, this ensured that the project started off with the right objectives to aim for.

Unless approached with a clearly defined want or need, every project will benefit from taking the time to define the problem and what the project wants to accomplish.

6.1.2  Planning
Planning is key to every successful project. It is about distributing resources, time, money, personnel and more. This project had to be defined and a technical understanding had to be reached before a project plan could be set. First knowing what had to be included in the project made it possible to make a time plan. Using a Gantt-schedule gave the project an easy to overview table of all the tasks. Changes had to be made along the project to adapt to new information or expressed desires from the company. This had only a small effect on the overall project, as notice was given with enough time.

Boundaries and delimitations helped focus the project on the most important tasks, something that saved time and effort better used elsewhere.

6.1.3  Research
Given the project and the low amount of in-house knowledge on the area of subframes made this part one of the largest. The bulk of the information was taken from companies and industries involving, or working close to, trucks and tipper bodies.

The first step was to gather what information SSAB already had. KSC was very helpful at fining and making interesting information available, information giving insight to what have previously been done and how similar work are being conducted.
From there, other companies were contacted and information available on their web-pages gathered, Scania's body building documents playing a central role. This gave a deeper understanding of the problems associated with subframes, and how they are overcome with today's designs.

By conducting a field study, was a first-hand look at the industry of HSS received. Having the opportunity to ask questions regarding HSS as well as subframes supported the project with important primary information. Studying products from several companies helped form an understanding on how steel is used in the best possible way.

All this information come to be valuable later in the concept generating phase and product development phase, where inspiration for both part solutions and larger structural solutions was found.

6.1.4 Conceptual Design

The conceptual design phase will always carry a central role in every NPD-project. This project was no exception as the conventional subframe design was to be challenged. By using and combining ideas and part solutions found during the research phase could a number of concepts be generated. Assembling these concepts into three groups was made with the intention to facilitate the large amount of ideas. By organising them by physical design and function could common strength and weaknesses be viewed easily. Solving one problem could therefore supposedly solve the same problem for every concept in the group.

One of the smartest steps taken in this phase was during the concept evaluation step. There are several tools available to evaluate concepts and there potential. They are however time consuming and know to overlook some aspects of the project or attributes of the product, therefore not always the best step to take. In discussion with the experienced co-worker Mr Gozzi, could the evaluation and elimination be conducted in an effective but still precise manner. This way, could concepts that would meet hidden difficulties in future development be highlighted early on, presenting the concepts true value. In the same way were concepts potentials found and discussed.

The project moved into the concept development phase with confidence that the right concepts had been chosen.

6.1.5 Product Development

The bulk of the product development work was conducted in Solidworks. The concepts were constructed and re-constructed a number of times to meet the demand specification as well as possible. By doing this work digitally could small changes be done continually, with little or no negative time affects.

The only negative side of this were delimitations that had to be made in order to conduct the tests. Excluding the hydraulic and Stabiliser were discussed both at SSAB and with BengtGustavsson at MDH. They have a significant effect on the tipper body, and how the subframe is affected by the forces during unloading. Despite their importance were their removal deemed necessary due to lack of detailed information, and because of the time restrain.

As part of the product development phase was the simulation testing with FEM. This is to be considered as a strong tool to use in any NPD-process where strength of construction is of central concern. This tool helped to generate the information that the result of this report builds
upon. By comparing this information against the RFs could the results be linked to the real world, as the physical RF is known to meet the demands. Consistent work have been the most important part during simulation, it ensures that the comparison can be made correctly and fair.

### 6.2 Final Result Evaluation

The result of this project shows a product concept that highlights the possibility of a new and bold design. It combines shaped plate with closed profiles to form a light weight but rigid construction.

The SSAB Octagon Subframe is simulated in the same way as the earlier concepts to evaluate how it performs.

In the 50mm stress-test in figure 46 below is a maximum stress-point of 395MPa reached, that puts it at a safe distance to 700MPa. However, this mean that it is stronger than it needs to be, giving room for more changes.

![SSAB Octagon subframe stress test](image)

SSAB Octagon subframe performs well at 5 degree angle. Only minor areas reach the yield limit as seen in figure 47. The octagon plate distributes the forces and the shape reduces the risk of buckling to appear.
Unloading at 10 degrees angle is an extreme case, therefore is an area surrounding the tipper axel exciding the yield limit of 700MPa, see figure 48. This part of the subframe might not be as strong as it needs to be. This project has not been working with any safety factors, assuming that the RF which every concept is measured against keeps the necessary safety limits. It is therefore hard to evaluate if this areas of high stress levels are within the tolerances or not. See chapter 7.2 Product Recommendations for appropriate measures.

The gradual ends on the front and rear profiles can be seen to work well by spreading the load over larger areas of the plate. The attachments are positioned in a similar manner as the RF. It stands to be decided if this is the best positions for the SSAB Octagon subframe, as the forces are unevenly distributed around the attachments.

In this simulation is the chassis frame fixed in Y and Z direction in the front, and can pivot around a point in the back. When the load of 15 tons is applied in a 10 degrees angle does SSAB Octagon Subframe deviate away 67mm from its original position, as shown in figure 49. Analyzing this in comparison to the RF presents an improvement of 20mm or 23%.
Figure 49. Maximum displacement of 67mm

Comparing the SSAB Octagon Subframe against the RF shows some clear improvements in several fields. SSAB was searching for a 10% improvement in strength, rigidity and weight reduction, something the result almost fully meets. The weight of the subframe has been reduced by 36kg or 7% in comparison. The design is still not fully developed and more changes and optimizations on the design may reduce the weight further.

In all three simulations are better values recorded with regards to strength and rigidity, a proof of the benefits with the new design. The reduced deviation (18% and 23%) speaks of a more rigid construction compared to the RF, an important aim of the project.

Finally, the height of the subframe has been substantially reduced, from 200 down to 140 millimeter. This can make a big difference when a truck is loaded with 36 tons of payload, improving the handling significantly.

6.2.1 Demands Specification

Here follows an analysis of how well the solution meets the demand specification.

General demands for a subframe

The subframe should:

1. Distribute the load evenly over the chassis frame
   The SSAB Octagon Subframe is in contact over the whole chassis frame, distributing the load as well as any conventional subframe.

2. Provide clearance for wheels and other parts which project above the frame
   The large variety of tipper bodies makes it hard to evaluate the SSAB Octagon Subframe in this aspect. Further research may show negative effects of the reduction in height.

3. Connect the bodywork to the chassis frame
   The SSAB Octagon Subframe is connecting the bodywork in a similar way as the RF.

4. Provide rigidity and reduce the stress in the rear overhang
   The simulation result indicates that the suggested solution is more rigid than the RF. This helps reduce the stress in the rear overhang.
5. **Contributes to dampening chassis oscillation**
With increased rigidity in the subframes should the resistant towards oscillation movements be higher, therefore dampening the effects on the chassis frame.

**Specific demands from SSAB**
**The subframe should:**

6. **Pass strength and stress simulation tests**
The SSAB Octagon Subframe performs well in all the simulation tests, comparison with the RF shows many improvements.

7. **Use HSS in a correct and optimized manner**
The design is made to take advantage of the material's strength, formability and weldability.

8. **Be adapted for use on Scania trucks**
Following the exterior lines of Scania's chassis frame makes the SSAB Octagon Subframe well adapted for use together with Scania trucks.

9. **Be adopted for use with tipper body trucks**
Size, load and connection points are set to fit with SSAB's tipper bodies.

### 6.3 Analysis of Research Questions

The aim of this pre-study has been to evaluate the possibility to develop a new subframe design, a design which is making good use of HSS. Three research questions were created to help the project. Where the product should answer to the demand specifications, should the whole project answer the RQs.

The RQs have been of great help all through the project. They have helped to keep the focus on relevant work. Every effort should direct or indirect help to answer these questions, work found not to be adding to these aims have quickly been dropped.

Here follows short answers to the projects RQs.

**RQ1: What are the rules and directives surrounding the construction of a subframe for tipper body trucks?**
The answer to the first RQ is found in the research chapter where directives from body building companies are covered. See chapter 4.3.8 General Directives for Subframe. This question built a large part of the base information on how to construct a tipper body subframe. Information on everything from screw quality to positioning of cross members is available to support the developer.

**RQ2: How can high strength steel improve a subframe construction?**
This RQ is best answered by SSABs own in-house information. By studying SSABs Design Handbook and Welding Handbook several tips and methods can be found. KSC has also assisted in finding material and examples on how HSS can improve an existing construction. Together with the simulations have all this information helped shaped the design of the final result.
RQ3: How can SSAB develop a tipper body subframe with a 10 percent improvement regarding strength, rigidity and weight?

Through the development and presentation of SSAB Octagon subframe, have the project answered the last RQ. Only the weight reduction did not reach a 10% improvement. The result still gives an example on how an alternative subframe can be constructed with improved performance.
7 RECOMMENDATIONS AND CONCLUSION

In this chapter is recommendations for future work given, followed by a short conclusion of this thesis.

7.1 Product Recommendations

The result of this project is a subframe for tipper body trucks. The SSAB Octagon Subframe meets the demands and requirements that were put down in the start of the project. It should be remembered that the result is not a finished product, but instead a new concept for a subframe solution.

Here follows some thoughts on how the SSAB Octagon Subframe can be further developed.

• The number and positions of the attachments need to be closer researched, as well as their design.
• Areas with high local stress points need to be evaluated and adapted.
• The surrounding equipment should be included in the simulations, analysing how they affect the result and if any problems with mounting exist.
• Analysing what welding techniques are best suited for the final construction.
• Should SSAB tipper bodies have a stabiliser, if so, how can it be incorporated in the design?
• Simulations should be conducted without the chassis frame. These results could reveal new strengths and weaknesses.

Some tipper bodies are design to rest against the subframe when fully loaded, this considered to work with this new design as well. The effects should however be kept under close observation.

7.2 Project Conclusion

This project has been challenging and exciting. Mixing empirical studies and product development is a good way of running a project, first learning the background and rules, and then apply this knowledge in the developing work.

The conclusion of this thesis is that, by changing the design and material can a new subframe that performs as well, or better than, the RF be produced. Through development and conducted simulation-tests have the project shown, that there is room and a possibility, to drastically change the design of a tipper body subframe.

The amount of primary data on this topic was low and one sided. While working deeper into this project, it became apparent that subframes are not an area under any real development. This makes room for big improvements but also forced the project to start from the very bottom.

Something that would have increased the reliability of the project is a chance to link the result to physical tests. It does not have to be tests on the SSAB Octagon subframe (though that would be the absolute best), but physical tests of the RF or similar construction. Comparing physical results against the RFs simulated result could give information on how well the
simulation-assumptions have been made. Possible deviations can then be assumed for the other concepts going through the same simulation.

The help from in-house resources have been important and of great value throughout this project. Most external companies have in a similar way shown a willingness to help and lend their knowledge to the project.

The Scania body building rules have, as previously mentioned played a central part in this project. As a final thought should it be remembered, that these are directives and recommendations, not rules set in stone.
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</table>
1 Ullmans Product Development Process

A general process that is well known by many people is the process of Ullman [Ullman 2010]. This process is based on phases which can give a positive affect and help to create a greater value.

The first step in this process is Product Discovery. In this step the development team discovers a customer need and states the market opportunity it gives.

The next step in this method is Project Planning. The development team plan their work and describe how the work will be handled and in which order.

The third step in this method is Product definition. In this step the main task is to understand the problems and lay the basis for the balance in the project. Finding the definition may appear to be a simple task, but many problems in developments project are poorly defined. This step in the method can be a major undertaking. The results of this step are the problem decomposed into smaller, more manageable “sub-problems”.

The fourth step is about Conceptual Design. The development team uses the results of the Project Planning and Product Definitions step to evaluate concepts for the product or product changes. To generate concepts, the customer’s requirements can be guidelines through the whole process. If the guidelines are followed throughout the project the concept can eventually lead to a qualitative product.

Product Development is the fifth step in this method. In this step the development team refines and evaluates the concepts. The most potential concept with the highest measured profit may be chosen for further development. If there is a future for the concept it might be put into an actual product.

The last step in this method is Product support. When the product is released to production there is still a need in manufacturing and assembly support, support for vendors and also helps for the customers with introducing the product. Things like patents and other security measures are also carried out in this step.
2 Ulrich and Eppinger Product Development Process

Another method for product development processes is Ulrich and Eppingers version. In their method they focused on six phases just like Ullmans method. They start up the development process with planning phase 0, which is about identify opportunities, define the mission statement and launch the process.

Phase 1, Concept Development: Is a concept generation phase where you seek answers on the main problem in the assignment. You also search and gather information from existing data and internally. With those two together you might have created a new concept solving the problem.

Phase 2, System-Level Design: Is about the architecture and construction on parts and components needed for the layout on the concept. There are two ways to use architecture on a product, functional or physical.

Phase 3, Detail Design: Highlights specification on materials, tolerances, and the geometry on the concept. In this phase it’s important to get full control and documentation on the production for the concept. You need to determine which tools needed to assembly, production costs and the products robust design.

Phase 4, Testing and Refinement: The main purpose is to test the concept and if needed do refinements and improvements. After the previous phases there can still be questions for example which material that is most suitable, or if the design needs improvement or refinements.

Phase 5, Production Ramp-Up: Is the final step in the method. In this phase the concept is almost ready for launch for the market. In case of flaws and remaining problems on the product this may still be corrected in this phase. The Ramp-up is to train workforce and try solving the remaining problems. When all problems seem to be corrected the product is ready for the market. [Ulrich and Eppinger 2008]
3 Demand Specification

General demands for a subframe
The subframe should:
   1. Distribute the load evenly over the chassis frame
   2. Provide clearance for wheels and other parts which project above the frame
   3. Connect the bodywork to the chassis frame
   4. Provide rigidity and reduce the stress in the rear overhang
   5. Protect the chassis frame
   6. Contributes to dampening chassis oscillations

Specific demands from SSAB
The subframe should:
   7. Pass strength and stress simulation tests
   8. Use HSS in a correct and optimized manner
   9. Be adapted for use on Scania trucks
  10. Be adopted for use with tipper body trucks
5 Interview with Richard Södereng, Scania

General discussion
My image is that SSAB sits on knowledge regarding bodywork and how bodybuilding will affect the chassis. We have assumed so because SSAB has in decades supported bodybuilders with design solutions.

Scanias Body building homepage (BBH) is heavily based on experience rather than calculations. Knowledge built on experience throughout Scania history. When things are broken, is the solution described in BBH.

BBH describes general solutions and are in many cases oversized depending on how the chassis-spec looks, and for which application the vehicle will be used. There is always an optimal solution for every vehicle, but usually it does not pay to make a special bodywork to fit a specific specification unless there is a very large volume. The body building directives should therefore be viewed as general examples. Body builders usually have the same subframe in their production, regardless of which Scania it is mounted on, despite the fact that we have very different chassis frames with large difference in cross-section, the same goes for other truck brands as well, despite chassis settings differ wildly.

Question based answers
1. Is reduced weight and centre of gravity something you always work towards?
Nowadays, Yes.
What are the benefits which in this case, follow?
Roll stability and load capacity.

2. Why is some movement between the subframe and chassis desirable?
It works like springs together with the chassis frame, as a whole is it part of the suspension system. It minimize the risk of vehicle vibration, and allows the chassis frame to move, which is needed when the vehicle go off-road for example.
   2.1. What negative effects would a too rigidly clamped subframe have?
   It may cause comfort disruption by reducing the suspension. Can provide "shaky" ride. Imagine sitting on an empty trailer.
   2.2. What negative effects would a too loosely clamped subframe have?
   It may cause vibrations due to too little damping in the suspension system (chassis frame and subframe is part of the whole suspension system). The most common reason are wheels being out of shape, which usually is not noticeable as long as the subframe is properly used.
   2.3. Why are not the mounting brackets welded on the chassis as well?
   It is never allowed to weld directly on the chassis frame, it has an negative effect on strength. Would be best to also bolt the subframe and minimize weld.

2. How is size and placement of reinforcements decided between the chassis and subframe?
Primarily because of bending and twisting forces.

3. What controls the placement and number of attachments?
From experience, they should fit as tightly as possible, but never longer than 900mm apart. Not too tightly between a flexible mount and fixed mount, because that puts high stress in the fixed bracket.
6 SSAB Product Program

### Domex

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Yield strength (MPa)</th>
<th>Tensile strength (MPa)</th>
<th>Elongation</th>
<th>Bending radius 90° bend</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
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<tr>
<td>Domex 460 MC</td>
<td>460</td>
<td>670</td>
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<td>19</td>
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<td>Domex 500 MC</td>
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<td>700</td>
<td>14</td>
<td>18</td>
<td>0.6 x10&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Domex 550 MC</td>
<td>550</td>
<td>760</td>
<td>14</td>
<td>17</td>
<td>0.6 x10&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>Domex 600 MC</td>
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<td>0.7 x10&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>880</td>
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<td>14</td>
<td>0.8 x10&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Domex 700 MC</td>
<td>700&lt;sup&gt;2&lt;/sup&gt;</td>
<td>950</td>
<td>10</td>
<td>12</td>
<td>0.8 x10&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Domex 960&lt;sup&gt;2&lt;/sup&gt;</td>
<td>980</td>
<td>1100&lt;sup&gt;2&lt;/sup&gt;</td>
<td>8</td>
<td>10</td>
<td>3.0 x10&lt;sup&gt;3&lt;/sup&gt;</td>
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<tr>
<td>Domex 1100&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1250</td>
<td>7</td>
<td>4.0 x10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>3.00–6.00</td>
<td></td>
</tr>
</tbody>
</table>

1. For thickness > 8 mm, may be 20 MPa lower.
2. New grade under development with preliminary specification.

### Hardox

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Hardness Nominal (HBW)</th>
<th>Impact toughness CVL typical 20 mm</th>
<th>Bending properties Transverse t=8 mm R=300 mm</th>
<th>Ref. service life interval</th>
<th>CEV/CET Typical 20 mm</th>
<th>Thickness (mm)</th>
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<tr>
<td></td>
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<tr>
<td>Hardox Hiltl</td>
<td>350</td>
<td>95&lt;sup&gt;1&lt;/sup&gt;–40&lt;sup&gt;1&lt;/sup&gt;</td>
<td>1.5&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.55/0.36&lt;sup&gt;2&lt;/sup&gt;</td>
<td>40&lt;sup&gt;1&lt;/sup&gt;–130</td>
<td></td>
</tr>
<tr>
<td>Hardox 400&lt;sup&gt;2&lt;/sup&gt;</td>
<td>400</td>
<td>45&lt;sup&gt;1&lt;/sup&gt;–40&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.41/0.28&lt;sup&gt;2&lt;/sup&gt;</td>
<td>3&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Hardox 450&lt;sup&gt;2&lt;/sup&gt;</td>
<td>450</td>
<td>40&lt;sup&gt;1&lt;/sup&gt;–40&lt;sup&gt;1&lt;/sup&gt;</td>
<td>2.5&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.43/0.29&lt;sup&gt;2&lt;/sup&gt;</td>
<td>4&lt;sup&gt;1&lt;/sup&gt;–130&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Hardox 500&lt;sup&gt;2&lt;/sup&gt;</td>
<td>500</td>
<td>30&lt;sup&gt;1&lt;/sup&gt;–40&lt;sup&gt;1&lt;/sup&gt;</td>
<td>3&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.72/0.48&lt;sup&gt;2&lt;/sup&gt;</td>
<td>3&lt;sup&gt;2&lt;/sup&gt;–80&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Hardox 600&lt;sup&gt;2&lt;/sup&gt;</td>
<td>600</td>
<td>20&lt;sup&gt;1&lt;/sup&gt;–40&lt;sup&gt;1&lt;/sup&gt;</td>
<td>4&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.73/0.55&lt;sup&gt;2&lt;/sup&gt;</td>
<td>8&lt;sup&gt;2&lt;/sup&gt;–50&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>Hardox Extreme</td>
<td>650–700</td>
<td>15&lt;sup&gt;1&lt;/sup&gt;–40&lt;sup&gt;1&lt;/sup&gt;</td>
<td>5&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.84/0.59&lt;sup&gt;2&lt;/sup&gt;</td>
<td>8&lt;sup&gt;2&lt;/sup&gt;–25&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

All plates are produced with AccuHot™ precision guarantee or closer.

1. Most/most all sides wear by SSAB WorldCast blank steel (1, 2, 3, 3).
2. CEV=C+15%M+(C+M)+V+S+(C+Ni)/5, CET=C+15%M+(C+Ni)/10+(C+Cu)/20+N/40
3. 70 mm
4. Thicknesses up to 160 mm are available upon request.
5. # 1600 mm, preferred widths are 1260, 1500 or 1600 mm.
6. Thicknesses up to 1200 mm are available upon request.
7. Typical values 300–600 mm
8. Typical values 0.70–2.10 mm

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## Docol

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Yield strength [MPa]</th>
<th>Yield strength after bake hardening [MPa]</th>
<th>Tensile strength [MPa]</th>
<th>Elongation A5 [%]</th>
<th>Bending radius 90° Bend</th>
<th>Thickness [mm]</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
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<tr>
<td><strong>Docol LA</strong></td>
<td>Cold-rolled high strength low alloyed steels for light weight structures.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Docol 420 LA</td>
<td>420</td>
<td>520</td>
<td>470</td>
<td>590</td>
<td>17</td>
<td>0.25 x t</td>
</tr>
<tr>
<td>Docol 500 LA</td>
<td>500</td>
<td>620</td>
<td>570</td>
<td>710</td>
<td>14</td>
<td>0.50 x t</td>
</tr>
<tr>
<td><strong>Docol Roll</strong></td>
<td>Cold-rolled steels designed for roll forming.</td>
<td></td>
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<tr>
<td>Docol Roll 800</td>
<td>600</td>
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<td>800</td>
<td>950</td>
<td>10</td>
<td>0.50 – 2.10</td>
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<tr>
<td>Docol Roll 1000</td>
<td>850</td>
<td>850</td>
<td>1000</td>
<td>1200</td>
<td>5</td>
<td>0.50 – 2.10</td>
</tr>
<tr>
<td><strong>Docol DP</strong></td>
<td>Cold-rolled dual phase steels with a microstructure mix of ferrite and martensite giving good formability and high strength. DP steels are suitable for advanced forming such as pressing.</td>
<td></td>
<td></td>
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<tr>
<td>Docol 500 DP</td>
<td>290</td>
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<td>600</td>
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<td>Docol 600 GC</td>
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<td>850</td>
<td>1000</td>
<td>1200</td>
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<tr>
<td><strong>Docol M</strong></td>
<td>Fully martensitic steels, suitable for applications with very high demands of strength and weldability.</td>
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<tr>
<td>Docol 900 M</td>
<td>700</td>
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<td>900</td>
<td>1100</td>
<td>3</td>
<td>3.0 x t</td>
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<td>Docol 1200 M</td>
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<td>Docol 1500 M</td>
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<td>1500</td>
<td>1700</td>
<td>3</td>
<td>3.0 x t</td>
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<tr>
<td><strong>Docol W</strong></td>
<td>Weather resistant steels, creates a red oxide layer on the surface preventing the steel from corrosion, suitable for outdoor applications.</td>
<td></td>
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<tr>
<td>Docol 700 W</td>
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<td>800</td>
<td>800</td>
<td>5</td>
<td>2.0 x t</td>
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<tr>
<td><strong>Docol Strap</strong></td>
<td>Packaging strap steels delivered in quenched and tempered conditions.</td>
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<td>Docol Strap 800</td>
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<td>900</td>
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<td>930</td>
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<td><strong>Dogal LA</strong></td>
<td>Cold-rolled high strength low alloyed steels for light weight structures.</td>
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<td>Dogal 420 LAD</td>
<td>420</td>
<td>520</td>
<td>470</td>
<td>590</td>
<td>17</td>
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<td>560</td>
<td>560</td>
<td>680</td>
<td>15</td>
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<td>640</td>
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<td>900</td>
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<tr>
<td><strong>Dogal DP</strong></td>
<td>Galvanized dual phase steels with a microstructure mix of ferrite and martensite giving good formability and high strength. DP steels are suitable for advanced forming such as pressing.</td>
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<td>1000</td>
<td>1200</td>
<td>6</td>
<td>2.5 x t</td>
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</table>

1. Also available with electro-galvanized surface.
2. Only available with hot-rolled substrate.
### Weldox

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>Yield Strength (MPa)</th>
<th>Toughness CVT typical</th>
<th>Reading properties Transverse t=9 mm Wt</th>
<th>Tensile strength (MPa)</th>
<th>CEW/CEP typical</th>
<th>Thickness (mm)</th>
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<tbody>
<tr>
<td>Weldox 700</td>
<td>700</td>
<td>165 - 40 °C</td>
<td>1.5</td>
<td>760</td>
<td>9.3</td>
<td>0.63/0.80</td>
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<tr>
<td>Weldox 900</td>
<td>900</td>
<td>881 - 40 °C</td>
<td>2.5</td>
<td>940</td>
<td>1100</td>
<td>7.1/0.41</td>
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<td>Weldox 960</td>
<td>960</td>
<td>841 - 40 °C</td>
<td>2.5</td>
<td>960</td>
<td>1150</td>
<td>6.3/0.40</td>
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<td>Weldox 1100</td>
<td>1100</td>
<td>671 - 40 °C</td>
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<td>1250</td>
<td>1550</td>
<td>4.9/0.40</td>
</tr>
<tr>
<td>Weldox 1300</td>
<td>1300</td>
<td>321 - 40 °C</td>
<td>4.0</td>
<td>1400</td>
<td>1700</td>
<td>4.0/0.40</td>
</tr>
</tbody>
</table>

Alloys are produced with Accusteel™ precision guarantee or closer.
1. CEW/CEP 3.0mm [Cu/Pb/Ag] (Cu/Pb/Ag) Cu/Pb/Ag
2. CEW/CEP 3.0mm [Bi/Pb/Ag] (Bi/Pb/Ag) Bi/Pb/Ag
3. Weldor 700 2.0mm
4. For 6 mm and full size test specimen.

### Prelaq

<table>
<thead>
<tr>
<th>Customer offer</th>
<th>Customer segment</th>
<th>Steel grade</th>
<th>Paint system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preloq FRS</td>
<td>Manufacturers of effective and easy installed roof water systems, based on double sided prepared sheet steel.</td>
<td>FRS/FRS</td>
<td>No</td>
</tr>
<tr>
<td>Preloq R+I+A</td>
<td>Long strip painting and linings with strict demands on functioning, flexibility and appearance.</td>
<td>R+I+A</td>
<td>GreenCoat/Nowo/VVVEF</td>
</tr>
<tr>
<td>Preloq Energy</td>
<td>Energy saving objects, indoor and outdoor roofs and walls. Applications where low thermal movement is beneficial like doors and sandwich panels.</td>
<td>PLX/PLX</td>
<td>Energy Interior</td>
</tr>
<tr>
<td>Preloq Prolak</td>
<td>Profiled sheet steel, steel root tiles, cassettes and sandwich panels.</td>
<td>Sub 280/SUB 350</td>
<td>Novo/Polyester/Polyurethane</td>
</tr>
</tbody>
</table>

The membrane coating is available in 275 - 350 μm².

The extensive color program can be found on the website [www.prelaq.com](http://www.prelaq.com).

### Toolox

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Hardness guaranteed (Rockwell)</th>
<th>Impact energy guaranteed (15 mm)</th>
<th>Yield strength Reuts (MPa)*</th>
<th>Tensile strength Rmuts (MPa)*</th>
<th>Elongation A5 (%)</th>
<th>Comprehensive strength Rmuts (MPa)*</th>
<th>Impact energy D5*</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40 °C</td>
<td>27</td>
<td>45</td>
<td>850</td>
<td>980</td>
<td>16</td>
<td>800</td>
<td>100</td>
<td>5 - 130</td>
</tr>
<tr>
<td>-20 °C</td>
<td>35</td>
<td>12</td>
<td>800</td>
<td>900</td>
<td>12</td>
<td>750</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>+20 °C</td>
<td>35</td>
<td>12</td>
<td>800</td>
<td>900</td>
<td>12</td>
<td>750</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>+30 °C</td>
<td>35</td>
<td>12</td>
<td>800</td>
<td>900</td>
<td>12</td>
<td>750</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>+40 °C</td>
<td>35</td>
<td>12</td>
<td>800</td>
<td>900</td>
<td>12</td>
<td>750</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>+50 °C</td>
<td>35</td>
<td>12</td>
<td>800</td>
<td>900</td>
<td>12</td>
<td>750</td>
<td>170</td>
<td></td>
</tr>
</tbody>
</table>

* Values are for guidance only.

The typical testing temperature for Toolox is room temperature.

### Toolox

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Hardness guaranteed (Rockwell)</th>
<th>Impact energy guaranteed (15 mm)</th>
<th>Yield strength Reuts (MPa)*</th>
<th>Tensile strength Rmuts (MPa)*</th>
<th>Elongation A5 (%)</th>
<th>Comprehensive strength Rmuts (MPa)*</th>
<th>Impact energy D5*</th>
<th>Approximate Hardness (HRC)*</th>
<th>Rmuts (MPa) after 170 hrs soaking time at the actual temperature</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40 °C</td>
<td>14</td>
<td>19</td>
<td>1250</td>
<td>13</td>
<td>1250</td>
<td>45</td>
<td>1060</td>
<td>910</td>
<td>5 - 130</td>
<td></td>
</tr>
<tr>
<td>-20 °C</td>
<td>14</td>
<td>19</td>
<td>1250</td>
<td>13</td>
<td>1250</td>
<td>45</td>
<td>1060</td>
<td>910</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+20 °C</td>
<td>14</td>
<td>19</td>
<td>1250</td>
<td>13</td>
<td>1250</td>
<td>45</td>
<td>1060</td>
<td>910</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+30 °C</td>
<td>14</td>
<td>19</td>
<td>1250</td>
<td>13</td>
<td>1250</td>
<td>45</td>
<td>1060</td>
<td>910</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+40 °C</td>
<td>14</td>
<td>19</td>
<td>1250</td>
<td>13</td>
<td>1250</td>
<td>45</td>
<td>1060</td>
<td>910</td>
<td></td>
<td></td>
</tr>
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<td>19</td>
<td>1250</td>
<td>13</td>
<td>1250</td>
<td>45</td>
<td>1060</td>
<td>910</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Values are for guidance only.

The typical testing temperature for Toolox is room temperature.

All other values are issued randomly and they are for information only.
7 Company Questions and Answers

Background and Objectives
My thesis involves seeking new applicable uses for high-strength steel. I want to look at how the HSS can improve existing designs. Being able to quickly make validations of products and components where the HSS can be used to a greater extent than they do today. No matter where improvements can be made and where problems arise when switching to HSS? As a starting point I have chosen to examine the possibility of introducing high-strength steel subframes. Unlike trucks and truck chassis subframe is a product not seen any major investment or development. For me to go ahead with this project, I have to create my understanding of what it is that controls the design and construction of high-strength structures. I have studied some materials available for bodybuilders and the like and it's been a good start. The document talks a lot about how to design and fastened subframe but it tells very little about why. Why should the framework be sometimes moving and sometimes rigidly clamped etc? To gain a deeper understanding of the controlling factors were underlying reasons be very interesting to understand. One area I am sure you have some knowledge of. You may be sitting on powerpoints or similar document in which the chassis and frame are discussed and why they look the way they do. These are of course of interest to take part of if it suits you.

Contact person Magnus Källman, Senior Manager, magnus@wagnfabriken.se

General questions regarding the use of HSS

• In your products, do you always work with HSS or only on demand from customer? We follow industry standard when we choose materials, but of course, we follow customer requirements of materials for our products.

• In your company, describe the difference between working with HSS and mild steel? We feel that it is more difficult to work with HSS in our business. Processing such as drilling, bending and welding requires better equipment and knowledge. Something that we feel we can improve on.

• When developing new products, do you include HSS steel in the original design? It happens to some degree. We are engaged in product development, mainly on customer request and then usually follow a predetermined specific material with the drawings. SSAB also account for part of the product development with their own material in focus.
Do your products have any certifications and what does it take to get them?
We currently only use Hardox(Hardox in my body) that can be seen as a guarantee of the material that we use. It assures the customer that the product is durable and is expected to provide a long service life.

Specific questions to Wagnfabriken

- Is the chassis frame build with a subframes additional strength in mind?
  Yes. The chassis frame is always built with the subframe in mind. It is very important to the whole structure. It helps to absorb and distribute the weight.

- Do you always strive to decrease the center of gravity and weight? What are the benefits?
  Yes. As a rule, all vehicles undergo a life cycle analysis. A weight loss makes big difference in terms of increased load capacity or reduced fuel consumption. Something that gives great impact over the vehicle's lifetime.

- Why is a certain degree of movement desireble?
  Not sure. It is decided from the truck manufacturers, we follow their recommendations.

- Why are not the attachments welded in both the chassi and subframe?
  The warranty on the chassis cannot be guaranteed if the welds are made against its beams. Material properties change, and therefore are only screw joints allowed.

Additional information

Profiles for subframe are 160x80x8
Mounted crane does not support the subframe so as not to impede its movement. The subframe requires several service points for hydraulics and wires. Increased height of the subframe provides increased strength and rigidity.

Contact person: Jonas Svensson, Production Manager, jonas.svensson@norje.se

General questions regarding the use of HSS

- In your products, do you always work with HSS or only on demand from customer?
  We always work with the HSS, is it central in every element of our products and its construction. On customer request, we are adding more and larger dimensions. Some want products in 100% HSS and we have nothing against that, always meeting their requirements.

- In your company, describe the difference between working with HSS and mild steel?
  Plates in Mild-steel tend to be wobbly and have a greater deviation from the set dimensions. Welding and punching HSS is going well, but we are experiencing some problems during drilling.

- When developing new products, do you include HSS steel in the original design?
We do this primarily at the request of the customer. They can come with requests and we try to meet them as best as possible and to solve problems and deficiencies that arise.

- Do your products have any certifications and what does it take to get them?

No. We have no certifications of our products. We will possibly introduce it on our welding work.

Specific questions to Norje

- Do you always try to reduce the weight of your products?

  Yes, especially on small trucks where reduced weight has a big impact on how much the device is allowed to lift. Even smaller buckets benefit greatly from a reduced weight with maintained strength. This gives increased lifting capacity, which is important for vehicles lifting many times per day.

- Additional information

  Norje bends and cuts the material themselves. They use a plasma cutter with an output of 260A can handle up to 20mm with good quality, or 32mm as max thickness.

  They also manufacture Fork Extensions with Domex 650 welded by a Motoman welding robot.

  Much of their welding is done with the hole thread where fluxes are in the wire core.

Contact person. Bosse Jonsson, Technical developer and sales, bosse@roadex.se

General questions regarding the use of HSS

- In your products, do you always work with HSS or only on demand from customer?

  We use it at customer’s request. If there is no demand, we have little use of HSS in our production.

- In your company, describe the difference between working with HSS and mild steel?

  We experience only small differences. There are no major problems switching to the HSS in our products.

- When developing new products, do you include HSS steel in the original design?

  Product development is mainly done without HSS.

- Do your products have any certifications and what does it take to get them?

  Hardox in my body is the only standard or certification or whatever you call it among our products. We live on a very good reputation which assures the customer of our qualitative products.

Specific questions to Wagnfabriken

- Do you always try to reduce the weight of your products, and what are the benefits?

  Absolutely. Reduced weight means increased loading capacity.

- Additional information
As the dimensions of the profiles in a subframe is reduced, so too is the torsional rigidity. This can sometimes be difficult to compensate with stronger materials only.

Fully welded caps or plates would make a subframe too stiff. BFAB produces grain trucks of up to 25 cubic meters. These must be as light as possible.

All constructs (container, flat, frame, etc.) should be as lightweight, strong and inexpensive as possible under BFABs customer Stena.

A truck is typically replaced after 5-6 years when they usually are depreciated over that period.

Today the material S-355 in BFABs shifter platform. Tests have shown that trucks with 2-3mm Domex 650 are intolerant to run scrap with. Holes arise.
Attachments

Rigid screw attachment
This connection between subframe and chassis relies heavily on friction. By pulling the two frames tightly together the occurring friction dampens oscillation movement. The surface treatment is important to consider as the friction is determined by the two surfaces materials.

Flexible attachment
This attachment method is longitudinally flexible. That means that it permits some movement horizontally along the frames length. The length and diameter of the screw decides the flexibility of the bracket. The tightening torque should be between 20-100 Newton meters, any higher torque and the purpose of the attachment is lost.

Some flexible attachments can be made up of compression springs, rubber cushions or cup springs. They accept movement in both longitudinal and vertical axis. This is the most elastic attachment method used between subframes and chassis frames. This kind of connection absorbs a large amount of vibrations. That makes them commonly positioned close to the driver cabin where vibrations would affect the drivers comfort.
Unconventional attachments
Researching the subject has shown that other less conventional methods for attaching subframe and chassis are being tested and used. They are not covered by Scania body building companies instructions, but customers can in certain circumstances opt to use them anyway.
The first picture shows an easy to remove spring bolt connection. The second picture shows a rigid bracket that is bent and screwed on in both ends.

Not recommended attachments
The following long U-bolt connection is not recommended by Scania. The risk of wear and rust is considerable.
## 9 Concepts and Evaluation

<table>
<thead>
<tr>
<th>GROUP A</th>
<th>This group takes the classical subframe and adds HSS. Minor changes and improvements can be made and tested but the overall design follows the typical subframe design.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical C-beam with reinforcement. Easy geometry for mounting, drilling and more. Change to E-beam for stronger geometry and less material. More difficult mounting and connections of cross members.</td>
<td>Checked profiles are mainly used when the load scenario is very simple and concrete. It stops the profile from buckling. To change the profile comes with several drawback and few benefits.</td>
</tr>
<tr>
<td>L-beam with crossbeam attachments. Welded end profile for tipper bearing.</td>
<td>The top part of the frame is needed for torsional strength and for the tipper body to lie upon. Concept will not undergo any further development.</td>
</tr>
<tr>
<td>Flat crossmembers in top and bottom of frame. Can be welded at intersection or move freely. A light weight solution compatible with several frame profiles.</td>
<td>This concept would be very interesting to look into. Only FEM-testing can tell of its true value. Ultra high steel could further improve it. Deeper research will be conducted.</td>
</tr>
<tr>
<td>Concept</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>Two identical plates welded together to form a cross member. Light weight but risk of buckling has to be advised.</td>
<td>Concept is missing strengthening top flanges. Buckling will there for be a problem. Concept will not undergo any further development.</td>
</tr>
<tr>
<td>A number of subframe profiles. FEM-testing can evaluate their benefits or drawbacks.</td>
<td>Changing a profile by adding more checks is mostly done to counter buckling. Buckling can be calculated when loading forces and support are given in great detail to optimize the use of material. In the case of a subframe these parameters are however not given in enough detail.</td>
</tr>
<tr>
<td>Profile without additional need of attachment. Bolt holes do however require high precision. Only low friction between the frames can be expected.</td>
<td>It is crucial for many tipper body trucks to have a variety of attachments, both rigid and flexible. This concept only allows for one type of connection. Concept will not undergo any further development.</td>
</tr>
<tr>
<td>A 45 degrees angled subframe will make the total height lower. The tipper body is also secure from movement sideways.</td>
<td>Interesting ide with a side cut subframe. This solution done however not work with SSABs own tipper bodies. Concept will not undergo any further development.</td>
</tr>
<tr>
<td>Crossmember made from two T-beams. Rigid and low weight. Weld points will come under high stress.</td>
<td>Recommendations tell that closed profiles are superior o open ones.</td>
</tr>
<tr>
<td><strong>GROUP B</strong></td>
<td>Group B will apply the use of checked plates instead of metal-profiles. Plates stretching from one side of the chassis frame to the next. This removes the need for separate cross members as one of its benefits.</td>
</tr>
<tr>
<td>A bottom plate reinforced with standard C-profiles on top. Construction further strengthens at rear part by top plate. Holes can be made where tubes and equipment needs to come through. Lower profiles then standard subframe.</td>
<td>Checked plate designed to make good use of the material can be an interesting concept. The plates can create closed profiles adapted to counter oscillation forces. Concept will be constructed and tested.</td>
</tr>
<tr>
<td>Fully enclosing profile. Requires only one weld on top but puts high demand on bending equipment and knowledge.</td>
<td>Concept follows the same line as the one before. Concept will be tested.</td>
</tr>
<tr>
<td>This profile is restricting the tipper body from moving sideways.</td>
<td>This profile will be very hard to produce as it contains checks over 90 degrees. The angled design may be implemented together with other concepts however. Concept will not undergo any further development</td>
</tr>
<tr>
<td>This design should give a very rigid subframe. Strong bending and oscillation ability’s.</td>
<td>Intresting concept. Should be tested for oscillation resistant.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>The tipper body can potentially be lowered about 200mm. The frames rigidity and oscillation properties have to be calculated. The chassis frame has to be adopted to take more bending force.</td>
<td>This concept is only partially using hollow profiles in its design. It is there for not efficient in its use of material. Concept will not undergo any further development</td>
</tr>
<tr>
<td>Square end pipe for easy connection with subframe profiles. Reinforcing side members bolted to the chassis frame.</td>
<td>These designs can be seen as complementary to other concepts. They will be kept under consideration.</td>
</tr>
<tr>
<td>This group will try to reduce the need of a subframe by giving the flatbed better support. With lower torsional stress the need of a strong subframe might be removed.</td>
<td>Theoretical testing has showed that these concepts are unrealistic or have little to no effect on stabilization. Concepts will not undergo any further development.</td>
</tr>
<tr>
<td>Different stabilization proposals. Inspiration has been taken from the stabilizator and end dump trucks.</td>
<td></td>
</tr>
<tr>
<td>Concept</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>Classical stabilizer</td>
<td>The classical stabilizer found connecting the subframe and the tipper body on some trucks could be reinforced. Placing a bigger version wider and higher might give larger support and remove some torsional force.</td>
</tr>
<tr>
<td>Stiff arm sliding</td>
<td>A stiff arm sliding along the bottom of the tipper body. The mounting point should be as far forward as possible. This could unload some of the stress from the rearmost part of the truck.</td>
</tr>
<tr>
<td>Slide bar</td>
<td>A side mounted slide bar. Uncertain effect.</td>
</tr>
<tr>
<td>![Diagram 1]</td>
<td>With two hydraulic pistons will the tipper body have strong and stable support in the front part of the truck as well. This should remove some of the need of a torsional stiff subframe.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>![Diagram 2]</td>
<td>Concept will result in increased weight and cost. Benefits are argued to be smaller than total drawbacks. Concept will not undergo any further development</td>
</tr>
<tr>
<td>![Diagram 3]</td>
<td>The classical stabilizer placed backwards. This could move some of the oscillation away from the rear overhang.</td>
</tr>
<tr>
<td></td>
<td>As discussed SSABs tipper bodies are not well adapted for connection underneath. Concept will not undergo any further development</td>
</tr>
</tbody>
</table>
10 Tipper Body Calculations

\[ 35^\circ \]

\[ 58.4^\circ \]

\[ 1504\text{mm} \]

\[ 3724\text{mm} \]

\[ M=37000\text{kg} \]
\[ A: 3724 \cdot T - F_2 \cdot 5228 = 0 \]

\[ F_2 = \frac{3724 \cdot 37000}{5228} = 26356 \text{kg} \]
11 Domex 700MC

PRODUCT
Domex cold forming steels are thermo-mechanically rolled in modern plants where the heating, rolling, and cooling processes are carefully controlled.

The chemical analysis, consisting of low levels of carbon and manganese, has precise addition of grain refiners such as niobium, titanium or vanadium. This together with a clean structure, makes Domex Steels the most competitive alternative for cold formed and welded products.

Domex 700 MC with designations D and E meet and exceed the demands for steel S700MC in EN-10149-2.

APPLICATION
The extra high strength steel grades are used in applications such as truck chassis, cranes and earthmoving machines. In these applications, the high strength of the steels is used to save weight and/or to increase the payload.

As a result of this and the good formability of the steels, the total costs can be reduced.

MECHANICAL PROPERTIES

Yield strength
\[ R_p^0, N/mm^2 \]
Tensile strength
\[ R_m, N/mm^2 \]
Elongation at failure
\[ \% \]

<table>
<thead>
<tr>
<th></th>
<th>( R_p^0 )</th>
<th>( R_m )</th>
<th>( A_s % )</th>
<th>( A_t % )</th>
</tr>
</thead>
<tbody>
<tr>
<td>7000</td>
<td>750 - 950</td>
<td>1000 - 1300</td>
<td>1500 - 1900</td>
<td>1500 - 1900</td>
</tr>
</tbody>
</table>

* For thicknesses > 8 mm, the minimum yield strength may be 20 N/mm² lower.

DIMENSION RANGE
Domex 700 MC is available in the range of sizes tabulated below in as rolled or pickled condition with mill edge.
For material with trimmed edges, the width is reduced by 35 mm.

Some exceptions may occur.

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Width (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00 - 8.00</td>
<td>1000 - 1300</td>
<td>1500 - 1900</td>
</tr>
<tr>
<td>9.00 - 10.00</td>
<td>885 - 1200</td>
<td>1500 - 1900</td>
</tr>
</tbody>
</table>

IMPACT STRENGTH
The Charpy V notch test is carried out according to EN 10045-1.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Test temperature</th>
<th>Energy level</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>-20°C</td>
<td>40</td>
</tr>
<tr>
<td>F</td>
<td>-40°C</td>
<td>27</td>
</tr>
</tbody>
</table>

* Other test temperatures and impact strengths are available subject to special agreement.

BENDABILITY

<table>
<thead>
<tr>
<th>Nominal sheet thickness, ( t )</th>
<th>Bending radius (( 90^\circ ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t \leq 3 ) ( mm )</td>
<td>1.0 ( m )</td>
</tr>
<tr>
<td>( 3 &lt; t \leq 6 ) ( mm )</td>
<td>1.2 ( m )</td>
</tr>
<tr>
<td>( t &gt; 6 ) ( mm )</td>
<td>1.5 ( m )</td>
</tr>
</tbody>
</table>
WELDING
The low contents of carbon, phosphorus and sulphur enable all
conventional welding methods to be readily used for Domex
700 MC. No preheating is necessary. A narrow heat affected
zone with a somewhat lower hardness is formed immediately
adjacent to the weld. However, if normal welding parameters
and methods are used, the heat affected zone is of no practical
significance.
Tensile test pieces taken across the weld can meet the same
minimum tensile strength requirements as the base metal.

CHEMICAL COMPOSITION

<table>
<thead>
<tr>
<th>C% max</th>
<th>Si % max</th>
<th>Mn % max</th>
<th>P % max</th>
<th>S % max</th>
<th>Al % min</th>
<th>Nb % max</th>
<th>V % max</th>
<th>Ti % max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12</td>
<td>0.10</td>
<td>2.10</td>
<td>0.025</td>
<td>0.010</td>
<td>0.015</td>
<td>0.09</td>
<td>0.20</td>
<td>0.01</td>
</tr>
</tbody>
</table>

1) If the material is to be hot dip galvanized, this must be stated in the order.
2) Sum of Nb, V and Ti = 0.25% max.

EXAMPLES OF DIFFERENT MATCHING AND OVER MATCHING FILLER METALS

<table>
<thead>
<tr>
<th>MMA</th>
<th>DNAV</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>OK 75.75</td>
<td>OK Tubrod 14.03</td>
<td>ESAB</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>ESAB</td>
</tr>
<tr>
<td>Erico 118</td>
<td>-</td>
<td>ESAB</td>
</tr>
<tr>
<td>Avocet 110</td>
<td>Fuego 1000</td>
<td>ESAB</td>
</tr>
<tr>
<td>Tenax 075</td>
<td>Fuego 42</td>
<td>Cerbelli NIMoCr</td>
</tr>
</tbody>
</table>

There are a large number of matching or over matching filler
metals that can be used for welding of Domex 700 MC, which
gives a weld that can meet the same minimum tensile strength
requirements as the base metal. Some examples of different
filler metals that can be used are tabulated below.

HEAT TREATMENT
Stress relief annealing should be carried out within the tem-
perature range of 530 - 580°C. Heat treatment above this
range, e.g. normalizing and hot forming, reduces the strength
and should be avoided.

TECHNICAL SERVICE AND INFORMATION
Knowledge Service Center will be pleased to assist with addi-
tional information concerning this product and other products
from SSAB.
DOMEX PROFILE 700

HOLLOW SECTIONS
PRODUCTION RANGE

DIMENSION PROGRAM SQUARE AND RECTANGULAR
Standard stock items are represented as white dots. The blue area indicates possible production range, while the grey area indicates ranges where trials may be possible. Limitations may occur.

The smoothness of the surface is in accordance with the base material used for production.
On the outside and inside surface of steel sections emulsion residues deriving from manufacturing, as well as smaller iron stains are allowed. An oil coat providing temporary corrosion protection is applied during the manufacturing process on the outside surface.

WHAT DIMENSIONS ARE POSSIBLE
TOOLS/DIMENSIONS
The dimensions that are possible are limited by the tools of our manufacturer.

As Domex Profile 700 hollow sections are produced at selected partners there are many possibilities for customization in dimensions. General thickness range 2.0 – 6.3 mm. Contact SSAB for more information.

For customized production (not specified as standard dimensions on stock list) special requirements regarding order quantities may apply.

TOLERANCES ACCORDING TO EN 10219-2
Size: H, B < 100 mm: 1% but min +/- 0.3 mm
      H, B > 100 mm: +/- 0.8 %
      H, B > 200 mm: +/- 1.0 %
Thickness: T < 5 mm: +/- 10 %
           T > 5 mm: +/- 0.5 mm
Shape: 90° +/- 1°
Outer Radius: T < 6 mm: C or R = 1.6 - 2.4 T
             T > 6 mm: C or R = 2.0 - 3.0 T
Straightness: 0.20 %, or max 3 mm/m length

DELIVERY CONDITIONS ACCORDING TO EN 10219-1
Steel Grade: Chemical composition in data sheet
             Suitable for thin layer dip galvanizing (class I according to EN 10025-2)