



The Systematic Development Process Applied on a Cab Rotation Unit

Pre-study, concept generation, embodiment design, material selection
and optimization

Applisering av den systematiska utvecklingsprocessen på en
rotationsenhet för hytter

Förstudie, konceptgenerering, designspecificering, materialval och
optimering

Daniel Gustafsson

Faculty for Health, Science and Technology

Degree Project for Master of Science in Engineering, Mechanical Engineering

30 hp

Examinator: Jens Bergström

Supervisor: Leo de Vin

2018-08-02

*“Assumptions are the mothers of all f*ck-ups!”*

Abstract

This master thesis studies and applies the systematic development process. The process is initially described in general, creating a template for the process, and later on applied on a real case scenario to show the performance. Finally eventual advantages, drawbacks and suggestions for future improvements are given.

The systematic development approach has been performed at Laxå Special Vehicles, who produce truck cabs and special truck chassis for Scania CV AB. The project has focused on the cabs, i.e. the Crew Cabs and the Low Entry. Crew Cabs are extended normal truck cabs, containing four doors to make additional passengers possible, suitable for fire trucks etc. Low Entry is a lowered normal truck cab, lowering the approaching height, making this cab type suitable for city applicable usage where the driver or passengers enter and leave the cab frequently. The task given was to develop the current cab rotation unit to be able to handle both cabs, which from the beginning only could handle the Crew Cabs, called CC28 and CC31. The major goal of this project has been to enable rotation of the Low Entry too.

Five phases – pre-study, concept generation, embodiment design, material selection and optimization – were carried out. The pre-study generated a fundamental base of knowledge, according to both the systematic development process and information about the tilt. The concept generation contained a problem degradation, generation of possible solutions and finally an evaluation of these. During the embodiment design the best suited concept was described and developed in detail to allow a suitable material to be selected during the material selection phase. The optimization process consisted of investigating properties according to mechanical strength and stiffness.

Two construction solutions to accommodate the mounting points height and length difference between the Crew Cab and the Low Entry were developed. These were a covering plate, called K4, and a mounting plate, called K100, handling the problems occurring for length and height respective. The development process is thus considered to be well operating. It generated a useful result, although possibilities for further improvements exists.

Keywords: Systematic development process, Crew Cab, Low entry, Laxå Special Vehicles.

“Det är inte lätt när det är svårt!”

Sammanfattning

Denna masteruppsats studerar och förklarar den systematiska utvecklingsprocessen. Processens olika steg beskrivs inledningsvis generellt, för att sedan appliceras på ett reellt fall för att demonstrera genomförandet. Avslutningsvis ges fördelar, nackdelar och eventuella förbättringsförslag på metoden.

Projektet genomfördes på Laxå Special Vehicles som producerar hytter och chassin för fordonstillverkaren Scania. Projektet fokuserade på hytterna som kallas Crew Cab och Low Entry, där den först nämnda är en förlängd hytt med fyra dörrar istället för två. Detta ger mer hyttutrymme, plats för fler passagerare och är därför vanlig i tillämpningar som till exempel brandbilar. Low Entry är en tvådörrarshytt vars insteg är lägre än för vanliga tvådörrarshytter, vilket gör den användbara i stadsnära miljöer där passagerare eller förare ofta lämnar och går in i hytten. Uppgiften som skulle lösas, och därmed målet, var att anpassa en rotationsenhet, även kallad tilt, för även kunna rotera LE. Ursprungligen var den endast anpassad för de två hyttvarianterna av Crew Cab, som kallas CC28 och CC31.

Arbetet behandlade fem faser – förstudie, konceptgenerering, designspecificering, materialval och optimering – vilka skulle genomföras för att nå ett användbart resultat. Förstudien fokuserade på att erhålla kunskap om den systematiska utvecklingsprocessen, hur denna skulle genomföras, samt information om hur rotationsenheten fungerade. Konceptgenerering innehöll en problemnedbrytning, konceptskapande och utvärdering av de genererade koncepten. Under designspecificeringen gavs det bästa konceptet/koncepten dimensioner och specificerade funktioner för att under materialvalsprocessen erhålla passande material. Under optimeringsfasen genomfördes analysering och optimering, med avseende på styrka och styvhet.

Två konstruktionslösningar utvecklades vilka löste var sitt delproblem som var höjd- och längdskillnad för den bakre monteringspunkten mellan Crew Cab och Low Entry. En omgjord monteringsplatta visade sig lösa höjdskillnaden bäst, kallad K100. Längdskillnaden togs om hand genom att applicera en längre glidskena som skulle täckas av luckor, kallade K4. Eftersom ett väl fungerande resultat erhöles visade den systematiska utvecklingsprocessen sig fungera som efterfrågat men med förbättringspotential.

Keywords: Systematisk produktutveckling, Crew Cab, Low Entry, Laxå Special Vehicles.

*“Det kan inte gå mer än åt h*****e!”*

Table of Contents

1	Introduction.....	1
1.1	The systematic development process	1
1.2	Description of the cab tilt	2
1.3	The problem description in short.....	3
2	Method	4
2.1	Pre-study	4
2.1.1	Problem investigation.....	4
2.1.2	State of art	4
2.1.3	Feasibility	5
2.1.4	Requirement specification and QFD	5
2.2	Concept generation	7
2.2.1	Clarify the problem	7
2.2.2	Concept generation from external sources	8
2.2.3	Concept generation from internal sources.....	8
2.2.4	Systematic investigation.....	9
2.2.5	Selection and reflection	11
2.3	Embodiment design	13
2.3.1	Comparison to already existing solutions	13
2.3.2	Identify crucial requirements	13
2.3.3	Produce spatial constraints	13
2.3.4	Function carrier layout	13
2.3.5	Function carrier comparison.....	13
2.3.6	Assembly of detailed layout	14
2.4	Material selection	15
2.5	Optimization	16
3	Results.....	17
3.1	Pre-study	17
3.1.1	Problem investigation.....	17
3.1.2	State of art	19
3.1.3	Possibility to carry out.....	20
3.1.4	Requirement specification and QFD	21
3.2	Concept generation	22
3.2.1	Clarify the problem	22

3.2.2	Search from external sources	23
3.2.3	Search from internal sources	24
3.2.4	Systematic investigation.....	24
3.2.5	Selection and reflection	38
3.3	Embodiment design	40
3.3.1	Comparison to already existing solutions	40
3.3.2	Identify crucial requirements	41
3.3.3	Produce spatial constraints drawings	43
3.3.4	Function carrier layout	44
3.3.5	Function carrier comparison.....	46
3.3.6	Detailed layouts.....	47
3.4	Material selection	50
3.4.1	Material selection for K4 – Covering plate	50
3.4.2	Material selection for K100 – Mounting plate	56
3.5	Optimization	62
3.5.1	Load case identifications for K100	62
3.5.2	Start point of optimization of K100	64
3.5.3	Optimization steps of K100.....	64
3.5.4	Final result of K100.....	67
3.5.5	Load case identifications for K4	67
3.5.6	Start point of K4 analysis	67
3.5.7	Simulation results of K4.....	68
3.5.8	Final results for K4.....	70
4	Discussion	71
4.1	Pre-study phase.....	71
4.2	Concept generation phase	71
4.3	Embodiment phase	72
4.4	Material selection phase	73
4.5	Optimization phase	73
4.6	The overall process	74
5	Conclusions.....	75
6	Future work.....	76
7	Acknowledgments.....	77
8	References.....	78
	Appendices	82

Abbreviations and Descriptions

Crew Cab (CC) – Extended cab with four doors.

Low Entry (LE) – Normal cab length but lowered for an easier cab entry.

Truck cabin (Cab) – The driver and passenger space for a truck.

Fixed side of the rotation unit – Head tripod.

Movable part of the rotation unit, using rail – Tail tripod.

Connection between the cab and rotation unit – Cup and hitch.

Safety sensor within cup – Mounting sensor.

Sensor along the floor avoiding cab damage – Laser sensor.

Finite element method (FEA) – Computer software.

Work load limit (WLL) – Maximum applied load on a construction.

Safety factor (SF) – A factor applied depending on load case.

Body in white (BIW) – Frame of the truck cab

Job initiators – Supervisors at Laxå Special Vehicles

Quality function deployment (QFD) – Connects customer demands to construction properties.

Rack – A carrier on which the cab is moved.

1 Introduction

*This section presents a short description of the **systematic development process**, the **history** and **why it is be useful** to applicate. Different **approaches** are also mentioned and how these affect the process. This is followed by a description of the **investigated rotation unit** that would act as an **example** of the systematic development process.*

1.1 The systematic development process

The history behind the systematic development process is rather short. Until the 1960's the developments of new products were done by experience from earlier projects and were seen more as an art instead of something that one could be educated in. There were no developed methods used for the different stages and different aspects that should be taken into consideration during the development of a new product. This was changed in the 1960's when the Japanese started to generate new products by using different methods and stages during the development process. Education was also done continuously to become more effective. This implementation produced products with higher quality and for a lower price. This was the start of systematic process development [1].

As a more systematic work flow had now been developed, but it took further years until the knowledge moved into the universities to be educated in. The education evolved from a mainly analysis approach to a combined synthesis analysis work flow. Starting with a demand- and wish identification, different synthesis methods were done to retrieve new solutions and the analysis methods are used to evaluate against the earlier settled demands [1].

The reason for using a systematic development approach was and is until today to earn more money. For companies using the structured new product development (NPD) process, i.e. a systematic approach, the chance for success increases. This was confirmed when researches stated expected time savings by 30-40% by introducing NPD into German mechanical engineering industries [2]. By structuring the work, companies can control the workflow, secure product quality and discover possible improvements [3]. Figure 1.1 shows the design methodology, i.e. a concrete course of actions during design development, including plans, working steps and design phases. [4]

During time the systematic process have been developed into different directions. One approach used, since the 1990's, is the green product development (GPD), focusing on the environment issue by minimize product environmental impact. GPD is relevant for industries with customers having high environmental demands or affected by special legislations [5].

Another approach, but in some point of views similar to GPD, is by applying lean product development (LPD). Similarities to

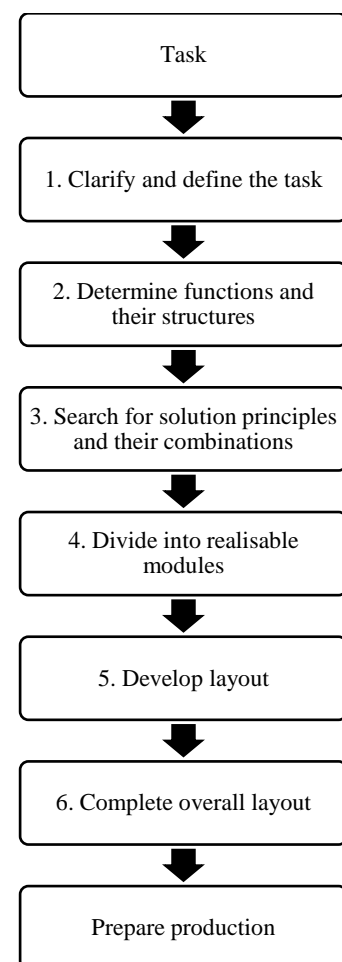


Figure 1.1 Systematic development according to Pahl and Beitz. [4]

GPD are for example to save resources [5] and continuously improve the work process [6]. LPD is highly applicable today in the global market where products need to be developed faster to earn money. This is possible due to improvements of the traditionally method, shown in Figure 1.1, by offer a more agile and flexible workflow, leading to less time consumed [6]. Four principles can be taken into consideration to make the systematic workflow, in Figure 1.1, more lean and effective [7]:

- Iteration principle – Check the specification continuously and involve affected people early in the project process.
- Parallel principle – Big tasks could be divided and worked with in parallel. The steps could also overlap to reduce the total project time to market.
- Decomposition principle - Dividing a total function into sub functions, using suitable experts for suitable areas.
- Stability principle – The solution should converge against a solution during the work.

To demonstrate this systematic approach it will be applied on the development of a rotation unit, also called tilt, for Scania truck cabs. Step by step the development process is proceeded, giving the reader knowledge how to attack similar development tasks. The method section will describe the systematic process in general while the result section will describe how to apply this process on the cab tilt and the process outcome.

1.2 Description of the cab tilt

Due to ergonomic aspects a tilt is used to rotate Scania cabs during assembly, avoiding work in positions that could cause human injure. The tilt contains of two tripods, one fixed called head and one moveable called tail, the latest uses rails and manual drift to move in forward and backward direction. Both tripods were rigged in the floor, in an approximate 100mm deep hole, from now on called foundation. This was done to remove the rail plate into a lower level, otherwise this would block the cab carrier, called a rack. Figure 1.2 show the head and movable tail tripod.

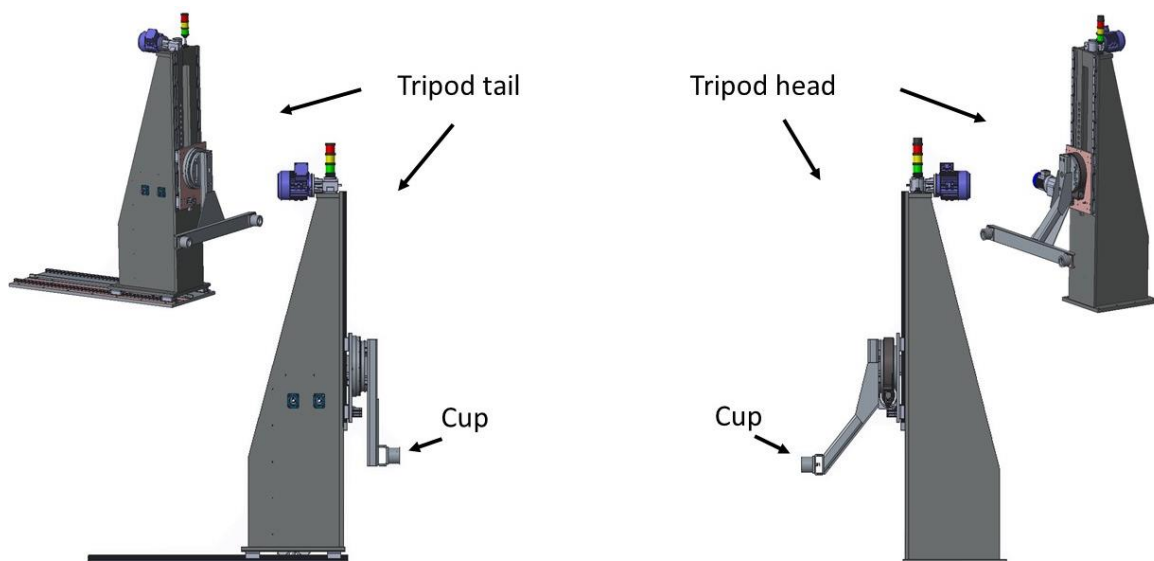


Figure 1.2 The tripod tail at left and tripod head to the right, shown from side and oblique view.

Tilting are possible for one type of cab in two different lengths, Scania Crew Cab 31 and Crew Cab 28, from now on called CC31 and CC28, where the number indicates an approximate length in diameters. By apply a mounting plate including a trail hitch, shown in Figure 1.3, on the cabs front and back it's possible to put the cab between the tripods and connect into the cups shown in Figure 1.2, and further on rotate it. The cab front was mounted at the head tripod while the tail at the back. A CC28 applied at chassis can be seen in Figure 1.4.

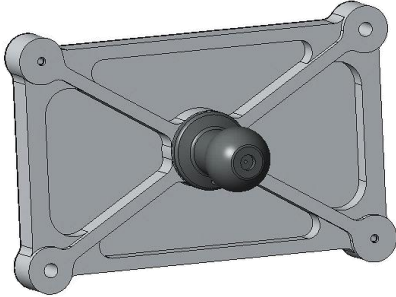


Figure 1.3 The mounting plate with the trail hitch included.



Figure 1.4 A CC28. [8]

1.3 The problem description in short

During special cases it would be useful to use the tilt for another cab, called Low Entry (LE), as well. This would force changes on the tilt to take differences between the cabs into account, which is investigated as an example of the systematic development process. The problem was deeply described in the result section, where following goals were settled:

- Obtain a solution making it possible to use the tilt for CC and LE.
- Minimize changes at the current tilt construction.
- Minimize the necessary time to change between the different cab types.

2 Method

*This section describes in general the systematic development process stage for stage, making it possible for the reader to apply this knowledge on own development projects. Methods starts with a **pre-study**, to retrieve information about the problem investigated, followed by a **concept generation**. The best suited concepts developed is specified during the **embodiment design** phase and given suitable materials during the **material selection** phase. Lastly, an **optimization** phase is performed taking strength and stiffness into account.*

2.1 Pre-study

The aim for the pre-study is to establish a requirement specification where demands and wishes are clearly displayed, which later on can be used to rate the generated concepts to each other. The product development can in many cases look complex and hard to handle, therefore it's important to break down the task in different steps before the specification can be created. The used method to obtain a useful requirement specification can be seen in Figure 2.1. Inspiration was also taken from [1], dividing the pre-study into two steps; determine problem and investigate problem [9].

2.1.1 Problem investigation

The first step, *problem investigation*, should give a stable background of the problem itself, why it is a problem and, finally, what the solution should be able to do. Descriptions of how to solve the problem should be avoided [9]. Good and bad things should be taken into consideration. The main information were obtained by interviews of the job initiators and users Further information were found in drawings and other product documents giving technical data such as loads and functions.

Problem degradation is used to identify the problem levels and break down the problem formulation into different reasons why the existing construction won't work. This method was found in [1], where the phrase "How" can be used to break the problem down further. This method will help to limiting the work area and what area to focus on.

2.1.2 State of art

State of art investigates similar products and their way of function. According to this project, benchmarking focused on how other cab manufactures were handling their cabs in their production line. Time was also spent looking for patents within the area [9].

2.1.1 Problem investigation

-Why a problem?

- Problem formulation
- Purpose
- Goals
- Bi effects
- Limitations
- Stakeholder analysis
- Problem degradation



2.1.2 State of art

-Get inspiration!

- Benchmarking
- Patent investigation



2.1.3 Is the project feasible?

-Continue or terminate?

- Compile information
- Technical aspects
- Economical aspects



2.1.4 Requirement specification

-What is searched for?

- Develop demands and wishes
- QFD
- Create the requirement specification

Figure 2.1 The workflow during the pre-study, with inspire by [9].

2.1.3 Feasibility

The third stage of pre-study - *Is the project feasible?* – meant that the information obtained during previous steps is evaluated. Based on this information a decision can be made if the product development process is possible to continue with or not. Aspects such as enough technical knowledge and cost should be taken into account. If this decision is hard to make, restarting at the pre-study phase for further problem investigation would be necessary [9].

2.1.4 Requirement specification and QFD

If the pre-study have worked through successfully it would be possible to develop correct customer criterions, i.e. requirements and wishes. It's very important to know what the final product need to fulfil. If this is done in a correct and accurate way, the project lead time will be shorter due to less misunderstanding during the upcoming project process. To produce a requirement specification the Olsson matrix can be used as a checklist to insure that the total product life and its aspects are treated, which is shown in Table 2.1. [1]. The criterion are also divided as functional or limiting, with well described examples in [10] as “carry load” or “max load” respective. Normally a requirement specification containing few requirements is preferable and the functional criterion should not be related to each other, described as axiom 1 and axiom 2 of design. Otherwise the specification becomes too complex making it hard to understand what to focus on. [11]

The established wishes can be graded in importance level, where 5 is high desired and 1 is low desired. It's important to note that the requirement specification will be used and updated continuously during the project process while more information are collected. The specification will therefore be more and more precise during the project work flow.

The requirement specification should not allow any individual assumptions or misunderstandings. To avoid this the demands and wishes should be: [1]:

- *Complete* – That could be solved by using the Olsson matrix and stakeholder analysis.
- Formulated *independent of solution* and *clear*.
- Able to be *measure* or *control* if they've been fulfilled.
- *Independent* on other wishes and demands.

Table 2.1 The Olsson matrix, acts as a checklist for the requirement specification [1].

Life phase	Aspects			
	Process	Environment	Human	Economic
Construction phase	1.1	1.2	1.3	1.4
Production	2.1	2.2	2.3	2.4
Sale and distribution	3.1	3.2	3.3	3.4
Using phase (Installation, use and maintenance)	4.1	4.2	4.3	4.4
End of life phase (Recycling etc.)	5.1	5.2	5.3	5.4

To transform the customer criterion into product properties the QFD, quality function deployment, can be used. By giving the *customer requirements* different weight and connect them to product properties it's possible to determine the properties affecting the customer requirements most. The *weight factors* given to the customer requirements is rated between 1-5, where 5 correspond to a demand and 1 correspond to a low expected wish, Table 2.1 [1].

The grade of relationship between a requirement and a property can also be rated that is done in the cell *relationship matrix* Figure 2.2. The factors of relationship is described as following [1,10]:

- 9 = Strong connection
- 3 = Medium strong connection
- 1 = Weak connection
- 0 = No connection

To grade the influence of each product property multiplications are done between each weight factor, at the left, with the value of relationship in the “relationship matrix”. This will result in a weighted rating for each product property. Higher weighted ratings are obtained if the property is connected with many customer requirements with demands or high wanted wishes [1].

Similarly to the customer requirements it’s good if the product properties are independent, which is hard to fulfil. Therefore the correlation triangle could be used, shown at the top of Figure 2.2. This could expose how properties depend on each other [1]. A plus (+) indicates a positive influence between the product properties, and minus (-) shows a negative influence. When later on generate concepts focus could be to reduce these negative influence between product properties [10]. The cell *Product comparison* can be used to compare concepts during the upcoming concept evaluation phase and the *target value cell* gives the limitation for each product property [1].

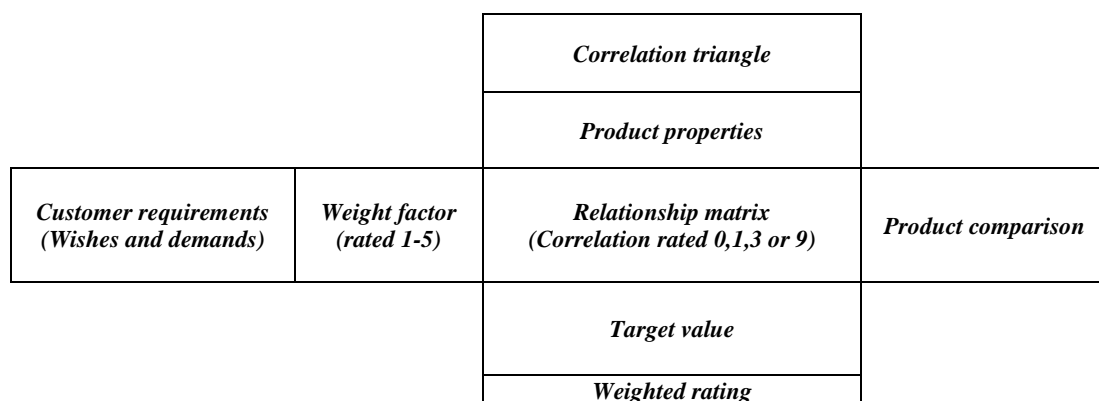


Figure 2.2 QFD matrix, quality function deployment converts customer requirements into rated product properties. [1]

2.2 Concept generation

This stage should result in a final concept solution that meet the requirement specification in a proper way. If the obtained demands are correctly formulated and accurate, the systematic workflow will cause a deep investigation and generate many different solutions of the problem, which later on can be sorted out and ranked compared to each other [1]. By spending extra effort on this stage the total project time can be reduced, by avoiding mistakes, such as discovering new limiting properties forcing rework [12]. To avoid later problems a five step method is used break down the concept generation in simpler activities shown in Figure 2.3. The method is used in an iterative way, finally reaching the best concept [3].

A good explanation of the design process is by mapping the sub functions into design parameters. I.e. each sub function can be fulfilled by many different layouts. This work will produce many concepts that fulfil the functional behavior but look in very different ways [11]. By later on evaluate how effective each concept is in different perspectives, it is possible to find a final solution.

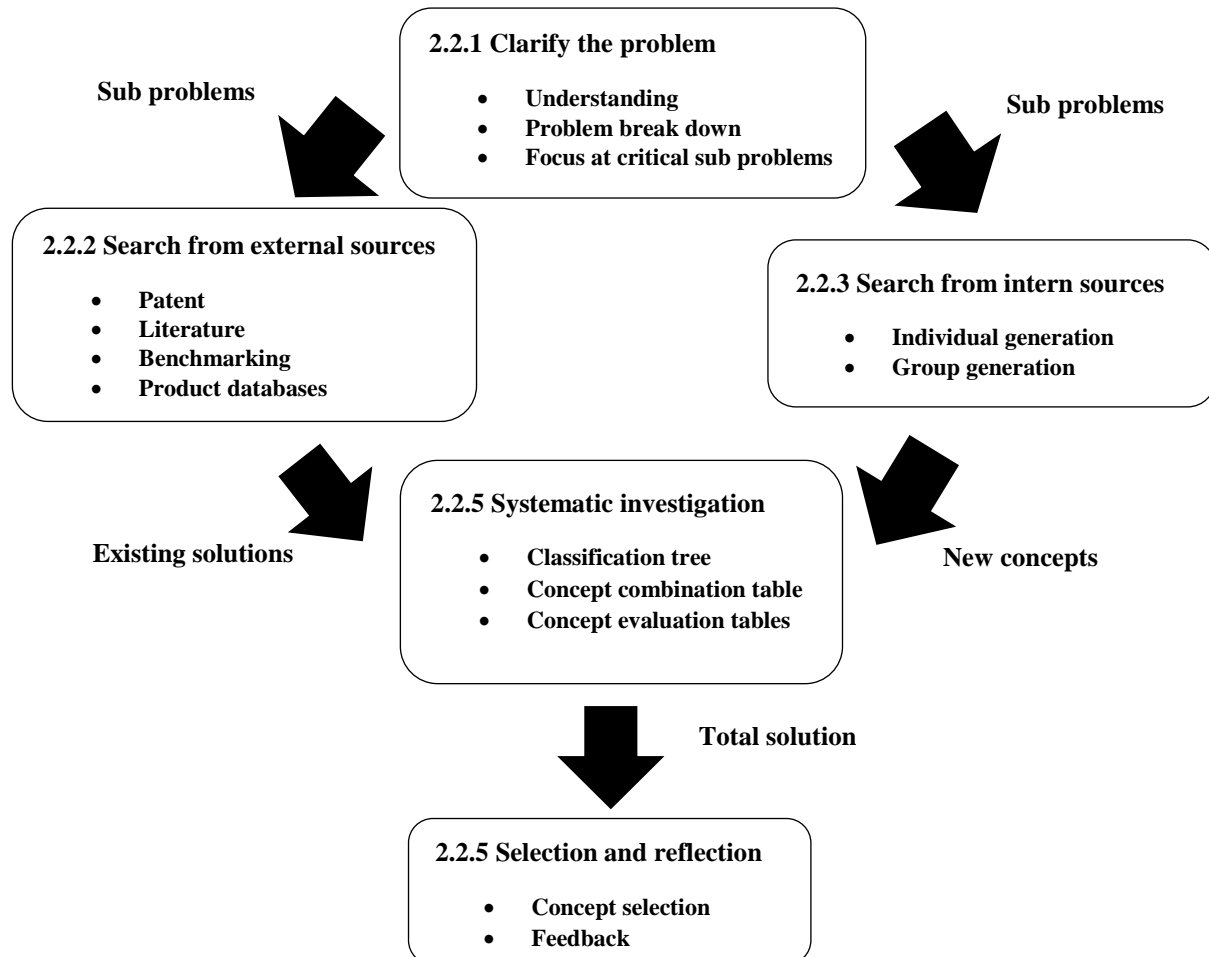


Figure 2.3 Description of the five steps method used [3].

2.2.1 Clarify the problem

With the requirement specification as base, this phase involves a simplification of the overall problem by breaking down the main problem into sub-problems due to high complexity of the original main problem. The method, called functional break down, starts with a black box-model handling an operand flow of e.g. material, energy and information [3]. To construct a black box, as shown in Figure 2.4 following should be done [9]:

- Establish the main function.
- Choose operands that will be handled in the black box.
- Establish the input and output of the black box.

The main function should be described broad to allow a bigger variation of conceptual solutions increasing the probability for new ideas. Originating from the requirement specification the demands may be changed from containing limiting values to just giving a certain function [1].

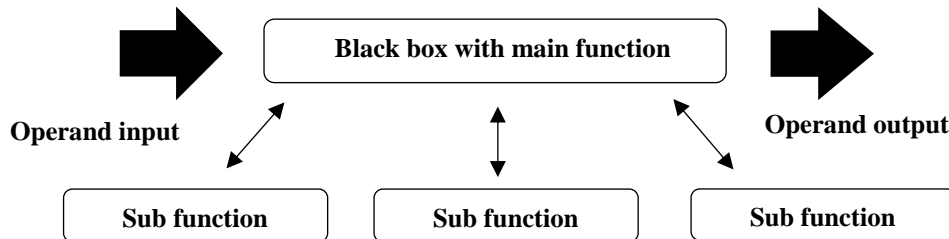


Figure 2.4 Black box structure [9].

The black-box is further degraded into a function structure containing sub functions until these sub functions are well understandable. By simplify the main problem into more limited sub problems it allows the product development to rate the importance of each sub function and prioritize on sub function the upcoming concept generation would start with [3]. The function structure could also contain supporting functions that contributes to the whole function in a more indirect way, which would be described in the result [4].

2.2.2 Concept generation from external sources

This is a systematic concept generation method, using external sources to get inspiration of possible solutions [1]. By implement already existing solutions, time and money can be saved and spent on later concept generation phases where no already existing solutions can be obtained. In this project, this phase focused on patent databases, literature, reports, benchmarking and product databases [3]. Notice that the focus were on sub problems, not the entire tilt as previously done during the pre-study method. The work flown parallel with the individual brainstorming in phase 3, Figure 2.3. TIPS – Theory of inventive problem solving – can with benefit be used. Based on the knowledge that many successful innovations do have many things in common, in different application areas and uses. A creative new solution for a certain area can therefore be obtained from another area. The most relevant TIPS principles commonly used are following: [1]

- Identify and avoid engineering contradictions, i.e. divide the problem depending on time or place.
- Divide a technical solution into, sub functions – as done in Figure 3.10.
- Evaluate the upcoming mechanisms probably used in the future.

2.2.3 Concept generation from internal sources

Following four things are important to have in mind during this phase [3]:

- Do not make early decision of what is good and bad.
- Generate many ideas.
- Welcome ideas that seems impossible.
- Use graphics or physical media to explain the concept.

2.2.3.1 Individual generation

The individual phase, was in this project, combined with the research made in section 2.2.2, where brainstorming was done together with influence of internet and patent investigations. Further information was tried to be found in literature and product databases.

2.2.3.2 Group generation

In this project, a group generation session was performed with other master thesis students to increase the creativity and increase the amount of solutions. The discussion method was used [1]. Starting with a broad problem description and step by step increase the amount of information. The goal was to obtain strange but useful solutions in the beginning, and in the end more precise solutions. Discussions were initially made in groups of approximately six persons and after each step of information discussed in general. Finally the whole group discussed the solutions together.

2.2.4 Systematic investigation

This phase can be done during three steps. Categorize the concepts, compare the similarities using a morphological table and, at last, rank the concepts against each other. Finally, these three steps should result in the best fitted concept solution for the given problem.

2.2.4.1 Classification tree

To get a good overview of the generated solutions classification trees are constructed for the sub functions, where the concepts are divided into smaller groups with similar properties. For example in this project, “integrated extender” or “extender that need to be mounted”, as can be seen in Figure 3.11 through Figure 3.14. The classification trees can reveal the information as follows, where point one and three were specially used [3]:

- Erase unpromising areas that won't be able to fulfil in the construction.
- Allow the work group to focus on divided areas that not affect each other.
- Reveal too small focus on certain areas.
- Further problem degradation.

2.2.4.2 Comparison and elimination

Due to a big amount of different concepts for each sub function in this project, a coarse evaluation was done for each sub function. This was based on the elimination matrix [1] including a value between 1 and 5, where 5 was good and 1 was bad. Multiplying the value caused a total rank combined with an indicating color, see Appendix B. The included aspects were following and the template used is shown in Table 2.2:

- Solve the main problem – Need to be fulfilled to progress to further investigation.
- The robustness – Ability to avoid malfunction over time.
- Ergonomic – Taking the exchange between LE and CC into consideration.
- No complicated construction – To minimize installation time and manufacture cost.
- Easy to understand – Easy to install in a correct way to avoid failure.

Table 2.2 The modified elimination matrix used, originally based on [1].

Sub solution	1. Solve the main problem	2. Robust	3. Ergonomic	4. No complicated construction	5. Easy to understand	Total points (0-625)	Comment
1	(Yes/No)						
2	(Yes/No)						
3	(Yes/No)						
4	(Yes/No)						
Etc.	(Yes/No)						
Decision:		Points>150 Proceed	50<Points<150 Proceed with drawbacks		Points<50 Eliminated		

The concepts obtaining over 50 points proceeded and were written down into a morphological matrix, where a template used is shown in shown in Table 2.3 [1]. The morphological matrix is commonly used to investigate the ability to combine the sub solutions/concepts into total solutions. Sub functions should be written in the left column and every solution/concept for each sub function written in the rows. In this way a good overview of the total combinations is obtained by using polygons going from the upper to lower row by arrows [1]. Table 2.3 does also show five different examples of possible ways to combine the solutions into a main function. To sum up, following is to be done in the morphological matrix [4]:

- Do only combine compatible sub functions.
- Do only continue with concepts meeting the demands in the requirement specification.
- Concentrate at promising combinations and establish why these total concept solutions are preferable before others.

Table 2.3 Morphological matrix showing five of many possible concept combinations [1]

Sub function	Solutions/concepts													
Sub function 1	1	2	3	4	5	6	7	8	9	10	11	12	13	Etc.
Sub function 2	1	2	3	4	5	6	7	8	9	10	11	12	13	Etc.
Sub function 3	1	2	3	4	5	6	7	8	9	10	11	12	13	Etc.

2.2.4.3 Systematic selection chart

As a next step a systematic selection chart matrix is used to reduce the solutions further, by state criterion as done earlier in section 2.2.4.2 [1,4]. The used elimination matrix with its criterion is shown in Table 2.4. If any of the concepts got the decision “?” more information was acquired to continue to following evaluations. This could involve questions about mechanical strength or necessary space, in this project.

Table 2.4 Elimination matrix [1,4].

Criterion						Decision		
(+)	Yes					(+)	Continue to next step	
(-)	No					(-)	Eliminate solution	
(?)	More info necessary					(?)	Search for more info	
Concept number	Solve the main problem	Fulfill the demands	Possible to construct	Within the frame of costs	Safe and ergonomic	Suit the company	Comment	Decision

2.2.4.4 Decision matrix

In the decision matrix, the requirement specification demands and wishes are used to rank the concept solutions. One concept is used as a reference and the other concepts are compared to it by a weighted value of importance, similar value as the importance of each wish given in the requirement specification. The evaluations are done repeatable, while bad concepts diminish and the reference changes to the previously highest ranked one. Between each evaluation the drawbacks can, if necessary, be improved by combining the concepts or improving a critical concept part. For example add a stiffening beam if the concept deflects too much. The criteria number make it easy to connect the information to the requirement specification. A decision matrix template is shown in Table 2.5 [1].

Table 2.5 An example of the decision matrix procedure [1].

Criteria number	Description	Solution							
		Weight	Reference Concept	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
	Wish A	5	DATUM	5-	5+				
	Wish B	3		3+	3+				
	Wish C	3		0	3+				
	Demand B	2		2+	2-				
	Demand E	4		4+	4+				
	Wish Q	2		2-	2-				
	Demand F	4		0	0				
	Etc.								
	Sum +			9+	15+				
	Sum 0			2	1				
	Sum -			7-	4-				
	Net value			2+	11+				
	Rank		3	2	1				
	Proceed		No	Yes	Yes				

2.2.5 Selection and reflection

As a final stage in the concept generation phase, a final solution is chosen and compared to existing solutions and developed further during the embodiment design section. The best suited solution will necessarily not always be the highest ranked one in the decision matrix, partly

because of the weight factors can be a bit wrong [3]. Therefore a final discussion with the job initiators can be important to make an agreement of the upcoming work [1].

If necessary, the requirement specification can be redone to be better suited for the chosen solutions, giving specific requirements where the functional behavior is described. There would also be possible to construct separate specifications if the solutions chosen have two or more divided systems [9]. The updated specification can be combined with a short description of the concept function and how it's connected to the requirement specification. Reasons of why certain solutions are used can also be given [1].

2.3 Embodiment design

When a working structure have proceeded from the concept phase an overall layout design need to be developed and evaluated. This are done with many corrective steps, alternating between analysis and usage of the upcoming ideas. A rough plan of the embodiment phase can be described with the steps shown in Figure 2.5 [4]. The goal with the embodiment design phase is to obtain basic data describing a well functioned and useful product, which could be manufactured in small amounts and tested. One should also be able to analyze and optimize the product during later phases [1].

2.3.1 Comparison to already existing solutions

Firstly before realization of the concepts there are useful to investigate if any already existing solutions occur that can be redesigned and used instead of the concept/concepts earlier generated during the concept generation phase. If such solutions occurs, descriptions and arguments of such choose need to be done.

2.3.2 Identify crucial requirements

By using the updated requirement list obtained from each part solution, crucial requirements are identified that affects the embodiment design. These are things such as size, direction of motion or material properties important during the material choice. In this project it was also suitable to introduce the safety aspects of the tilt construction [4].

2.3.3 Produce spatial constraints

Measurements would be investigated and drawn up to get a clear overview of length and size limitations. This allows the embodiment designer to realize and understand the restricting areas in space [4].

2.3.4 Function carrier layout

When step one and step two are done, a rough layout of the function carriers can be developed from the chosen concept [4]. The components fulfilling the functions could be divided into three main groups depending on the complexity of component choice and development [1].

- Common used components – Choice of component that is well known and understandable.
- Limited group of existing components – Comparison between existing components are done.
- New component - developed for the specific application.

2.3.5 Function carrier comparison

Before starting, the three previous steps needs to be deeply and well investigated to allow the possibility to obtain good and precise preliminary layouts during this step. The function carriers are evaluated against each other as done previously during the concept generation phase and described deeper in [1], using a decision matrix shown in Table 2.5. To ensure that no aspect are forgotten the upcoming checklist was, in this project, used:[4]:

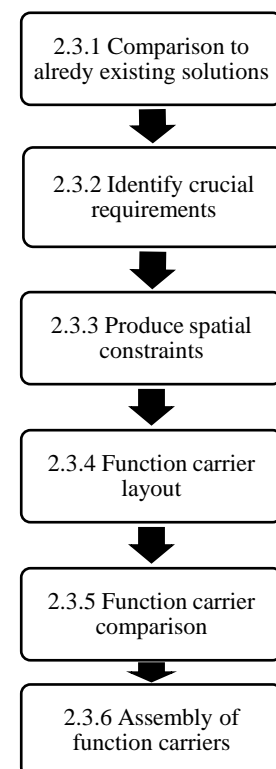


Figure 2.5 The different stages during the embodiment design inspired by [4].

- Function – Is the function fulfilled?
- Working principle – Are the searched advantages obtained?
- Layout – Is enough durability obtained?
- Safety – Also in the wider sense of reliability and availability.
- Ergonomics – Human-machine context, also aesthetics.
- Production – Production facilities and type of construction.
- Quality control – Throughout the production process.
- Assembly – During and after the production of parts.
- Operation – Intended use and handling.
- Maintenance – Upkeep, inspection and repair.

2.3.6 Assembly of detailed layout

Function carriers are assembled, measurements settled and the construction drawn up to get a total solution. Settled measurements are also of important character due to correct interactions if optimization is needed during upcoming phases.

2.4 Material selection

The material properties limiting the component performances in different point of views, such as mechanical strength, weight, stiffness or environmental issues [13]. Material selection can be done in different ambiguous levels, i.e. copy from earlier, by deeper investigation or by development of new materials [1]. There are five specific steps during the material investigation phase, presented in Figure 2.6 [13]:

- Translation – State the demands, wishes and limitation of the product.
 1. Define functional requirements.
 2. List the constraints and develop equations for them.
 3. Develop an equation for the objective.
 4. Identify the free specified variables in the constrain function.
 5. Substitute the free variables from the constraint equation into the objective function.
 6. Group the variables into, functional-, geometry- and material properties creating a performance equation: $P = f(Function) \times f(Geometry) \times f(Material)$
 7. Identify the material indices and use during the upcoming screening.
- Screening – Eliminate the materials that cannot do the job by limitations.
- Rank – Evaluate and sort out the best fitted materials using material maps.
- Documentation – Get a deeper understanding of the top ranked materials and evaluate.
- Final material selection.

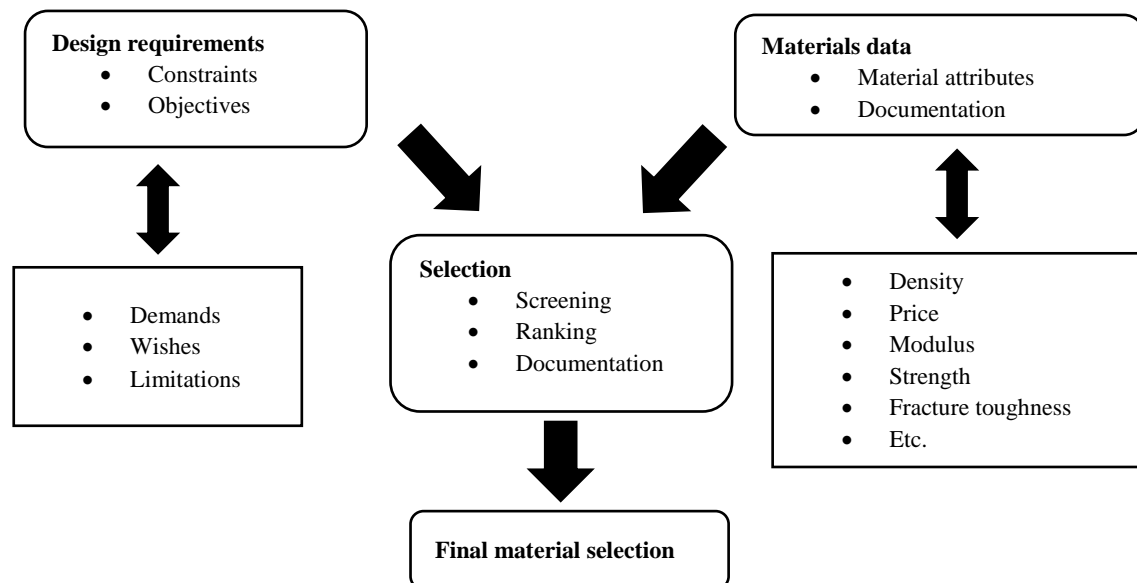


Figure 2.6 The material selection process [13].

2.5 Optimization

In many cases an optimization process is necessary to obtain an attractive construction. Weight is in many cases important due to ergonomic or environmental aspects, and would therefore be reduced. This is called the objective function, i.e. minimize weight. There are other things affecting the rate of weight reduce too, for example mechanical strength or limited deflection, these are called constraints [1]. By construct effective it's possible obtain the lowest objective function but sustain the constrained properties. This can be done by using finite element analysis (FEA) and an iterative process by, simulation, construction, improvement and so on, until satisfaction.

But as a first step the load cases should be identified. The worst load case together with the safety factor should act as the constraint during the analysis. For lifting equipment, the implementation of a safety factor (SF) can be described as [14–16]:

$$WLL = \frac{\sigma_{UTS}}{SF} \quad (2.1)$$

Containing the work load limit (WLL), which described the maximum possible applied stress. σ_{UTS} is the stress when construction fails. For a certain construction a higher SF would therefore cause a lower applied load allowed.

3 Results

*By applying the theory and method onto the development of the cab tilt, this chapter gives a clear example of how the systematic process can be applied and worked through with. Results from, for example, the obtained **requirement specification**, **problem degradation**, **elimination matrices**, **decision matrices**, **function carrier evaluation**, **material selection maps** and **simulations** are explained, according to the tilt construction.*

3.1 Pre-study

By initially stating the problem formulation, purposes and goals, this stages would finally result in a requirement specification. It was important to make this phase accurate due to allow reasonable evaluations during the concept generation phase.

3.1.1 Problem investigation

The initial information obtained, written down in short were following:

3.1.1.1 Problem formulation

In some cases, during special orders, there would be necessary to use the tilt for Scania Low Entry cabs as well, from now called LE. This cab had another geometry than CC28 and CC31 and changes were therefore needed at the tilt. The differences between the cabs are shown in Figure 3.1 through Figure 3.3.

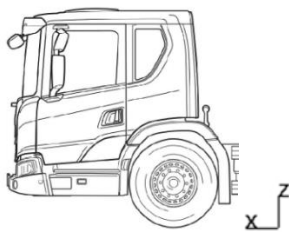


Figure 3.1 A Scania Low Entry, also called LE in this report [17].

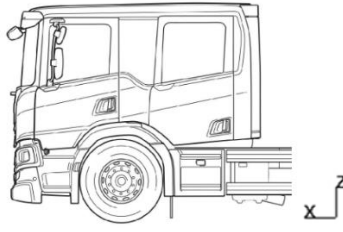


Figure 3.2 A Scania Crew Cab, also called CC28 in this report [8].

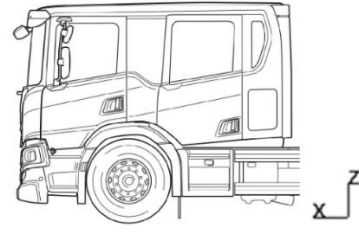


Figure 3.3 A Scania Crew Cab, also called CC31 in this report [8].

3.1.1.2 Job requestor

The company requesting this task was Laxå Special vehicles, producing two types of Scania cabs, i.e. CC and LE, where the CC was produced from scratch to nearly complete cab at the site. LE was mainly produced into body in white (BIW) at Laxå, but during special orders also assembled at the site in Laxå. During these special orders it was necessary to use the tilt for LE.

3.1.1.3 Purpose

Using a systematic development approach the space of different solutions will be investigated a suitable redesign of the existing tilt will be obtained. This create a more ergonomic work situation during assembly of LE meanwhile save space and money due to using the already existing tilt.

3.1.1.4 Goals

The goals aimed for during this development process were following:

- Obtain a solution making it possible to use the tilt for CC and LE.
- Minimize changes at the current tilt construction.
- Minimize the necessary time to change between the different cab types.

3.1.1.5 Secondary effects

If the goal would be reached, this would cause following secondary effects:

- Ergonomic assembly by the LE cab.
- Parallel work flow between LE and CC would be impossible.
- Construction changes would possibly affect the cab change time in a negative manner.
- Space and money would be saved if the current tilt can be used, avoiding new investments and installation.

3.1.1.6 Project limitations

This thesis work had a work capacity of 20 weeks fulltime, i.e. 40 hours per week, affecting the depth of the investigation. Therefore possible changes were limited to smaller areas, i.e. the main function of the tilt would be sustained, focusing on adjustments, which would be obtained by using step 1-6 in Figure 1.1. The work would not involve any prototype at the final stage.

3.1.1.7 Stakeholder analysis

By interviews of tilt manufacturer and assembly line personnel, safety functions could be identified that would be necessary to know during the development process. There would also be enough space around the cab front when using the tilt to simplify assemblage of cab interior.

3.1.1.8 Problem degradation

The result from the problem degradation is shown in Figure 3.4, where different reasons to the problem are shown. Due to the time allocated for this project phase was limited, the decision was made to focus on a solution for grabbing the cab both from the front and back, as shown in path 1.1 in Figure 3.4. To do anything with the cab length was not an opportunity due to big construction changes and necessary costs. Initially the rail plate was assumed too complex to change because it was already fixed into the ground. These reasons lead to further investigation of path 1.1.1.1 and 1.1.2. During a later phase in the project, changes on the rail plate were seemed as a possible solution and path 1.1.1.3.1 was investigated too.

The reasons to not investigate the one side grab of the LE cab depended on the limited project time frame and uncertainty of the tripod behavior. Together, the tripods were constructed for a total weight of 800kg during front and back side grab. If a LE of approximate 300kg would be mounted by only one side grab this would cause moments and forces the construction probably not was dimensioned for. To allow rotation the both mounting arms would rotate the same, which would not occur during one side grab. This was an additional reason to not work deeper into the one side grab approach, shown as path 1.2 in Figure 3.4.

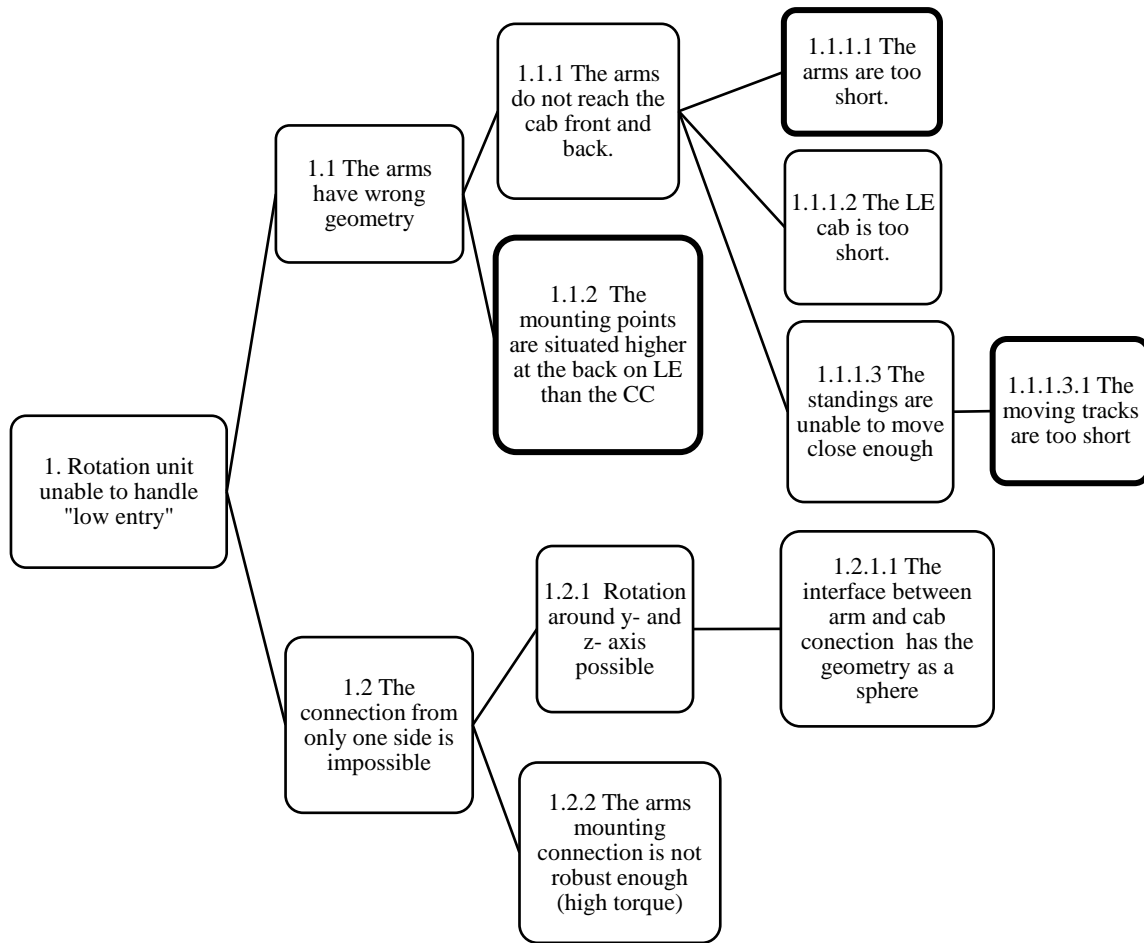


Figure 3.4 The problem degradation structure and its different levels.

3.1.2 State of art

The benchmarking investigated how other truck manufactures handled their cabs during production and assembly. Handling different kinds of rotation motion were of great interest to see how the cabs could resist forces and torque during the rotation. One video of rotation of the new generation Scania cab was obtained showing how the door frame could withstand the forces during rotation, shown in Figure 3.5 [18]. The tilt system of the old Scania cab generation was also obtained, grabbing the cab at the front window frame, shown in Figure 3.6 [19]. Using such solution as in Figure 3.6 was not an alternative, due to the inability to assemble through the front window. As a final word both Figure 3.5 and Figure 3.6 shown that the cabs were strong enough at the door and window frames.



Figure 3.5 The new cab generation (NCG) – generation 6 - with the door frame handling the rotation forces [18].



Figure 3.6 Tilt system for the older generation Scania cab, called NGS. Using the front window frame as grab point [19].

For other truck manufacturers, no cab rotation were obtained by investigation production line videos. For MAN and Mercedes different fastening systems were found where the cab hang in upward position. Using wires and mounting places at cab front and back were in common for the found situations that resulted in a rather unstable situation where the cab could swing. But an advantage allowing swing movements was the ability get the cab at the right spot during cab-chassis assembly. Wires do also takes small place, but are unable to withstand pressure. The manufactures MAN and Mercedes are examples of using wires in upward position, shown in Figure 3.7 and Figure 3.8 [20,21].



Figure 3.7A MAN truck using wires in upward position [20].



Figure 3.8 A Mercedes cab using wires in upward position [21].

The patent investigation lead to some inspiration useful for the upcoming concept generation phase, but no constructions similar to the whole tilt system were found.

3.1.3 Possibility to carry out

The pre-study resulted in enough information to continue the project by limiting the work area made during the work degradation in section 3.1.1. The project did also seem possible from a technical point of view, where the necessary information about important properties were, or could be obtained. The construction resulting from this project would also be possible to be manufactured by the existing tilt manufacturer.

The economic aspect was not seemed as a problem due to the single part manufacturing, probably by simple parts and the cost will be equal to the material- and manufacturing costs. It should also resist usage for a cab generation life length, which is approximate 15-20 years. Without any solution to the problem there will be impossible to assemble the LE, which would cause lower company income. Of this reason the economic aspect was therefore of low rated character during the project.

3.1.4 Requirement specification and QFD

The requirement specification obtained from the Olsson matrix is shown in Table 3.1. The QFD diagram obtained in Appendix A, shown that the lengthening and height mechanism were of greatest importance to fulfil the requirements and wishes obtained in the requirement specification. Layout properties and the dock mechanism did also have a big effect. Therefore the upcoming focus would be laid on these areas. Notice that the correlation triangle and product comparison not were performed in the QFD during this project.

Table 3.1 Final requirement specification giving the customer demands and wishes.

Criteria number	Cell	Criteria statement	D= Demand W, 5= High rated wish W, 1= Low rated wish	F=Function L=Limitation
1.	1.1	Cab docking at front <u>and</u> back	D	F
2.	1.1	Fulfil standard SS-EN ISO 12100:2010	D	L
3.	1.1	Fulfil standard EN 349+A1:2008	D	L
4.	1.1	Retain the automatic stop function by sensor	D	L
5.	1.1	Easy accessed cab-interior and -underbody	W, 5	F
6.	1.1	Possible to fix other cabs than LE and CC	W, 3	F
7.	1.1	Simple maintenance	W, 3	F
8.	1.1	Similar style as current	W, 2	L
9.	1.2	Environmental friendly material	W, 1	L
10.	1.3	Avoid sharp edges	W, 4	L
11.	1.4	Minimize development cost	W, 3	L
12.	2.1	Single part manufacturing possible	D	L
13.	2.2	No unfriendly materials during manufacturing	D	L
14.	2.3	Low weight on parts	W, 2	L
15.	2.4	Minimize manufacture cost	W, 2	L
16.	4.1	Possible to rotate both LE and CC	D	F
17.	4.1	Allow the two lengths of crew cab	D	F
18.	4.1	Life length of a cab generation	D	L
19.	4.1	Allow 360 degrees rotation of a normal roof cab	D	F
20.	4.1	Not deform plastically	D	L
21.	4.1	Hold the cab tight	D	F
22.	4.1	No cab damage	D	F
23.	4.1	Short exchange time (Same cab type)	W, 5	F
24.	4.1	Minimum maintenance	W, 5	L
25.	4.1	Limit the deflection	W, 4	L
26.	4.1	Exchange time short (different cab type)	W, 3	F
27.	4.3	Ergonomic change between cabs	W, 4	F
28.	4.3	Easy to understand	W, 3	L
29.	4.4	Minimize amount of wearing parts	W, 2	L
30.	5.1	Recyclable material	W, 2	L

3.2 Concept generation

The total function was broken down into sub functions and concepts were individually- and group generated against these functions. An elimination matrix was used to check against important criteria and later on an evaluation was done in a decision matrix. As a final stage the last concepts were discussed with the job initiators and a final choice settled.

3.2.1 Clarify the problem

The black box diagram can be described as in Figure 3.10, where the main function of the total system is to rotate the cab that handle the operands arms, forces, laser sensor and mounting sensor. Input and output were set to *Cab in normal position* and *Cab in rotated position*.

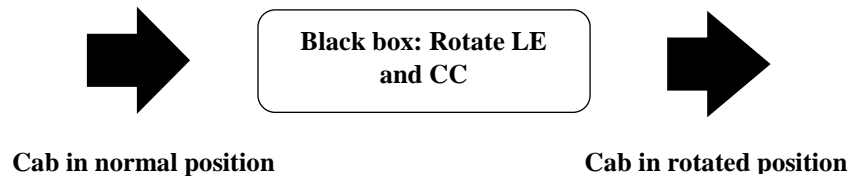


Figure 3.9 The black box diagram performed.

This black box was broken down further into the function structure containing the sub functions and supporting functions as shown in Figure 3.10, starting with a cab in normal position and ending up with a rotated cab. One functional and one force operand were introduced, handling the functional behavior and ability to absorb forces, respectively. One supporting function were the mounting sensors, securing properly mounting within the cups. Another supporting function was to avoid rotation of the cab into the ground, called laser sensor.

The mechanisms of sub function 2, 3 and 8 were of major focus during the work. Also sub function 1 was taken into account during this stage to obtain possible cab connecting improvements. Sub functions 4, 5, 6, and 7 were of minor interest due to connection to the total tilt construction or by taken necessary dimension into consideration to sustain the forces.

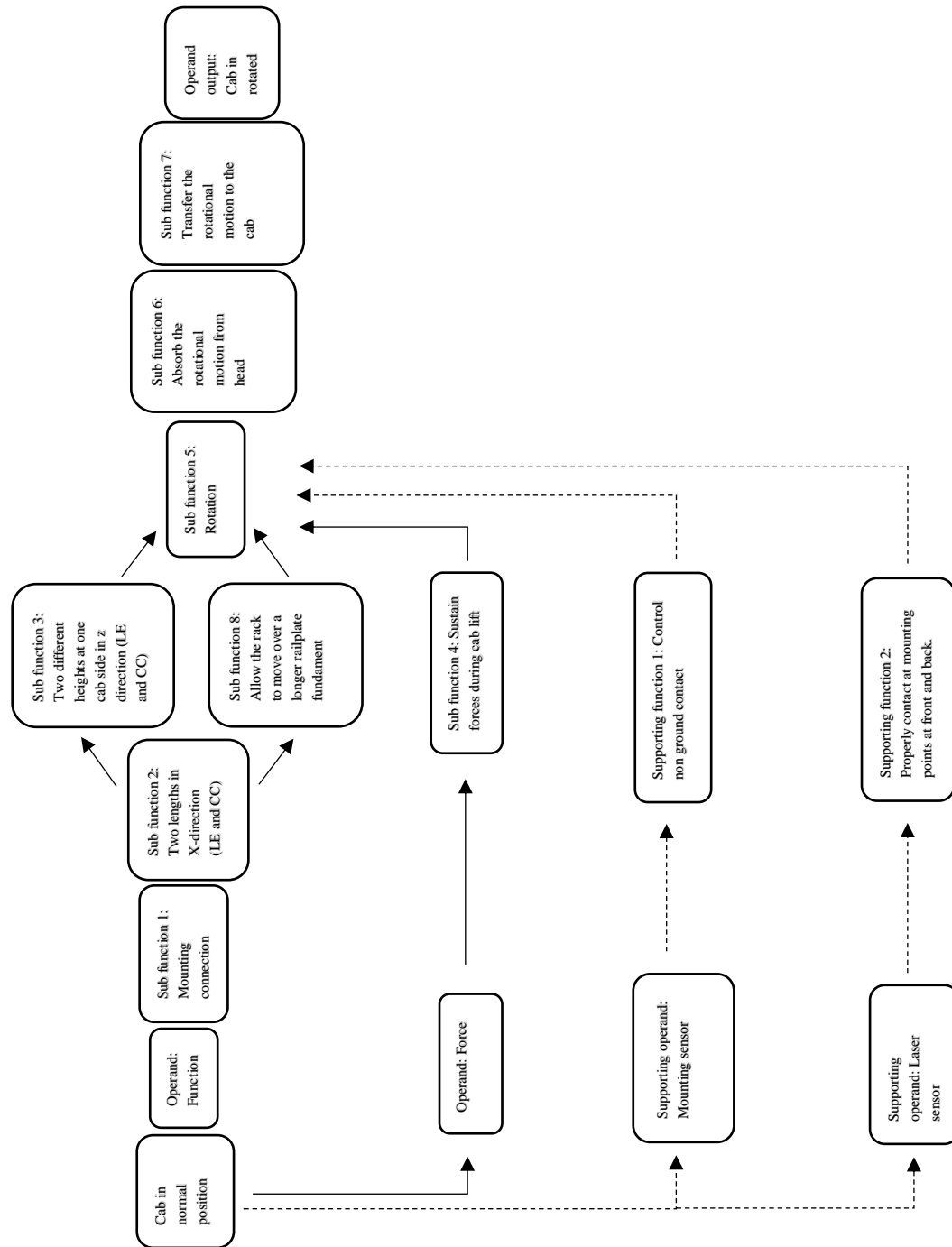


Figure 3.10 The expanded black box diagram with inputs and outputs, called function structure.

3.2.2 Search from external sources

According to sub solution 1, concepts originating from the original truck hatch were obtained. Also, totally new types of connections between the cab and arms were developed during this process. A bigger number of concepts were created for the sub function 2 and 3. For sub function 2, the concept generation caused both integrated solutions and constructions that needed to be applied when changing from CC to LE and vice versa. The solutions did also differ in way it worked, manual or driven by cylinder, or if it used the already existing cups or not. In contrast, sub function 3 did not need to take the cab interior access into account as much, the solutions of sub function 3 could therefore probably be fixed.

Changes at the tripod was allowed in a limited extent. Some concepts were therefore developed for sub function 8, which contained different ways to covering the foundation hole necessary, when lengthening the rail plate, to allow rack roll over.

3.2.3 Search from internal sources

The group generation session generated some new concepts and did also challenge the session leader with questions. This was important due to broaden the problem view. Solutions were obtained solving the whole problem and partly the sub functions.

3.2.4 Systematic investigation

After this section there the best suited concepts for each sub function were presented, by first dividing them in a classification tree, secondly using elimination matrices and a morphological matrix. Finally the concepts were compared and evaluated to each other using the decision matrix.

3.2.4.1 Classification tree

Using a classification tree initially revealed too low focus at *Extender that need to be mounted* for sub function 2 and *Added to the construction* for sub function 3. Therefore, extra effort was spent at these areas. The decision was also made to eliminate all concepts containing hydraulic or pneumatic cylinders. Figure 3.11 through Figure 3.14 show the most important parts of the classification trees, while Appendix B show totally completed classification trees for sub function 1, 2, 3 and 8. The numbers within the parenthesis in Figure 3.11 through Figure 3.14 are the concept numbers solving the sub function investigated.

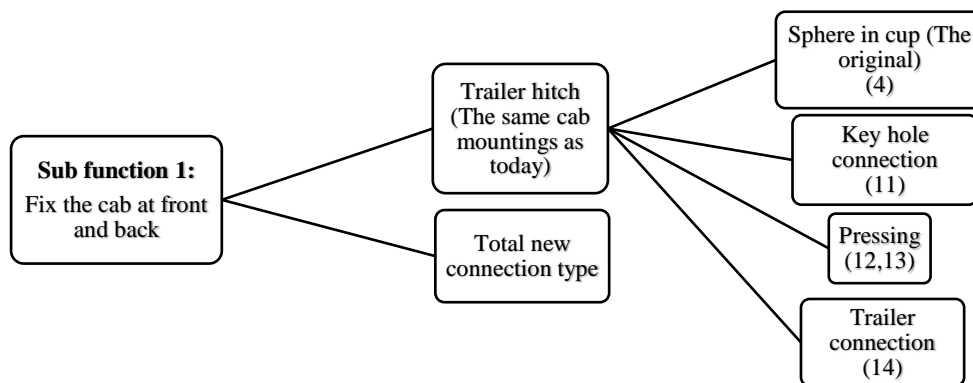


Figure 3.11 Sub function 1 - Mounting connection type.

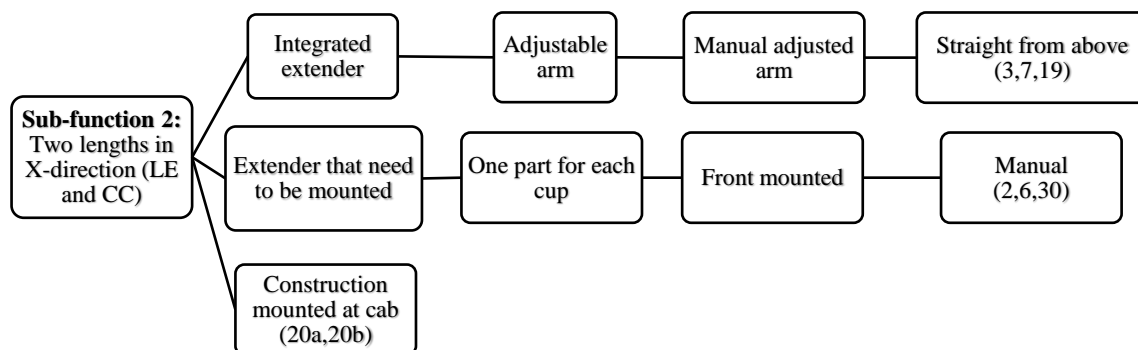


Figure 3.12 Sub function 2 – Lengthening mechanism compensating for different cab lengths.

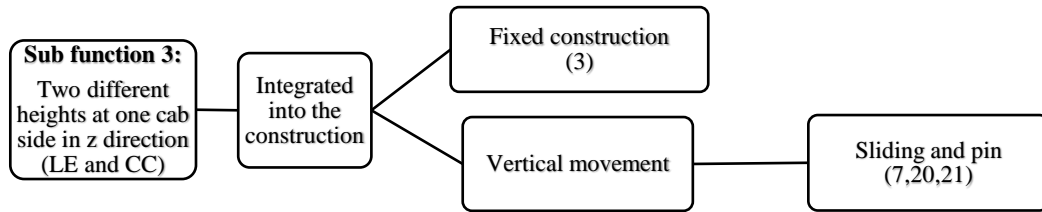


Figure 3.13 Sub function 3 – Compensating for the different mounting height at cab backs.

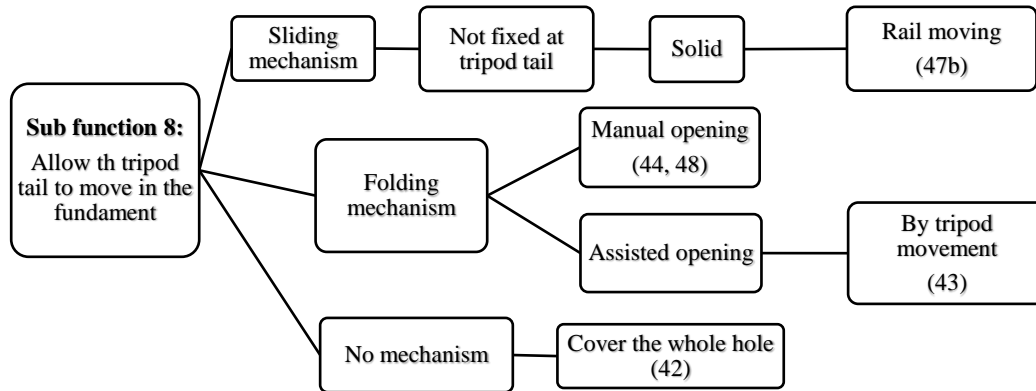


Figure 3.14 Sub function 8 – Construction covering the hole while lengthening a longer rail.

3.2.4.1 Comparison and first elimination

The first elimination, shown in Appendix B, resulted in the given concepts in the morphological matrix, Table 3.2. By using the morphological matrix comparisons could be done between the different concepts depending on similarities, complexity and possible combinations, the amount could be reduced further more. Remaining concepts are shown as underlined in Table 3.2, while deeper descriptions of the decisions made are found in Appendix B.

Due to a late introduction for sub function 8 into the project, these concepts were not involved in the first elimination. All of them did therefore proceed. A combination between the proceeded sub functions were not done because each sub function seemed to act independent to the other sub functions. Concepts obtained from the group generation session, called G1, G2 etc., were introduced during this stage, also shown in the morphological matrix below.

Table 3.2 The proceeding solutions after the modified elimination matrix and morphological matrix.

Sub function	Sub solutions/concept																			
Mounting connection (Sub 1)	1	2	3	<u>4</u>	5	6	8	9	10	11	12	13	14	-						
Two lengths (Sub 2)	<u>1</u>	<u>2</u>	3	5	7	8	9	<u>16</u>	<u>19</u>	<u>20a</u>	20b	24	25	27	<u>28</u>	29	<u>30</u>	31	<u>35</u>	<u>36</u>
Two heights (Sub 3)	1	2	<u>3</u>	<u>3b</u>	5	<u>7</u>	<u>13</u>	<u>14</u>	15	16	17	<u>20</u>	<u>21</u>	-						
Allow tripod to move (Sub 8)	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	-								
Group generated concepts	<u>G1</u>	<u>G2</u>	<u>G3</u>	<u>G4</u>	<u>G5</u>	<u>G6</u>	<u>G7</u>	<u>G8</u>	-											

3.2.4.2 Proceeded concepts

Underlined concepts in the morphological matrix shown in Table 3.2, are given in Figure 3.15 through Figure 3.19, for sub functions 1, 2, 3, 8 and group generated. All concepts generated are shown in Appendix B.


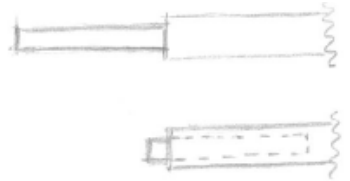
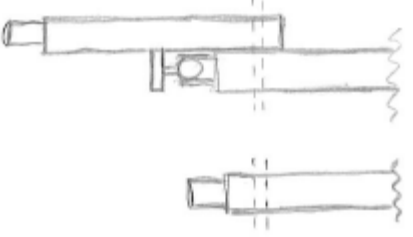

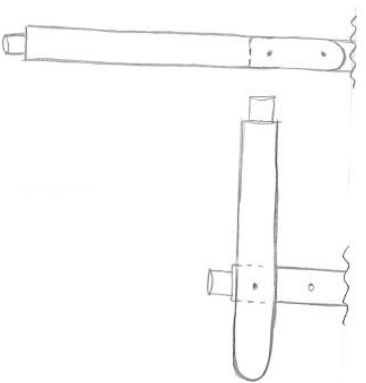
Sub function 1	Description
	<p>Concept 4 – This is the original connection used at the current design.</p>

Figure 3.15 Proceeded concepts - Sub function 1.

Sub function 2	Description
	<p>Concept 1 – The arm has an internal beam that can be drawn out during LE mode.</p>
	<p>Concept 2 – Extender beams are applied on and fixed with pins at the arm. The original hitch cup connection are also used.</p>
	<p>Concept 16 – Extenders are applied at the side of the original arm</p>
	<p>Concept 19 – Arms are put down when the LE mode is used.</p>

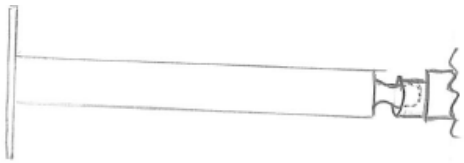
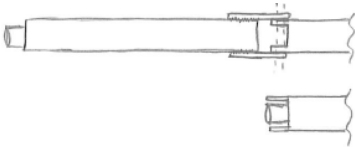
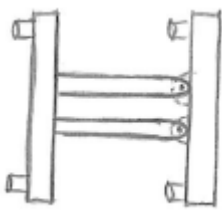
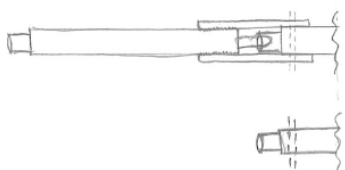
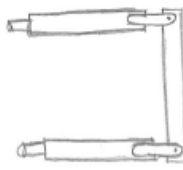
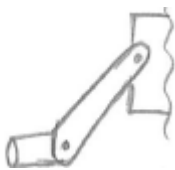
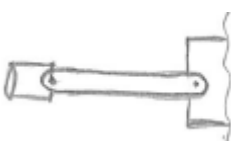
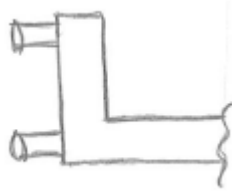

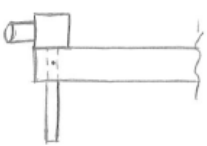
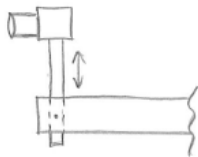
		Concept 20a – Extender arms are mounted at the cab and will compensate the length difference between LE and CC.
		Concept 28 – Pins are used to connect at applied ears at the existing construction.
		Concept 30 – Extenders are applied with pin similar as concept 1, but the cup will be at the same level as original arm height. The right picture is above view.
No picture.		Concept 35 - Lengthening the tail tripod permanent and letting the possible movement of the tripod tail compensate the length difference between LE and CC.
		Concept 36 – A jointed arm is adjusting the length by be turned up and down.

Figure 3.16 Proceeded concepts - Sub function 2.

Sub function 3		Description
		Concept 3 – Two fixed positions for compensating for cab mounting height difference.
		Concept 3b – Similar to concept 3 but consist of two horizontal beams. The upper beam can be movable if other heights than LE is needed.
		Concept 7 – A thin pipe with the cup mounted on is moved up and down depending on cab mode.

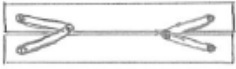
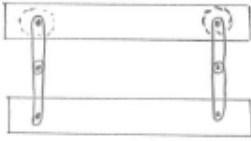
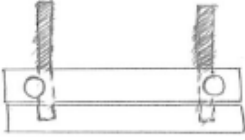
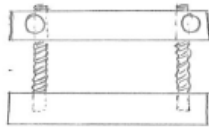

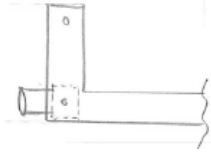
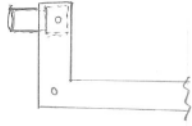
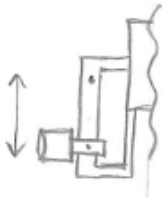


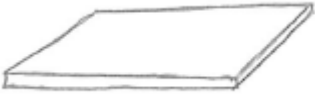
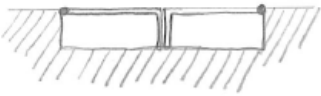
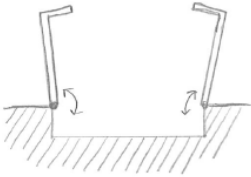
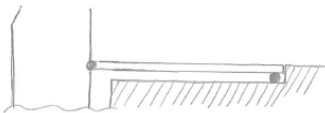
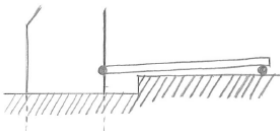
			Concept 13 – Similar to concept 12 but the bars are connected by a beam to make the construction more stable.
			Concept 14 – Using big screws to allow height adjustment and at the same time become stable in all positions.
			Concept 20 – A cup slides into the beam within a slit. Movement is stopped by pin.
			Concept 21 – A cup is fixed on a bushing that slides outside the beam. The movement is stopped using a pin.

Figure 3.17 Proceeded concepts - Sub function 3.

Sub function 8		Description
		Concept 1 – Consists of several jointed plates that can be compressed together.
		Concept 2 – One solid plate covering the foundation hole and will be removed manually by lifting
		Concept 3 – Counters are turned up automatically when the tripod is moved in the forward direction, because of construction on the tail tripod.
		Concept 4 – Counters are turned up manually by hand.
		Concept 5 – A plate is fixed at the tail tripod and follows its movement backward and forward.

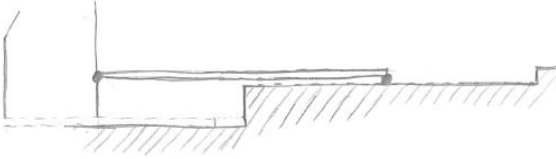
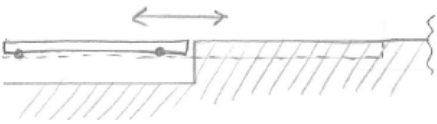
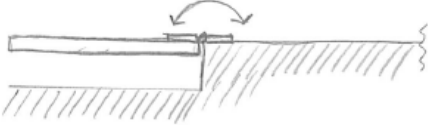

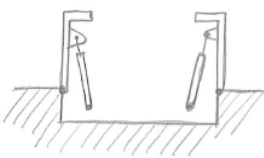
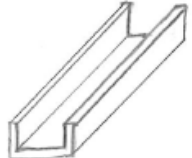
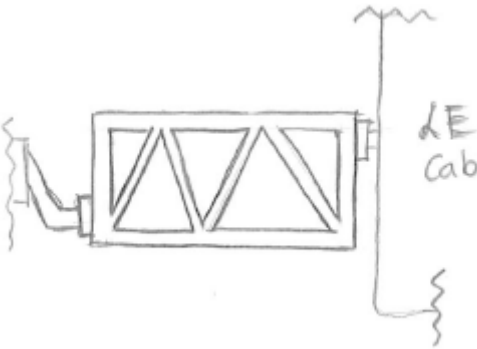
	Concept 6 – A longer plate than concept 5 is fixed at the tail tripod and follows its movement, covering. This covers more situations than concept 5.
	Concept 7a and 7b – A plate has wheels (7a) or rails (7b) to be pushed forward when the rail plate need to be free during LE mode.
	Concept 8 – A plate is turned forward, not to the sides as in concept 3 and 4.
	Concept 9 – The covering is rolled up during LE mode.
	Concept 10 – Counters are turned up by hydraulic cylinders.
	Concept 11 – A narrow beam is placed over the rail plate at a suitable place to allow roll over. The width is similar to the CC rack, wheel.

Figure 3.18 Proceeded concepts - Sub function 8.

Group generated concepts	Description
	Concept G1 – A frame construction is mounted between the tripod tail and the LE cab, compensating for both height and length.
No picture	Concept G2 – Add a rail plate to the tripod head, causing possible movement of both the tripod head and tail.
No picture	Concept G3 – Lengthening the existing rail plate for the tripod tail.

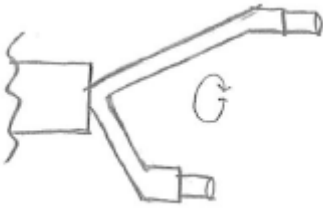
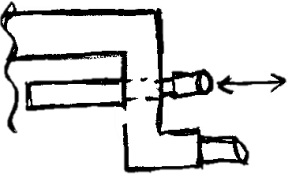
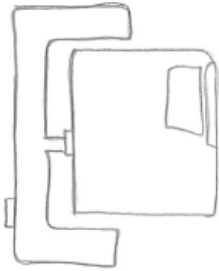
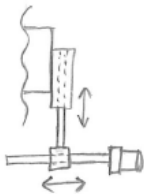

	<p>Concept G4 – Another arm is used that is rotated 180° depending on the cab mode.</p>
	<p>Concept G5 – Both length and height compensated.</p>
	<p>Concept G6 – Construction added at cab back compensating for both height and length.</p>
	<p>Concept G7 - The arm can be extended in both height and length depending on cab mode.</p>
	<p>Concept G8 – By turning the arm into different angles different height and lengths will be obtained.</p>

Figure 3.19 Proceeded concepts - Group generated.

3.2.4.3 Systematic selection chart

The elimination matrix is shown in Table 3.3, handled sub function 2, 3, 8 and the group session generated concepts.

Table 3.3 Elimination matrix of the total solutions.

Criterion							Decision	
(+)	Yes						(+)	Continue to next step
(-)	No						(-)	Eliminate solution
(?)	More info necessary						(?)	Search for more info
Concept number	Solve the main problem	Fulfil the demands	Possible to construct	Within the frame of costs	Safe and ergonomic	Suit the company	Comment	Decision
Sub function 2								
1	+	+	+	+	+	+	Ergonomic. A bit complicated.	+
2	+	+	+	+	+	+	Easy construction. Different front height during LE.	+
16	+	+	+	+	+	+	Can be heavy. Simple.	+
19	+	+	?	+	+	+	Will the arm be able to fold up?	?
20a	+	?	+	+	+	+	Too big bending moments?	?
28	+	+	+	+	+	+	Heavy. Lifting equipment probably needed during CC – LC change.	+
30	+	+	+	+	+	+	Simple	+
35	+	+	?	+	+	+	Rails long enough? Sensor need to be moved.	?
36	+	-					Moving part that must sustain high moments is not safe.	-
Sub function 3								
3	+	?	+	+	+	+	Will the cup have enough space during CC mode?	?
3b	+	?	+	+	+	+	Will the cup have enough space during CC mode?	?
7	+	+	+	+	+	+	The sliding beam strength critical	+
13	+	-					The strength and the turning mechanism not as good as 14.	-
14	+	+	+	+	+	+	Some problem may occur due to simultaneously rotation.	+
20	+	+	+	+	+	+	Simple, but the cube maybe stuck within the beam.	+
21	+	+	+	+	+	+	The sliding bushing need a safe pin connection.	+
Sub function 8								
1	+	+	+	+	+	+	Need to be thick. No stiffening possible.	+
2	+	+	+	+	?	+	Heavy depending on material and construction	?
3	+	+	+	+	+	+	No lifts needed.	+
4	+	+	+	+	?	+	Heavy depending on material and construction	?
5	-						Not possible to mount CC the hole won't be covered.	-
6	+	-					Too long foundation hole. This may cause injure.	-
7	+	+	+	+	-		To heavy. No stiffening possible due to floor volume.	-
7b	+	+	+	+	+	+	Milled volume will complicate the moving carrier.	+
7c	+	+	+	+	+	+	Milled volume will complicate the moving carrier.	+
8	+	+	+	+	?	+	Stiffening needed to reduce thickness and weight	?
9	+	+	-				Impossible to roll a metal sheet	-
10	+	+	+	+	+	+	Ergonomic, higher possibility for malfunction	+
11	+	+	+	+	-		Don't cover the whole hole. May cause injure.	-
Group session generated								
G1	+	+	?	+	+	+	Sensor may malfunction at its current position	?
G2	+	-					To extensive construction changes	-
G3	+	-					Concept 41-51 investigates this further	-
G4	+	-					Will not fit. Cab will be in its way during CC mode.	-
G5	+	+	-				Tail will be in its way for the movable "pistons"	-
G6	+	+	-				Complex. G1 is simpler.	-
G7	+	+	-				Won't have enough space	-

3.2.4.4 Calculations and deeper investigations – Sub function 2

It was uncertain if concept 19 could be turned up without touching the cab in its upright position. Measurements at the cab were needed to investigate the turning mechanism in concept 19, resulting in a concept development into 19b, which has a rotation center of the arm was moved closer to the head tripod. A deeper explanation is shown in Appendix B.

Concept 20a was uncertain due to the bending forces created at the mounting points at the cab. The calculations shown in Appendix B resulted in forces low enough to be handled by bolts fitting in the existing four holes at the cab front. According to the cab strength, this was not investigated by calculations, but the mounting points were of high strength character that should sustain the high forces during the use of a complete truck. The assumption of enough strength was therefore taken.

The rail length had a critical role for concept 35, and was investigated by calculations shown in Appendix B. This shown that the place during CC31 mode will be too small and concept did therefore not proceed to the upcoming decision matrices.

3.2.4.5 *Calculations and deeper investigations – Sub function 3*

According to concept 3 and 3b a calculation was done according to the risk of touch between LE back and upper cups. This risk was considered possible due to the curved form, shown in Figure 3.20. The distance obtained of the outward curvature was 20 mm, which seemed enough. Eventual soft support between the cups and cab could also be developed to secure no cab damage during CC mode.

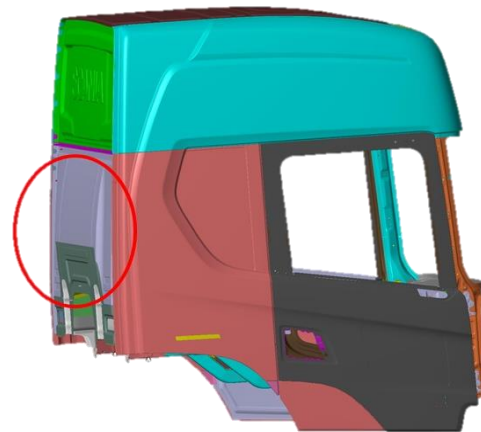


Figure 3.20 Curved form at the back taken into consideration for concept 3 and 3b in sub function 3. (The cab back is similar between LE and CC)

3.2.4.6 *Calculations and deeper investigations – Sub function 8*

Concept 2, 4 and 8 were dependent on the weight, which need to be minimized to make the solutions more ergonomic. This could be solved by using stiffening structures and lighter materials. In concept 8 the laser does also need to be taken into consideration where the stiffening plates would take place.

The space left after turning concept 8 would be small but probably long enough for the transportation rack used. But the counter need to be turned before the cab is moved into place in mounting position into the head tripod, otherwise the counter may cause cab damage during turning.

3.2.4.7 *Calculations and deeper investigations – group generated concepts*

According to G1 the sensor would not fulfil its function when the LE is placed closer to the head. Eventual cab damage could therefore occur during rotation. To have a functional G1, the sensor has to be moved, which seemed as possible to do by the job initiators.

The general concept solution G3 – *Lengthen the rail* – was affecting the tilt with a longer foundation hole where the longer rail would be placed. A longer hole caused some problem due to the ability to move the cab rack over this hole. The possibility to solve this problem were further investigated by concept number 1 to 11 for sub function 8.

3.2.4.8 Decision matrices - sub function 2

The comparison evaluations using a decision matrix are shown in Table 3.4 and Table 3.5. Sub function 2 was evaluated during two steps due many concept investigated, where each decision matrix was concluded with necessary construction changes. Criteria number 7 did not affect sub function 2. From the group generated concepts, G1 was the only one proceeded. The properties of G1 was assumed to be comparable to sub function 2, and was therefore evaluated in the Table 3.4 too. Concept 1 was a used as a reference concept initially and secondly concept 20a was used.

Table 3.4 First decision matrix for sub function 2, using concept 1 as reference.

Criteria number	Description	Weight	Reference 1	Solution						
				2	16	19b	20a	28	30	G1
6.	Easy accessed cab-interior and -underbody	5	DATUM	0	0	5-	0	0	0	0
7.	Possible to fix other cabs than LE and CC (Specific for sub function 3)	3		-	-	-	-	-	-	-
8.	Simple maintenance	3		3+	3+	3+	3+	3+	3+	3+
9.	Similar style as current	2		0	0	0	0	0	0	0
11.	Avoid sharp edges	4		0	0	0	0	0	0	0
15.	Low weight on parts	2		2-	2-	0	2-	2-	2-	2-
16.	Minimize manufacture cost	2		2+	2+	2+	2+	2+	2+	2+
24.	Short exchange time (Same cab type)	5		0	0	0	0	0	0	0
25.	Minimum maintenance	5		5+	5+	5+	5+	5+	5+	5+
26.	Minimum deflection at arm end	4		0	0	0	0	0	0	0
27.	Exchange time short (different cab type)	3		3-	3-	0	0	3-	3-	3-
28.	Ergonomic change between cabs	4		4-	4-	4-	4-	4-	4-	4-
29.	Easy to understand	3		0	0	0	0	0	0	0
30.	Minimize amount of wearing parts	2		2+	2+	2+	2+	2+	2+	2+
	Sum +			12+	12+	12+	12+	12+	12+	12+
	Sum 0			6	6	6	7	6	6	6
	Sum -			9-	9-	9-	6-	9-	9-	9-
	Net value			3+	3+	3+	6+	3+	3+	3+
	Rank		3	2	2	2	1	2	2	2
	Proceed		No	No	Yes	Yes	Yes	No	Yes	Yes

The obtained result from the first decision matrix shown that concept 20a seemed the best, while the rest, except for 1, are equal and reaching the same net value. Concept 19b would in some manner hide the front window during assembly and did therefore get 5- points for that criteria. But, 19b had other good advantages such as the ergonomic aspect and to get rid of the drawback re-construction was made, as shown in Appendix B, by moving the arm away from the cab. Concept 1, the telescopic function, came last partly because the complicated structure, probably causing maintenance for good function. There were also contingent according to the necessary length space during unextended position.

Concept 2 and 30 were of rather high similarity. But due to better abilities to absorb the moments created during 90° rotation concept 30 proceeded further and its strength was improved further against rotation, giving concept 30b.

The concepts 28 and G1 were similar, i.e. heavy constructions, needed to be assembled when shifting between CC and LE. G1 had the advantage that the sub function 3 was included and did therefore proceed instead for concept 28.

Table 3.5 Second decision matrix for sub function 2, using 20a as reference.

Criteria number	Description	Weight	Reference 20a	Solution				
				16	19c	28	30b	G1
6.	Easy accessed cab-interior and -underbody	5	DATUM	0	0	0	0	0
7.	Possible to fix other cabs than LE and CC (Specific for sub function 3)	3		-	-	-	-	-
8.	Simple maintenance	3		0	0	0	0	0
9.	Similar style as current	2		0	0	0	0	0
11.	Avoid sharp edges	4		0	0	0	0	0
15.	Low weight on parts	2		0	0	2-	0	2-
16.	Minimize manufacture cost	2		0	2-	2-	0	2-
24.	Short exchange time (Same cab type)	5		0	0	0	0	0
25.	Minimum maintenance	5		0	5-	0	0	0
26.	Minimum deflection at arm end	4		0	0	0	0	0
27.	Exchange time short (different cab type)	3		3-	3+	3-	3-	3-
28.	Ergonomic change between cabs	4		0	4+	4-	0	4-
29.	Easy to understand	3		0	0	0	0	0
30.	Minimize amount of wearing parts	2		0	0	0	0	0
	Sum +			0	7+	0	0	0
	Sum 0			12	9	9	12	9
	Sum -			3-	7-	11-	3-	11-
	Net value			3-	0	11-	3-	11-
	Rank		1	2	1	3	2	3
	Proceed		Yes	No	Yes	No	Yes	No

Concept 20a and 19c was evaluated as the best suited solutions for sub function 2, where 20a shown relative short exchange time and no certain strong disadvantages, while concept 19c had the advantages of ergonomics and exchange time. The second place was divided by the concepts 16 and 30b, but only 30b proceeded because of higher possibility grade for realization. Concept 16 did not proceed due to concerns according the mounting for the extended arms. Figure 3.21 through Figure 3.23 show the proceeded concepts, 19c, 20a and 30b.



Figure 3.21 Concept 19c - Turning arm.



Figure 3.22 Concept 20a - Arm extender mounted at cab.



Figure 3.23 Concept 30b - Arm extender mounted at arm.

The major drawbacks of concept 28 and G1 were the weight. High weight would cause bad ergonomic and long exchange time properties. Probably there would be necessary to use lifting equipment to avoid personnel injury.

3.2.4.9 Decision matrices - sub function 3

Sub function 3 was investigated during one step in Table 3.6. Concept 3 as the reference concept, which also resulted as the best suited in the decision matrix.

Table 3.6 Decision matrix for sub function 3 – using concept 3 as a reference.

Criteria number	Description	Weight	Solution					
			Ref. 3	3b	7	14	20	21
6.	Easy accessed cab-interior and -underbody	5	DATUM	0	0	0	0	0
7.	Possible to fix other cabs than LE and CC (Specific for sub function 3)	3		3+	3+	3+	3+	3+
8.	Simple maintenance	3		3-	3-	3-	3-	3-
9.	Similar style as current	2		0	0	0	0	0
11.	Avoid sharp edges	4		0	0	0	0	0
15.	Low weight on parts	2		2-	2-	2-	0	0
16.	Minimize manufacture cost	2		2-	2-	2-	2-	2-
24.	Short exchange time (Same cab type)	5		0	0	0	0	0
25.	Minimum maintenance	5		0	0	5-	0	0
26.	Minimum deflection at arm end	4		4-	4-	0	0	0
27.	Exchange time short (different cab type)	3		0	0	3-	0	0
28.	Ergonomic change between cabs	4		-4	0	0	0	0
29.	Easy to understand	3		0	0	3-	0	0
30.	Minimize amount of wearing parts	2		2-	2-	0	2-	2-
	Sum +			3+	3+	3+	3+	3+
	Sum 0			8	8	7	10	10
	Sum -			17-	13-	15-	7-	7-
	Net value			14-	10-	12-	4-	4-
	Rank		1	5	3	4	2	2
	Proceed		Yes	No	No	No	Yes	Yes

The reference, concept 3, was evaluated as the best and proceeded to further discussion with the concepts 20 and 21 placed as second mainly because of higher construction complexity. The ability to adjust the mounting height for other heights than CC and LE was not a demand and of that reason concept 3 was seemed good enough.

Concept 7 was erased mainly because of its instability of the sliding beams whose were more sensitive to deflection than Concept 20 and 21. Likely was concept 3b sensitive to forces due

to the combination of adjustability and ability to be fixed for the middle part of the upper beam. This construction part may be weak if not right dimensions are used to secure a stable function. Concept 20 and 21, solve this in a better way, using a fixed mounted upper beam, while the adjustable mechanism moves between these beams. Concept 3b was also seemed heavier during adjustment than concept 20 and 21. Figure 3.24 through Figure 3.26 show the proceeded concept 3, 20 and 21.

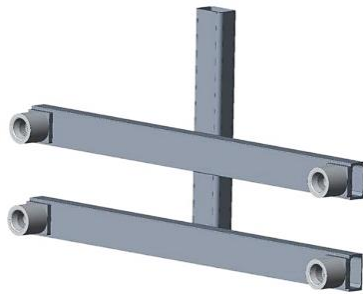


Figure 3.24 Concept 3 - Fixed upper beam.

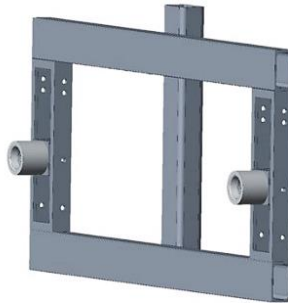


Figure 3.25 Concept 20 - Internal sliding

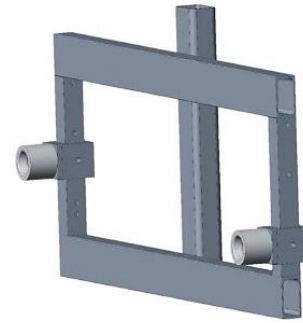


Figure 3.26 Concept 21 - External sliding bushing.

3.2.4.10 Decision matrices - sub function 8

Sub function 8 was done during two steps using decision matrix shown in Table 3.7 and Table 3.8.

Table 3.7 First decision matrix for sub function 8, using concept 1 as reference.

Criteria number	Description	Solution								
		Weight	Reference 1	2	3	4	6	7a	7b	10
6.	Easy accessed cab-interior and -underbody	5	DATUM	0	0	0	0	0	0	0
7.	Possible to fix other cabs than LE and CC (Specific for sub function 3)	3		-	-	-	-	-	-	-
8.	Simple maintenance	3		3+	0	0	0	0	0	3-
9.	Similar style as current	2		0	0	0	0	0	0	0
11.	Avoid sharp edges	4		0	0	0	0	0	0	0
15.	Low weight on parts	2		2-	0	2-	2-	2-	2-	0
16.	Minimize manufacture cost	2		2+	0	2+	2+	2+	2+	2-
24.	Short exchange time (Same cab type)	5		0	0	0	0	0	0	0
25.	Minimum maintenance	5		5+	5+	5+	5+	5+	5+	0
26.	Minimum deflection at arm end	4								
27.	Exchange time short (different cab type)	3		3-	0	3-	3-	0	0	3+
28.	Ergonomic change between cabs	4		4-	4+	4-	4-	4+	4+	4+
29.	Easy to understand	3		3+	3+	3+	3+	3+	3+	0
30.	Minimize amount of wearing parts	2		2+	2+	2+	2+	2+	2+	0
	Sum +			15+	16+	12+	12+	16+	16+	7+
	Sum 0			4	8	6	5	6	6	8
	Sum -			9-	2-	9-	9-	2-	2-	5-
	Net value			6+	14+	3+	3+	14+	14+	2+

	Rank		5	2	1	3	3	1	1	4
	Proceed		No	Yes	Yes	Yes	No	No	Yes	No

Concept 3 came at first place because of no certain drawbacks compared to the reference concept 1 and did therefore proceed to the next decision matrix as reference. 7a and 7b were also at first place and were very similar, with wheel or rail function as only difference. The rail function, 7b, seemed more possible to carry out and did therefore proceed further and 7a did not. Concept 2 did also proceed to the upcoming decision matrix because of its simplicity. This caused drawbacks as high weight and non-ergonomics, which need to be taken into consideration if this would be chosen as the final concept.

Table 3.8 Second decision matrix for sub function 8, using concept 3 as a reference.

Criteria number	Description	Solution				
		Weight	Reference 3	7a	7b	
6.	Easy accessed cab-interior and -underbody	5	DATUM	0	0	0
7.	Possible to fix other cabs than LE and CC (Specific for sub function 3)	3				
8.	Simple maintenance	3		3+	3+	3-
9.	Similar style as current	2		0	0	0
11.	Avoid sharp edges	4		0	0	0
15.	Low weight on parts	2		2-	0	0
16.	Minimize manufacture cost	2		2+	2+	0
24.	Short exchange time (Same cab type)	5		0	0	0
25.	Minimum maintenance	5		5+	5+	0
26.	Minimum deflection at arm end	4				
27.	Exchange time short (different cab type)	3		3-	3-	0
28.	Ergonomic change between cabs	4		4-	4-	0
29.	Easy to understand	3		0	0	0
30.	Minimize amount of wearing parts	2		2+	2+	0
	Sum +			12+	12+	0+
	Sum 0			5	6	11
	Sum -			9-	7-	3-
	Net value			3+	5+	3-
	Rank		3	2	1	4
	Proceed		Yes	Yes	Yes	No

The concepts 3 and 4, in Figure 3.28 and Figure 3.29, were very similar but 3 contained a ploughing component that would lift the counter construction upwards, which may need maintenance. This decreased the total rank of concept 3. One benefit for concept 3 compared to the other concepts was the ability for two alternative ways of use, i.e. opening by hand or by moving the tail tripod in forward direction.

Concept 2, in Figure 3.27, was ranked as second and was simple and seemed robust. But issues concerning the ergonomic and exchange time aspects were of major importance and affected concept 2 in a negative manner. Even if the amount of maintenance was of higher necessity in concept 3, this would affect concept 3 in a small extent in use but affected the scoring to a big extent, which shown that the decision matrix can give an uncertain result and a final discussion was important.



Figure 3.27 Concept 2 - Covering plate with some type of stiffening applied at its down faced side.

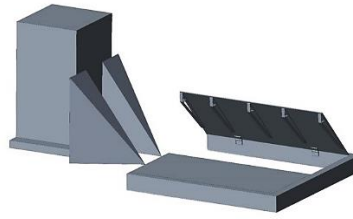


Figure 3.28 Concept 3 - Covering counters with tripod and ploughing construction included.

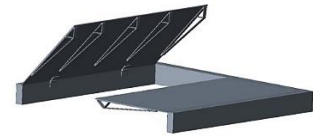


Figure 3.29 Concept 4 - Covering function including stiffening at its down faced side.

3.2.5 Selection and reflection

During the final meeting with the job initiators the decision was made to continue with concept 3 for sub function 3, using two horizontal fixed beams to take care of the different mounting height. To solve the different cab length concept 4 for sub function 8, seemed to solve the problem in the best way, even if this would require some changes at the tail tripod where a longer rail plate would be necessary. No concept was chosen from sub function 2 because of concept 4 did already fulfill these problems. Concept 3 and 4 for respective sub function are shown in Figure 3.30 and Figure 3.31, and were here from called K3 and K4 respective.

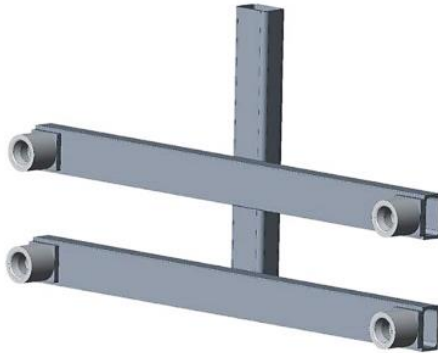


Figure 3.30 Concept 3 solving sub function 3, hereby called K3 - different heights.

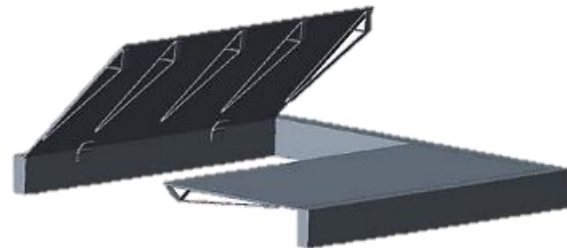


Figure 3.31 Concept 4 solving sub function 8, hereby called K4 - different length.

3.2.5.1 K3 – Height mechanism

This solution was very similar to the original design but did also contain a horizontal beam at a height suitable for the LE back mounting points. It would be suitable if the lower beam, used for CC, was welded while the upper beam was fixed by bolts to allow eventual height changes. During special circumstances other cabs than CC and LE maybe placed in the tilt, therefore the upper beam would be movable using bolts instead for welds. The suited requirement specification for concept K3 is shown in Table 3.9.

Table 3.9 Requirement specification of concept K3.

Criteria number	Cell	Criteria statement	D= Demand W, 5= High rated wish W, 1= Low rated wish	F=Function L=Limitation
	1.1	Two heights for cab back mountings	D	F
	1.1	Use the current cup and hitch connecting	D	F
	1.1	Allow other cabs to be rigged than LE and CC	D	F
	1.1	Fulfil standard SS-EN ISO 12100:2010	D	L
	1.1	Fulfil standard EN 349+A1:2008	D	L
	1.1	Weldable material	D	L
	1.1	Simple maintenance	W, 3	F

	1.1	Match the current design	W, 2	L
	1.2	Environmental friendly material	W, 1	L
	1.3	Avoid sharp edges	W, 4	L
	1.3	Low movable beam weight	W, 4	
	1.4	Minimize development cost	W, 3	L
	2.1	One part manufacture possible	D	L
	2.2	No unfriendly materials during manufacturing	D	L
	2.4	Minimize manufacture cost	W, 2	L
	4.1	Life length of a cab generation	D	L
	4.1	The arm would not deform plastically	D	L
	4.1	Use the current sensor type for correct cab rig	D	F
	4.1	Avoid damaging contact between cups and cab.	D	F
	4.1	Minimum maintenance	W, 5	L
	4.1	Minimum deflection at arm ends	W, 4	L
	4.3	Ergonomic change between cabs	W, 4	F
	4.3	Easy to understand when mounting at what cup	Ö, 3	B
	4.4	Minimize amount of wearing parts	Ö, 2	B
	5.1	Recyclable material	Ö, 2	B

3.2.5.2 K4 – Length mechanism

K4 contained two counters that would be opened manually from the floor. The weight was of critical character, i.e. a suitable material and design were therefore needed to obtain K4 as light and ergonomic as possible. Some changes were also needed at the tilt, i.e. the tail tripod would need a longer rail and a driving chain. The suited requirement specification for K4 is shown in Table 3.10.

Table 3.10 Requirement specification of concept K4.

Criteria number	Cell	Criteria statement	D= Demand W, 5= High rated wish W, 1= Low rated wish	F=Function L=Limitation
	1.1	Forward tripod movement possible	D	F
	1.1	fulfil standard SS-EN ISO 12100:2010	D	L
	1.1	fulfil standard EN 349+A1:2008	D	L
	1.1	Stable counter frame to mount the counters on	D	F
	1.1	Simple maintenance of the turning mechanism	W, 3	F
	1.1	Similar style as the current tilt	W, 2	L
	1.2	Environmental friendly material	W, 1	L
	1.3	Minimize the risk for injury during counter turning	D	F
	1.3	Avoid sharp edges	W, 4	L
	1.4	Minimize development cost	W, 3	L
	2.1	One-part manufacturing possible	D	L
	2.2	No unfriendly materials during manufacturing	D	L
	2.3	Low weight on turning counters	W, 5	L
	2.4	Minimize manufacture cost	W, 2	L
	4.1	Possible to rotate both low entry and crew cab	D	F
	4.1	Life length of a cab generation	D	L
	4.1	Counters and its frame would not deform plastically	D	L
	4.1	The counters would not touch the tripod arm during folding	D	L
	4.1	Minimum maintenance of the construction	W, 5	L
	4.1	Minimum deflection at the counters during down folding	W, 4	L
	4.3	Make the counter opening and close easy	W, 5	F
	4.3	Easy to understand how the turning mechanism works	W, 3	L
	4.4	Minimize amount of wearing parts	W, 2	L
	5.1	Recyclable material	W, 2	L

3.3 Embodiment design

A comparison of an already existing solution compared to the final chosen concepts was done. The best suited ones was thereafter investigated due to critical aspects and spatial constraints. When the function carriers were settled exact measurement could be decided and a final layout could be created. *CREO Parametric 3.0*, was used to construct the included parts.

3.3.1 Comparison to already existing solutions

When the concept generation phase was done for this project, a new already existing solution appeared from a recently developed tilt of similar character, solving the mounting point height difference by using other mounting plates on the cab. The original and the height adjusted mounting plate are shown in Figure 3.32 and Figure 3.33. But, the height difference of the discovered mounting plate, Figure 3.33, did not take enough height into consideration, which forced some modifications to make it suitable. K100 was the name given to the plate suitable for the application for this project. By using K100 instead of K3, changes on the tilt arms could be avoided causing reduced total costs and retain the sensor safety function as it was. An adapted requirement specification for K100 was developed, as could be read in Table 3.11.

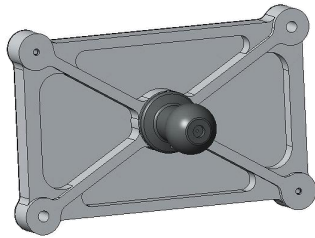


Figure 3.32 The existing mounting plate used during CC mode in the investigated tilt, taking no height difference into consideration.

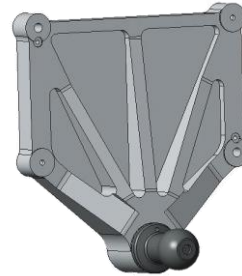


Figure 3.33 The discovered solution that seemed to solve the height difference in a better way than K4. But this plate did not adjust for enough height.

Table 3.11 Adapted requirement specification suited for K100 and based on the original shown in chapter 3.1.4.

Criteria number	Cell	Criteria statement	D= Demand W, 5= High rated wish W, 1= Low rated wish	F=Function L=Limitation
1.	1.1	Compensating the necessary height difference	D	F
2.	1.1	fulfil standard SS-EN ISO 12100:2010	D	L
3.	1.1	fulfil standard EN 349+A1:2008	D	L
4.	1.1	Use the existing cab mounting holes	D	F
5.	1.1	Use the existing cup and hitch connection	D	F
6.	1.1	Keep a similar style as current plates	W, 4	L
7.	1.2	Environmental friendly material	W, 1	L
8.	1.3	Avoid sharp edges	W, 4	L
9.	1.4	Minimize development cost by construct suitable for cheap processes. Design for manufacturing (DFM)	W, 5	L
10.		Construct effective due to force transition	W,5	F
11.	2.1	Two parts manufacturing possible	D	L
12.	2.2	No unfriendly materials during manufacturing	D	L
13.	2.4	Minimize manufacture cost	W, 2	L
14.	4.1	Life length of a cab generation	D	L
15.	4.1	Sustain forces in all rotation angles possible	D	F
16.	4.1	Not deform plastically	D	L
17.	4.1	Have acceptable deflection	D	F
18.	4.1	No cab damage	D	F
19.	4.1	Minimum maintenance	W, 5	L
20.	4.3	Minimize the necessary weight due ergonomics	W, 4	F
21.	4.3	Easy to understand how to mount the plate on the cab	W, 3	L
22.	4.4	Minimize amount of wearing parts	W, 2	L
23.	5.1	Recyclable material	W, 2	L

3.3.2 Identify crucial requirements

Crucial requirements were divided in the safety, measurement and material aspects. This were done for both K100 and K4.

3.3.2.1 Critical safety aspects

Standards used for the original tilt were applied. For the obtained constructions, K4 and K100, *safety of machinery – minimum gaps* [22] and *Safety of machinery – general principles of design*, [23] were used, giving a systematic way of risk identification and elimination. The necessity of risk reduce could be obtained by Figure 3.34, and if needed, eliminated by following procedures:

- Security by machinery design – By using the critical distances given in [22].
- Technical security systems applied at the machinery.
- By giving information about the usage of the machinery.

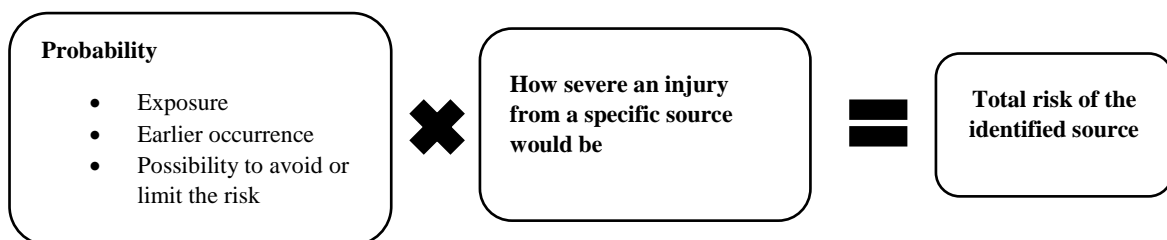


Figure 3.34 Systematic risk identification obtained from [23].

While moving the tripod back- and forward into right position it would be a potential risk of crushing between the tripod and the down folded counters, during CC mode, or foundation edge, during LE mode. Using Figure 3.34, this risk were assumed to minor importance due to low possibility of occurrence. This because of the tripod movement were adjusted manually.

Another potential risk was identified when folding down the counters where crushing of finger could occur between the counter and the concrete edge. The necessary space of 25mm, given in [22], could not be used due to the inability to be rolled over by the rack wheels. By applying indirect safety [4,24], using a gas cylinder the closing speed could be lowered and safety increased. Warnings should also be added to make the users aware. A gas cylinder is shown in Figure 3.35.



Figure 3.35 A gas spring cylinder that could increase the safety by slow down the counter closing and avoid crushing. Obtained and with permission from [25].

For K100 there were no standards applicable from the current tilt construction, where the major risk was mechanical strength and safety. Due to handling heavy weighted cabs, K100 where not allowed to failure during any circumstances and a safety factor of four or five were therefore found in [26], commonly used for lifting equipment. The safety factor of five was therefore used for the upcoming work, confirmed by discussions with the job initiators.

3.3.2.2 Critical measurements aspects

There were two critical measurements of major importance for K4. If the foundation wideness was too broad this may cause too high counters in turned up position, touching the tripod arm in its lowest position, shown as the vertical arrow in Figure 3.36. But, the foundation did also need to be broad enough to allow the tripod to move in it. By calculations the foundation was allowed to be 920mm broad, restricted by the rail plate width of 720mm shown in Figure 3.37. Calculations are shown in Appendix C. The free horizontal space between the turned up counters and the tripod head was also critical, if this would be long enough for a LE rack to be rolled between, which it seemed to be. This measurements are shown with the horizontal arrow in Figure 3.36, showing the counters as a rectangle at the left hand side.



Figure 3.36 Critical measurements for K4. The counters should not be too high, and the length of the LE rack needed enough space between the turned up counters and the head tripod.

Some measurements were of simpler character. For K4, the rail plate and the tripod tail driving chain needed to be extended as much as the difference between the CC28 and the LE cab lengths, i.e. approximate 954mm, depending on the exact thickness of K100. The placement of the rail plate rails and chain where also important to achieve due to construct the counters for possible load support. 95mm is the distance to the rails and 370.5 to the chain, se Figure 3.37. As last thing the plunch cylinder hole for LE mode needed to be situated 420mm from edge at the new rail plate similarly as the current one.

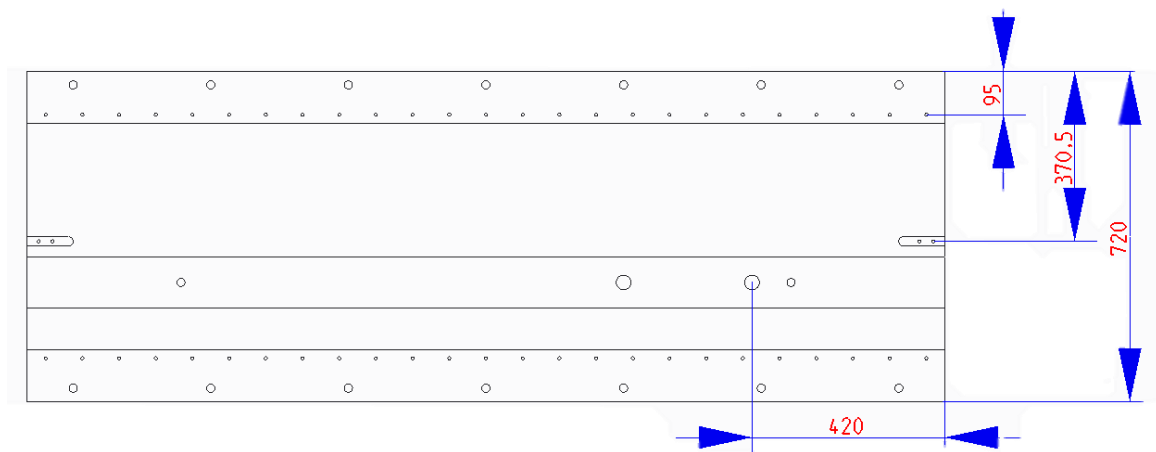


Figure 3.37 Distances of the rail plate from above. 95mm to the rail, 370.5mm to the chain center 420mm to the plunch cylinder hole and a plate width of 720mm.

For K100 only two critical measurements were identified. Firstly, a height compensation of 375mm, from the existing mounting plate center, was needed to be functional. Secondly, the construction should suit the existing mounting holes at the LE cab back. Figure 3.38 show the back mounting holes with the mentioned dimensions.

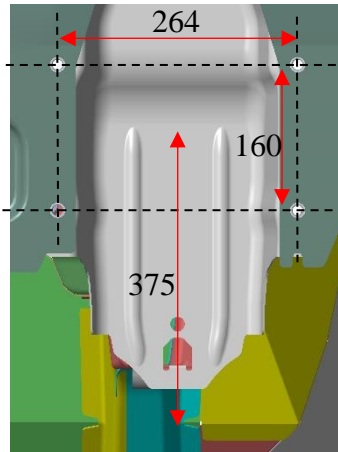


Figure 3.38 Critical measurements of K100 given in mm. Hole-to-hole width and height. Necessary height difference for the hitch compared to existing plate.

3.3.2.3 Critical material aspects

According to materials, both K4 and K100 needed materials that were both light weighted, due to ergonomics, and at the same time high mechanical strength, to sustain the applied loads. K4 would be able to absorb the force from one wheel of a CC31 rack without yielding or obtain to big deflection while K100 would absorb the moments and forces during rotation.

3.3.3 Produce spatial constraints drawings

According to concept K4, the spatial constraints considered the measurements and space in the rail plate hole. It should be possible for the counter mechanism to take place in the hole, but the thickness of the counters were limited. For concept K100, the spatial constraints handled the limited space around the mounting holes on the cab. The free space could be very useful to obtain a stiff and effective construction due to the exerting forces. Measurements of the spatial constraints for K4 and K100 are shown in Figure 3.39 through Figure 3.42, given in millimeters with its closest integer.

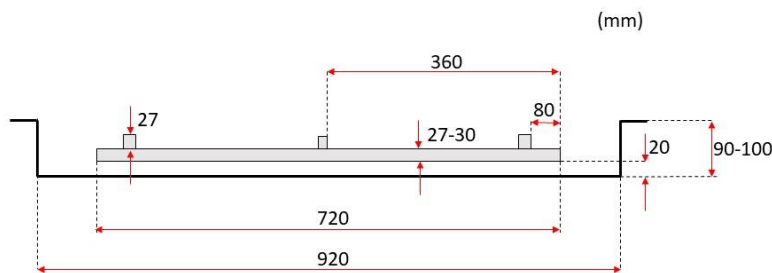


Figure 3.39 Spatial constrain drawing of the rail plate and the foundation, concept K4. The blacklined is the foundation space and the grey part is the rail plate.

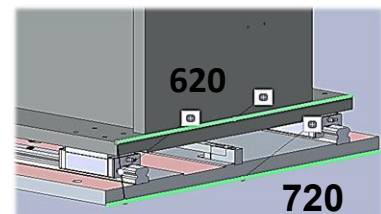


Figure 3.40 Rail plate and tripod CAD layout.

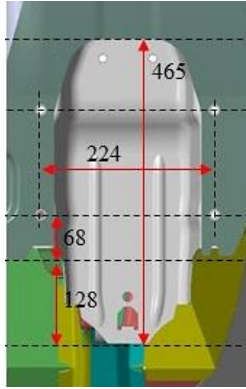


Figure 3.41 Spatial constraints drawing of the mounting points for concept K100, seen from normal view, describing possible width and height.

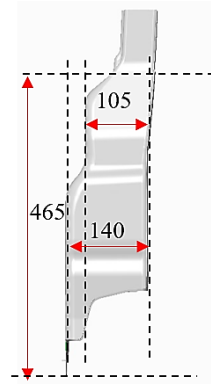


Figure 3.42 Spatial constrain drawing of the mounting points for concept K100, seen from the side view, describing possible depth.

3.3.4 Function carrier layout

Rough layouts were produced to show how a certain function would be solved in different ways. K100 was not affected during this stage, due only to two necessary components, the mounting plate and the original trail hitch. K4 would contain several interacting functions and were therefore investigated more deeply.

3.3.4.1 Function carriers K4

For concept K4 the function carriers taken into consideration were following:

- Frame function – Holding the counters into right position in the hole.
- Hinge function – The hinge placement to function in a good way.
- Covering function – What type of counter that allow trolley roll over.
- Gas cylinder function – Where the cylinder/cylinders should be placed.

The frame and hinge functions were of common used character, where standard components will be used to save time and make the total simpler. Frame function were including the way of connect the counters in the foundation giving examples such as using mounted beams, self-standing frames, direct mounted into the concrete or by using angled brackets. The hinge function considered the placement of a hinge, i.e. mounted from above or from below. Descriptions for the function carrier alternatives are given in Figure 3.43 and Figure 3.44, including advantages and drawbacks.


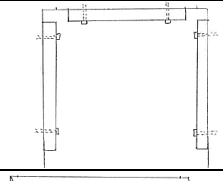
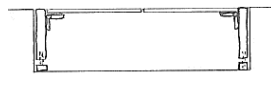
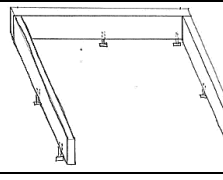
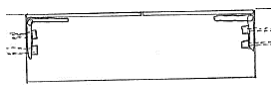
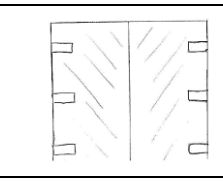
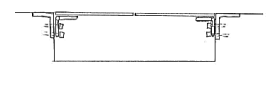
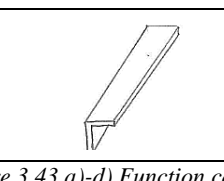
		a) F1 Advantages: <ul style="list-style-type: none"> • Robust, stable Drawbacks: <ul style="list-style-type: none"> • Foundation hole need to be exact to make the counters fit in a functional way.
		b) F2 Advantages: <ul style="list-style-type: none"> • Able to adjust in height. • Exact hole measurements not required. Drawbacks: <ul style="list-style-type: none"> • May need stiffening to make the frame stable.
		c) F3 Advantages: <ul style="list-style-type: none"> • Simple solution Drawbacks: <ul style="list-style-type: none"> • The foundation hole need to be exact. • Directly mounted in concrete may be critical.
		d) F4 Advantages: <ul style="list-style-type: none"> • Creates a hard 90° edge. • Ability to weld and use bolt.

Figure 3.43 a)-d) Function carriers for frame function, called F1-F4.

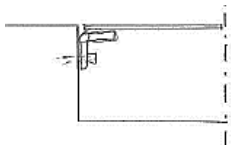
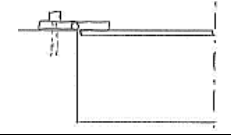
	a) H1 Advantages: <ul style="list-style-type: none"> • Do not block the rack wheel during roll over. • May absorb the forces in a better way. Drawbacks: <ul style="list-style-type: none"> • May need a column to allow the counter to turn.
	b) H2 Advantages: <ul style="list-style-type: none"> • Simpler to mount at the construction Drawbacks: <ul style="list-style-type: none"> • Will in some extent the wheels during roll over.

Figure 3.44 a)-b) Function carriers for hinge function, called H1-H2.

There were not as much experience of cylinders and the covering plate function, therefore these were investigated a bit further. The cylinder would be ordered from a manufacturer while the covering counter would be developed from scratch to fit the application. Figure 3.45 and Figure 3.46 show the developed function carriers for the cylinders and the covering function.

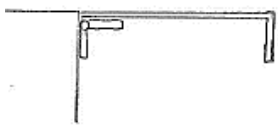
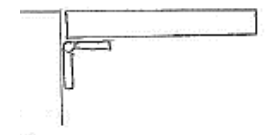
	a) C1 Advantages: <ul style="list-style-type: none"> • End support can be done by bending the plate. • Able to obtain with slip protecting pattern. Drawbacks: <ul style="list-style-type: none"> • Ineffective cross-section against bending.
	b) C2 Advantages: <ul style="list-style-type: none"> • Effective cross-section can be obtained, minimizing the deflection. Drawbacks: <ul style="list-style-type: none"> • Limited thickness • Limited variants of extruded material. Hard to found a suitable shape.

Figure 3.45 Function carriers for the covering function, called C1-C2.

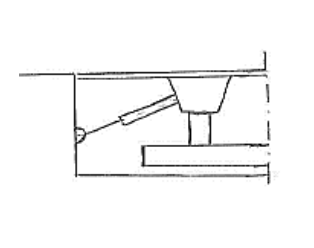
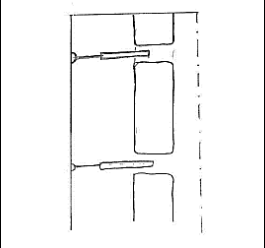
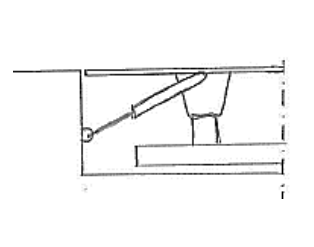
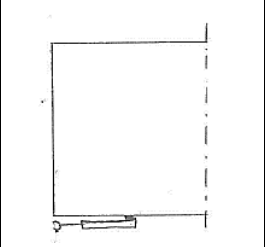
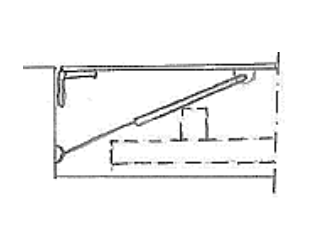
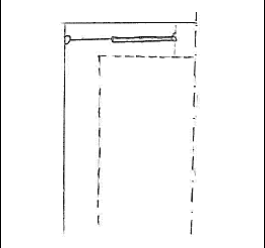
		<p>a) G1</p> <p>Advantages:</p> <ul style="list-style-type: none"> • Two cylinders possible at each counters, giving a more equal load distribution. <p>Drawbacks:</p> <ul style="list-style-type: none"> • Limited space in height, due to rail plate. • Length limited if the rails will be used as support for the counters.
		<p>b) G2</p> <p>Advantages:</p> <ul style="list-style-type: none"> • Easy to access. <p>Drawbacks:</p> <ul style="list-style-type: none"> • Limited space in height, due to rail plate. • Only one cylinder possible. • May warp the counter when turning it up.
		<p>c) G3</p> <p>Advantages:</p> <ul style="list-style-type: none"> • More height available due to no rail plate. <p>Drawbacks:</p> <ul style="list-style-type: none"> • Impossible to access when the counters are closed. • May warp the counter when turning it up.

Figure 3.46 Function carriers for the cylinder function, called G1-G3.

3.3.4.2 Function carriers K100

The main thing considered of K100 was the production. Properties and design will to a great extent depend on the manufacturing process used, i.e. if it will be milled from one piece or assembled by several pieces by welding for example. The main function was to absorb and transmit the forces and moments occurring during rotation.

3.3.5 Function carrier comparison

As shown in the decision matrix, Table 3.12, F4, H1, C1 and G3 will proceed to next step for a total embodiment. G3 obtained a lower net value than G2, but due to the ability to get a negative angle on the cylinder, forcing the counters downwards in closed mode, G3 proceed instead. This decision was made during discussion with the job initiators. Likewise, the way of manufacturing of K100 was discussed and decided to be milled, offering a component free from possible defects from weld joints.

Table 3.12 Decision matrix for concept K4 and its different function carriers.

Description	Solution										
	Ref. F1	F2	F3	F4	Ref. H1	H2	Ref. C1	C2	G1	G2	G3
Function	DATUM	0	0	0	DATUM	0	DATUM	-	DATUM	0	+
Working principle		0	0	0		-		0		+	+
Layout		-	-	+		0		0		0	0
Safety		0	0	0		0		0		0	0
Ergonomics		-	0	0		0		0		0	0
Production		-	+	+		0		-		0	0
Quality control		0	0	0		0		0		+	0
Assembly		-	0	0		0		0		+	0
Operation		-	0	0		-		-		-	-
Maintenance		0	0	0		0		0		0	0
Sum +		0+	1+	2+		0+		0		3+	2+
Sum 0		5	8	8		8		7		6	7
Sum -		5-	2-	0		2-		3-		1-	1-
Net value		5-	0	2+		2-		3-		2+	1+
Rank	2	3	2	1	1	2	1	2	3	1	2
Proceed	-	-	-	Yes	Yes		Yes				Yes

3.3.6 Detailed layouts

K4 and especially K100 will be analyzed during later steps, but this phase put the function carriers together creating an embodiment design.

3.3.6.1 Concept K4

A detailed picture of a 90° bracket is shown in Figure 3.47 and the suggested welding hinges in Figure 3.48, which would be welded at the counter 90° bracket. This would create the opening and closing mechanism. A suitable gas cylinder was earlier described in Figure 3.35.



Figure 3.47 Concrete edge bracket, with permission from [27].



Figure 3.48 Weld hinge, with permission from [28].

According to the spatial constraints given in Figure 3.39, the counter were developed into two widths, 485mm and 425mm, to allow a bending support at the middle area of the rail plate, Figure 3.49. Otherwise, using the same length, the railplate chain would block the supporting function. The concrete floor was not completely flat, therefore the bend support was given a height of 40mm, to allow later height adjustment compensating for the floor inaccuracy. Initially the plate was given a plate thickness of 5mm as a start for the upcoming simulations. Figure 3.50 shown the five bar pattern commonly used for plates.

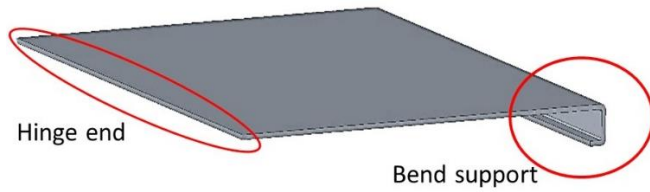


Figure 3.49 485mm wide plate describing the jointed hinge end and the bending support.

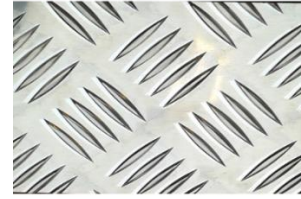


Figure 3.50 Five bar pattern of a 5/7 aluminum With permission from [29].

To absorb the forces in a better sense a middle support and edge support, was applied. The middle support was situated parallel and with its center, placed 175mm from the hinge end. This would allow usage of the rail plate rail as a support point. The mid support was constructed by bended plate and would be mounted at the entire counter length underside, i.e. 1000mm. This meant that some additional weight to the counters.

The edge support would be applied at the foundation edge to support the counters where no middle support were possible. A length of 300, while a width and height of 20mm was applied. It was situated a close to the bend support, but without risk for blocking the bended edge when turning the counters. An embodiment design for K4 including counters, weld hinges, gas cylinders, concrete edge brackets and supports are shown in Figure 3.51 and Figure 3.52.



Figure 3.51 Assembled layout of K4, half opened showing the cylinder, middle support and edge support placements.

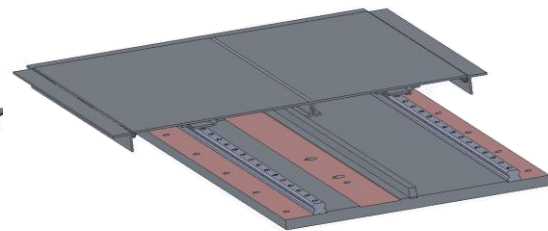


Figure 3.52 Assembled layout of K4, showing the interactions between middle and bended supports.

3.3.6.2 Concept K100

K100 would only consist of two parts, the mounting plate that would be redesigned and the trail hitch, which would be copied from the existing solutions. Clarity, simplicity and safety was applied to the mounting plate, i.e. few parts, understandable working principle and designed with safety in mind. The principle of direct and short force transmission path was used, due to absorb the forces in an effective way. This was realized by applying material in the straight areas between the hitch and mounting holes, allowing effective force transfer [4,24]. According to [30] K100 would be more resistant to moment by make the construction high, i.e. distribute material a far distance from the bending center. For this reason the material between the hitch and mounting hole became rather thin but high, shown in Figure 3.53.

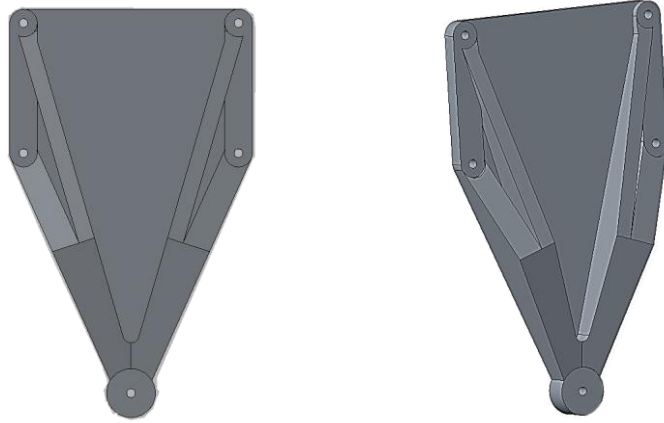


Figure 3.53 K100, the first layout.

3.4 Material selection

It was decided to investigate the material for the counters of the K4 and the whole structure of K100, firstly by reducing weight, secondly because no earlier preferences occurred. The mechanical properties were also important. A material selection process were done individually for K4 and K100, while the material selection for the rest of the parts were copied off earlier usage. Formulas and values of the constants C_1 and n were obtained from [13]. The used definitions were following:

- A – Area (m^2).
- b – Width (m).
- c – Price per unit mass (Sek/kg).
- C – Cost (Sek).
- C_1 – Constant connected moment load cases.
- E – Young's modulus (Pa).
- F – Force applied (N).
- h – Thickness (m).
- I – Moment of inertia (m^4).
- L – Length (m).
- m – mass (kg).
- M – Moment (Nm).
- M_X – Material index. Where X indicates the objective, i.e. mass or cost.
- n – Constant connected to the load case of buckling.
- S – Stiffness (N/m).
- S^* – Lowest stiffness accepted.
- y – Half the beam thickness.
- Z – Resistance against bending (m^3).
- σ – Internal stress
- σ_{ys} – Yield strength
- δ – Deflection (m).
- ρ – Density (kg/m^3).
- ϕ_B^e – Shape factor for elastic bending.
- ϕ_B^f – Shape factor for failure bending.

3.4.1 Material selection for K4 – Covering plate

The work was divided into a translation-, screening-, ranking-, documentation- and final selection phase. Resulting in a suggested material suitable for the K4 application.

3.4.1.1 Translation phase - K4

1. Functional requirements:

- Function: A free panel covering the rail plate hole, which need to sustain an approximate point force from a wheel rolling over. Figure 3.54 show the load case.

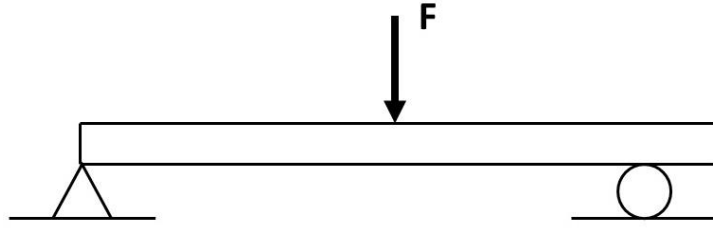


Figure 3.54 K4 investigated as a free panel with an applied point force.

- Constraints:
 - Deflection was limited, i.e. high stiffness wanted.
 - Yield strength would not be reached.
- Objective:
 - Mass would be minimized – Ergonomic aspect.
 - Cost would be minimized.
- Free variables:
 - Selection of material.
 - The thickness of the panel, h .

2. List the constraints and develop an equation for them

- High stiffness

$$S = \frac{F}{\delta} = \frac{C_1 EI}{L^3} \geq S^* \quad (3.1)$$

- High yield stress

$$\sigma = \frac{M}{I} y = \frac{M}{Z} < \sigma_{ys} \quad (3.2)$$

3. Develop equation for the objective

- Minimize the mass

$$m = AL\rho = bhL\rho \quad (3.3)$$

- Minimize cost

$$C = cAL\rho = cbhL\rho \quad (3.4)$$

4. Free variables in constraint function was

- Plate thickness, h . But it was limited to approximate 25mm free space above the rail plate.
- Moment of inertia, I

5. Creating the performance equation, P :

- For the stiffness:

$$I = \frac{bh^3}{12} \quad (3.5)$$

$$(3.5) \text{ in } (3.1) \quad h = \sqrt[3]{\frac{12S}{C_1 E b}} L \quad (3.6)$$

$$(3.6) \text{ in } (3.3) \quad m_1 = \sqrt[3]{\frac{12S^*}{C_1 b}} b L^2 \frac{\rho}{\sqrt[3]{E}} \quad (3.7)$$

$$(3.6) \text{ in } (3.4) \quad C_1 = \sqrt[3]{\frac{12S^*}{C_1 b}} b L^2 \frac{\rho c}{\sqrt[3]{E}} \quad (3.8)$$

- For the yield strength:

$$Z = \frac{b h^2}{6} \quad (3.9)$$

$$(3.9) \text{ in } (3.2) \quad h = \sqrt{\frac{6M}{b \sigma_{ys}}} \quad (3.10)$$

$$(3.10) \text{ in } (3.3) \quad m_2 = \sqrt{\frac{6M}{b}} b L \frac{\rho}{\sqrt{\sigma_{ys}}} \quad (3.11)$$

$$(3.10) \text{ in } (3.4) \quad C_2 = \sqrt{\frac{6M}{b}} b L \frac{\rho c}{\sqrt{\sigma_{ys}}} \quad (3.12)$$

6. The material indices obtained were:

- Mass material indices:

$$(3.7) \text{ gave mass index: } M_{mass,1} = \frac{\rho}{\sqrt[3]{E}} \quad (3.13)$$

$$(3.11) \text{ gave mass index: } M_{mass,2} = \frac{\rho}{\sqrt{\sigma_{ys}}} \quad (3.14)$$

- Cost material indices:

$$(3.8) \text{ gave cost index: } M_{cost,1} = \frac{\rho c}{\sqrt[3]{E}} \quad (3.15)$$

$$(3.12) \text{ gave cost index: } M_{cost,2} = \frac{\rho c}{\sqrt{\sigma_{ys}}} \quad (3.16)$$

3.4.1.2 Screening phase - K4

By using initial limitations, the amount of unsuitable materials could be diminished, making the material maps simpler with less content. The limitations settled in [31] were:

- Consist of metal material - *ferrous, non-ferrous, precious, and other*.
- Young's modulus, E, would be higher than 840MPa. See Appendix D for calculations.
- Good or excellent weldability – To weld the middle placed support against the counter.
- All beryllium- and magnesium-based materials were eliminated according to human health and fire risk, respective [31].
- Good or excellent metal press forming properties due to create the bending support.

3.4.1.3 Rank and material maps – K4

According to K4 there were both conflicting constraints, i.e. stiffness and yield strength, together with conflicting objectives, i.e. mass and cost. To take the conflicting constraints into consideration, the performance equations was set equal to each other, for the mass and cost respective. Using Equation 3.7, 3.11, 3.13 and 3.13, following equation was obtained:

$$\frac{\sqrt[3]{\frac{12S^*}{C_1 b}} L}{\sqrt{\frac{6M}{b}}} M_{mass,1} = M_{mass,2} \quad (3.17)$$

The geometrical and functional variables, called the coupling constant, was calculated 0.5192, shown in Appendix D. By logarithm, Equation 3.17 became the form $y = kx + m$, with coupling line slope, $k = 1$, and $m = \log(0.5192)$. Using a selection box, the most attractive materials closest to origo could be identified and selected for deeper investigation. Figure 3.55 show the material map obtained with mass as the objective. Closer to origo gave more attractive materials. The box section did only consist of aluminum, where the two 8000-series were outstanding. 5000-series were of great majority, but the box did also contain one 6000-series that was chosen of curiosity.

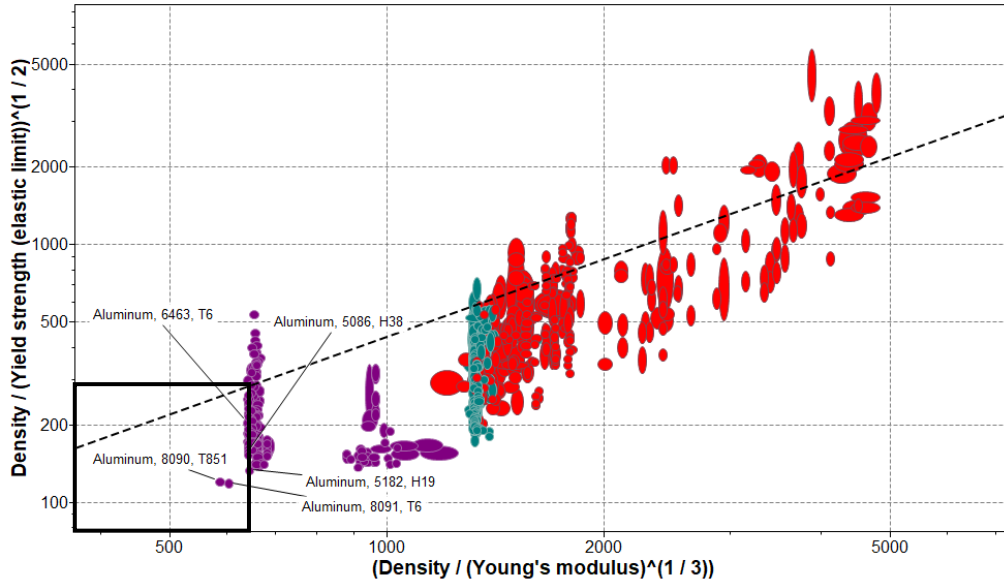


Figure 3.55 Conflicting constraints according to mass shown the box section and the chosen materials.

A similar procedure was done according to the cost, using Equation 3.8, 3.12, 3.15 and 3.16. The only difference to the mass was the price factor introduced into the material indices, $M_{cost,1}$ and $M_{cost,2}$. Therefore, the slope, k , and start value, m were equal. Figure 3.56 show the material map obtained with cost as an objective. This shown that the 8000-series are much more expensive than the 5000- and 6000-series. No box was used here.

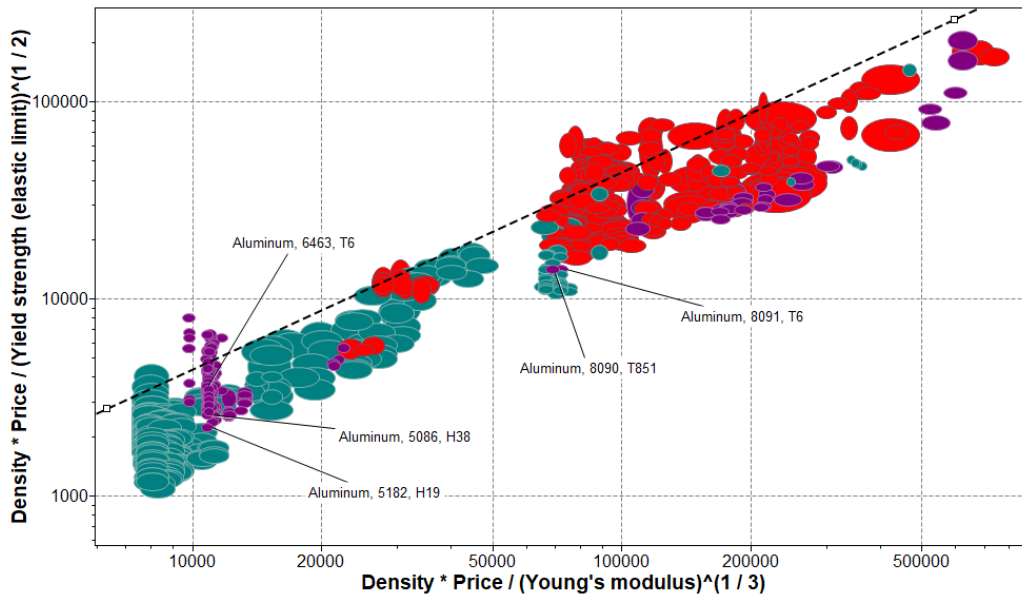


Figure 3.56 Conflicting constraints according to price.

By producing a tradeoff map containing density and price, this relationship was investigated. This shown if the good materials from the earlier graphs were good from the perspectives of both mass and cost. The tradeoff is shown in Figure 3.57, confirming the expensive behavior of the 8000-series obtained in Figure 3.56.

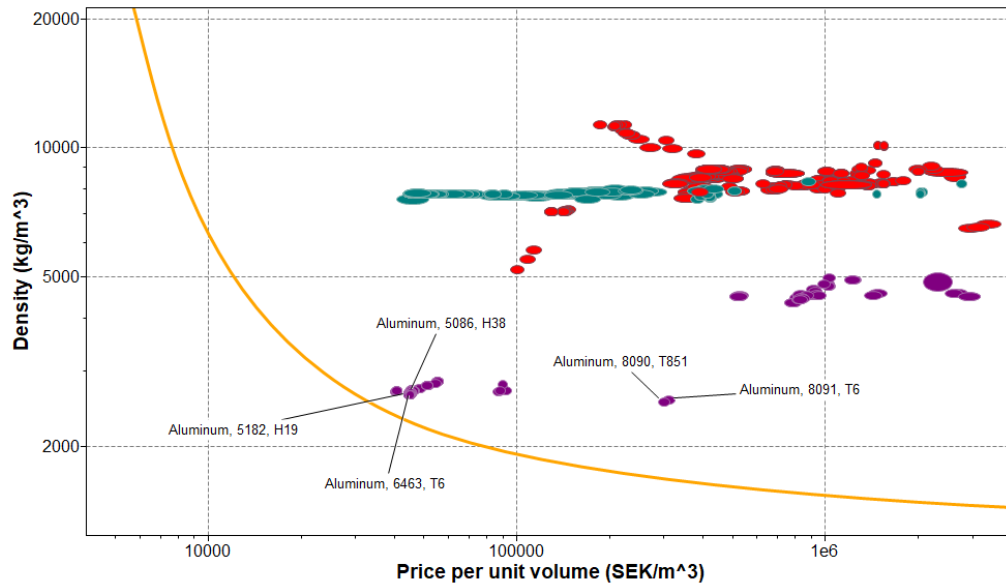


Figure 3.57 Tradeoff between price and density showing the chosen materials.

3.4.1.4 Documentation of selected materials – K4

The documentation contained information of common uses, the type of strengthening procedure and the ability to work with the material. Table 3.13 representing cost-, stiffness- and strength properties [31]. Fracture strength was calculated by ten uses each day for 20 years, giving an approximate value of 10000 cycles of load. The material documentation states as follows:

- **Aluminum 5086 H38**

This aluminum alloy was strain hardened and stabilized and its main alloy constituents were magnesium, manganese and chromium. Common uses included automotive and aircraft parts, drilling rigs and transportation equipment [31]. It was a high strength alloy well suitable for welding, especially using electric arc[31,32]. The properties according to machinability were good and the forming properties were somewhat less good compared to the annealed O state, which was good [32]. The H38 temper was one of the strongest tempers produced for this alloy, closely related to H18 [33]. Yield- and ultimate tensile strength given in Table 3.13 were confirmed by [34].

- **Aluminum 5182, H19**

The condition of this aluminum alloy was only strain hardened and its major alloy elements were magnesium and manganese. Common uses were automotive body sheets, reinforcement members [35], brackets and parts [31]. Weldability and resistance against corrosion were considered as favorable. [35]. The H19 temper had the strongest effect on the strength for the 5182 aluminum alloys [36]. The yield strength and ultimate tensile strength given in Table 3.13 were confirmed by [37].

- **Aluminum 6463, T6**

By using solution heat-treatment and artificially ageing and using magnesium and silicon as alloy elements, the strength was obtained, which was a bit lower than for the 5000 series, shown Figure 3.55 [31]. The most common applications were extruded architectural and trim sections [38]. By [39], the yield- and ultimate tensile strength investigated were somewhat higher than 214MPa and 241MPa respective.

- **Aluminum 8090, T851**

8090, T851 was a wrought alloy [40] that was solution heat-treated cold-worked and artificially aged to obtain its high strength properties, containing lithium, copper, magnesium and zirconium [31]. When properly alloyed the alloy would obtain high strength and high toughness, while the lithium content caused lower density. Aerospace technology and army weapons were suitable applications [40] due to its high cost compared to other aluminum alloys [41]. Yield-, ultimate tensile strength and Young's modulus were somewhat lower in [42] given the values of 370MPa, 450MPa and 77Gpa respective.

- **Aluminum 8091, T6**

8091 was similar to 8090 but only solution heat treated and artificially aged, not cold worked. It did also contain the same constituents, i.e. copper, lithium, magnesium and zirconium, with some higher content of copper, compared to 8090. [31].

3.4.1.5 The material selection – K4

5000-series seemed to be the best suitable material group. Relative high strength and relative low cost. 8000 series were lighter and stronger but much more expensive. 6000 had the same cost as the 5000 series, but was weaker according to yield and ultimate tensile strength. Comparing the 5000-series, the *Aluminum 5182, H19* seemed as the best choice, common used as reinforcement members and sheets. It is also stronger than the *Aluminum 5086 H38*, investigated. If not this materials would be available, this procedure had proven that an aluminum alloy from the 5000-series in strain hardened condition, “H”, would be preferable.

Table 3.13 Given the material properties of price, stiffness and strength [31]

Material	Price (SEK/m ³)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Fracture strength at 10 ⁵ cycles (MPa)
Aluminum 5086, H38	4350-4620	70-73,6	283-313	345-381	160-190
Aluminum 5182, H19	4350-4620	68,5-72,1	373-413	400-442	210-230
Aluminum 6463, T6	4330-4660	72,2-75,8	160-187	185-216	90-120
Aluminum 8090, T851	28700-31000	80-84	435-450	480-530	190-215
Aluminum 8091, T6	2970-32200	77-81	440-505	505-595	190-220

3.4.2 Material selection for K100 – Mounting plate

There were two behaviors identified for K100. One occurring during 0° rotation causing risk of buckling and one case during 90° rotation, creating moment forces that need to be handled.

3.4.2.1 Translation phase K100

1. Functional requirements:
 - Function: A beam that would absorb compression, tension and moment, Figure 3.58.

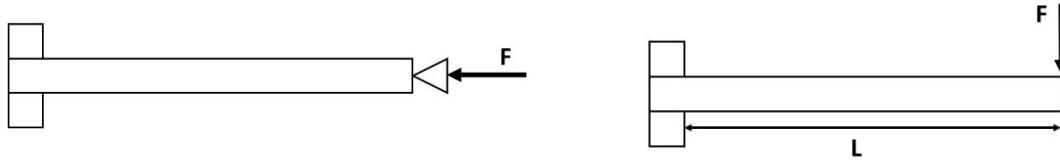


Figure 3.58 Buckling- left- and moment – right. Observe that it is another moment case than for K4.

- Constraints:
 - Deflection was limited, i.e. high stiffness wanted.
 - Yield strength would not be exceeded.
 - Objective:
 - Mass would be minimized due to the ergonomic aspect.
 - Free variables:
 - Material selection.
 - Area, A.
 - Shape – Introducing shape factor, ϕ .
2. List the constraints and develop equations: This was done for the case of buckling and moment, which generated two equations each, covering the constraints of stiffness and yield.

- Buckling and tension:
 - High stiffness:

$$F_{crit} = \frac{n^2 \pi^2 EI}{L^2} \quad (3.18)$$

- High yield stress:

$$\sigma = \frac{F_{crit}}{A} < \sigma_{ys} \quad (3.19)$$

- Moment:
 - High stiffness:

$$S = \frac{F}{\delta} = \frac{C_1 EI}{L^3} \geq S^* \quad (3.20)$$

- High yield stress:

$$\sigma = \frac{M}{I} y = \frac{M}{Z} < \sigma_{ys} \quad (3.21)$$

3. Develop equation for the objective:

- Minimize the mass:

$$m = AL\rho = bhL\rho \quad (3.22)$$

4. Free variables in constraint functions were:

- Area, A
- Shape, ϕ
- Moment of inertia, I

5. Obtained performance equation, P , using free variables:

- Buckling:

- Stiffness:

A square was used as a reference area, giving the elastic bending shape factor to:

$$\phi_B^e = \frac{I}{I_o} = \frac{12I}{A^2} \quad (3.23)$$

$$(3.23) \text{ in } (3.18) \quad A = \sqrt{\frac{F_{crit} L^2 12}{n^2 \pi^2 E \phi_B^e}} \quad (3.24)$$

$$(3.24) \text{ in } (3.22) \quad m_{buckling,1} = \sqrt{\frac{12 F_{crit}}{n^2 \pi^2}} L^2 \frac{\rho}{\sqrt{E \phi_B^e}} \quad (3.25)$$

- Yield strength:

$$(3.19) \text{ in } (3.22) \quad m_{buckling,2} = F_{crit} L \frac{\rho}{\sigma_{ys}} \quad (3.26)$$

- Moment

- Stiffness

Using a square as reference area, with elastic bending shape factor:

$$(3.23) \text{ in } (3.20) \quad A = \sqrt{\frac{12 S L^3}{c_1 E \phi_B^e}} \quad (3.27)$$

$$(3.37) \text{ in } (3.22) \quad m_{moment,1} = \sqrt{\frac{12 S L^3}{c_1}} L \frac{\rho}{\sqrt{E \phi_B^e}} \quad (3.28)$$

- Yield strength

Using a square as reference area, with failure bending shape factor:

$$\phi_B^f = \frac{Z}{Z_o} = \frac{6Z}{A^{3/2}} \quad (3.29)$$

$$(3.29) \text{ in } (3.21) \quad A = \left(\frac{6M}{\phi_B^f \sigma_{ys}} \right)^{2/3} \quad (3.30)$$

$$(3.30) \text{ in } (3.22) \quad m_{moment,2} = (6M)^{2/3} L \frac{\rho}{(\sigma_{ys} \phi_B^e)^{2/3}} \quad (3.31)$$

6. The indices obtained is:

- Buckling material indices:

$$(3.25) \text{ gave mass index: } M_{buckling,1} = \frac{\rho}{\sqrt{E \phi_B^e}} \quad (3.32)$$

(3.26) gave mass index:
$$M_{buckling,2} = \frac{\rho}{\sigma_{ys}} \quad (3.33)$$

- Moment material indices:

(3.28) gave mass index:
$$M_{moment,1} = \frac{\rho}{\sqrt{E\phi_B^e}} \quad (3.34)$$

(3.31) gave mass index:
$$M_{moment,2} = \frac{\rho}{(\sigma_{ys}\phi_B^e)^{2/3}} \quad (3.35)$$

3.4.2.2 Screening phase K100

By using initial limitations, the amount of unsuitable materials could be diminished, making the material maps simpler. The limitations set was:

- Consist of metal material - *ferrous, non-ferrous, precious, and other* - because of in-house experiences and knowledge.
- Magnesium and beryllium were eliminated because of fire- and health risk, respective [31].
- Highest cost of 1000 sek/kg.

3.4.2.3 Rank and material maps – K100

K100 contained two different load cases, i.e. buckling and moment and an investigation were therefore needed for each case using similar work flow as for K4, with conflicting constraints, stiffness and yield strength. For buckling, Equations 3.25, 3.26, 3.32 and 3.33 were used, leading to Equation 3.36. For moment, Equations 3.28, 3.31, 3.34 and 3.35 were used causing Equation 3.37.

$$\frac{\sqrt{\frac{12F_{crit}L^2}{n^2\pi^2}}}{F_{crit}L} M_{buckling,1} = M_{buckling,2} \quad (3.36)$$

$$\frac{\sqrt{\frac{12SL^3}{C_1}}}{(6M)^{2/3}L} M_{moment,1} = M_{moment,2} \quad (3.37)$$

The method followed the same work flow as for K4. According to logarithmic function given the form of $y = kx + m$, m for buckling was $\log(0.018)$ and for moment $\log(1.037)$, whose calculations are shown in Appendix D. Coupling line slope k was 1 in both cases. Figure 3.59 and Figure 3.60 show the obtained material maps for buckling and moment, respective.

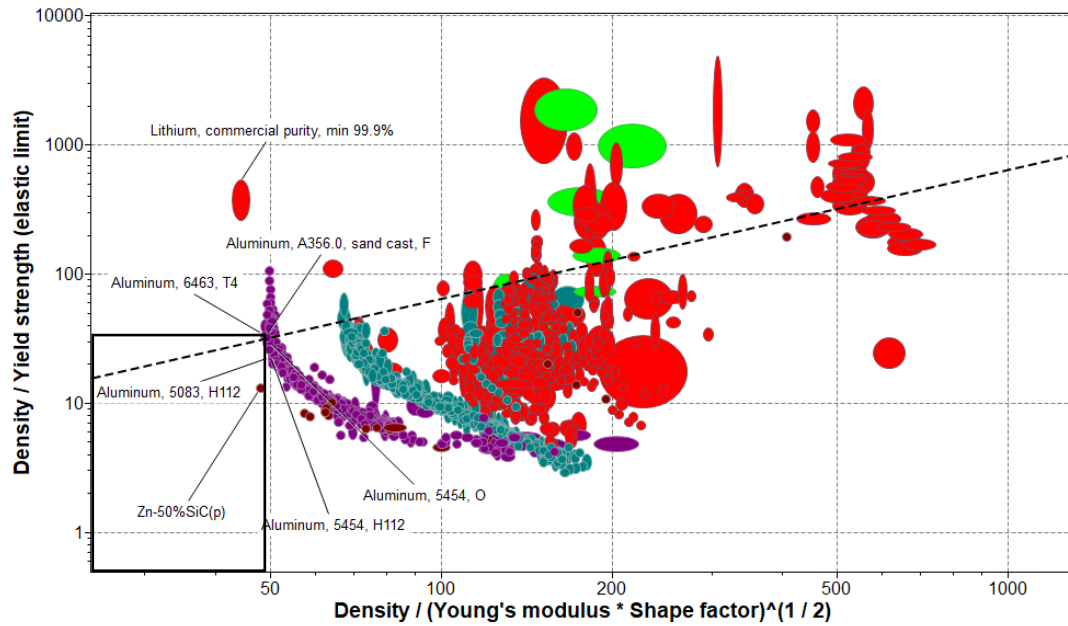


Figure 3.59 According to buckling, the box gives the most attractive materials.

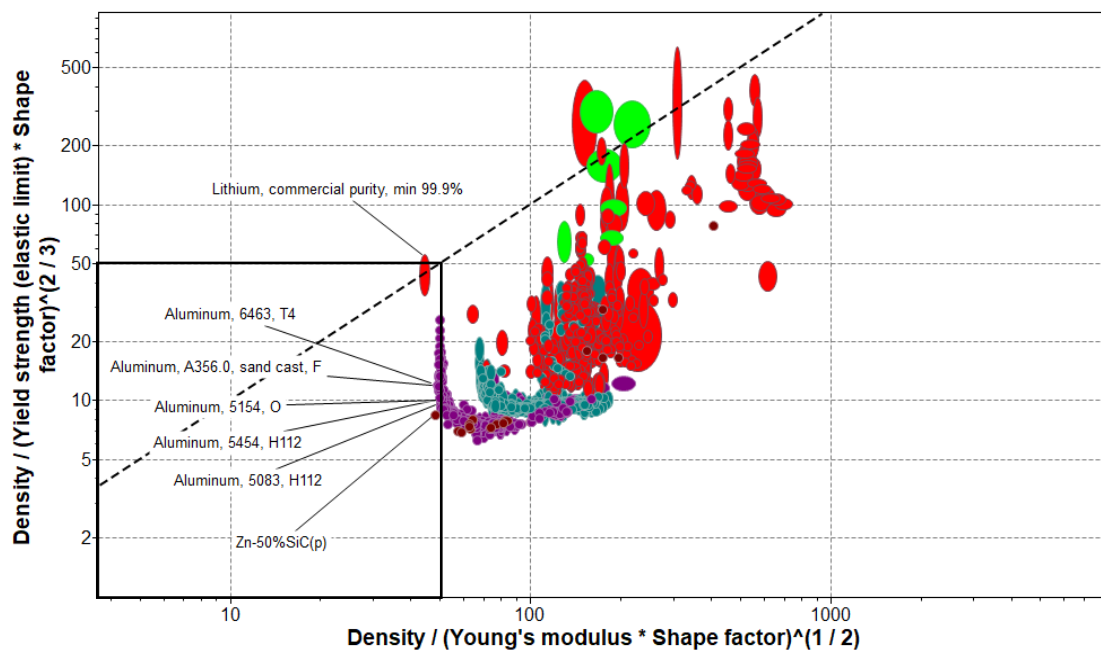


Figure 3.60 According to moment, the box gives the most attractive materials.

3.4.2.4 Documentation of selected materials

The materials proceeded from Figure 3.59 and Figure 3.60 were different kinds of aluminum alloys, a lithium material and a zinc matrix composite. Applications for lithium did not match the application area, i.e. not suitable for structural uses, while the zinc composites were an experimental composite, where no certain uses were given. Therefore the documentation stage focused on the aluminum materials. The fracture strength, was calculated for a lower value than K4, namely 10000 cycles of load. The material documentation settled were following:

- **Aluminum 6463 T4**

Solution heat treated and normally aged to stable condition, containing magnesium and silicon [31]. [43] gave a somewhat higher yield- and ultimate tensile strength, while a bit lower stiffness, with the values of 90MPa, 170MPa and 69GPa respective. The most common applications were extruded architectural and trim sections, similar to 6463 T6 investigated for K4 [38].

- **Aluminum, A255,0, sand cast, F**

A255 was an as-fabricated sand casted aluminum alloy, suitable for high strength applications, such as space frames, wheel axle housings, intake manifolds. Silicon were the element and but did also contain a magnesium [31]. Machining and casting properties were good [44].

- **Aluminum, 5154, O**

This was in annealed state, which gave the highest ductility state of 5154 [45]. It contained Magnesium and Chromium making it suitable for pressure vessels, welded constructions, cryogenic use or cooking utensils [31]. Values for strength and stiffness were confirmed by [46].

- **Aluminum 5454, H112**

Contained magnesium, manganese and chromium, while strain hardening the material H112 temper was obtained. This procedure made the material suitable for welded structures and pressure vessels [31]. The machinability was good or poor. The best machinability was obtained in the H34 tempered state. Weldability was good, using commercial methods [47]. The yield- and tensile strength upper limit given in Table 3.14 were confirmed by [48].

- **Aluminum, 5083, H112**

Wrought aluminum alloy that was strain hardened as only mean, containing magnesium, manganese and chromium. Suitable applications were auto- and aircraft applications, TV-towers, drilling rigs and transportation equipment, areas requiring good weldability, moderate strength and corrosion resistance [31]. The workability was of average level while the machinability was poor [49]. The upper yield- and ultimate tensile strength limits in Table 3.14 were confirmed by [50].

Table 3.14 Given the material properties of price, stiffness and strength for K100 material [31].

Material	Price (SEK/m3)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Fracture strength at 10 ⁴ cycles (MPa)
Aluminum 6463 T4	4330-4660	72,2-75,8	77-87,5	125-146	80-105
Aluminum 356, 0, Sand cast, F	4460-4880	71-74,5	118-130	164-180	120-140
Aluminum, 5154, O	4370-4700	70,5-74	105-116	223-247	100-120
Aluminum 5454, H112	4370-4650	70-73,6	83-124	214-237	160-185
Aluminum, 5083, H112	4370-4650	70-73,6	110-124	269-297	125-220

3.4.2.5 *The material selection*

According to Table 3.14, sand casted, 5454 H112 and the 5083 H112 gave the highest values of yield strength. 5454 H112 seemed to have more suitable application areas where loads were handled, the poor machinability was a drawback. The casted aluminum had much better machinability but lower ultimate tensile strength and the way of manufacture the component by casted aluminum was uncertain, due to only a few K100 was necessary. A final choice would therefore been between *Aluminum 356, sand cast* and *Aluminum, 5083, H112*. Cost did not have a major effect during this choice.

3.5 Optimization

K100 had a complex geometry and help from computer aided engineering (CAE) tools, *Dassault systems – Abaqus*, were needed for calculations to reduce the necessary weight. Through this phase a safety factor of five was included obtained from [26]. Self weight of the mounting plate, K4 was small compared to the cab and was therefore neglected. Eventual failure for K4 was not as critical and no safety factor were therefore seemed as needed during the calculations. The K4 thickness investigated was 5mm.

3.5.1 Load case identifications for K100

For K100, it was important to reduce its weight due to ergonomic aspects, necessary mechanical properties would be sustained. Load calculations were therefore done for five load cases, 0°, 45°, 90°, 135° and 180° rotation, where 0° was upward position. Figure 3.61 show a description of the cab mass distribution, between the cab front and back.

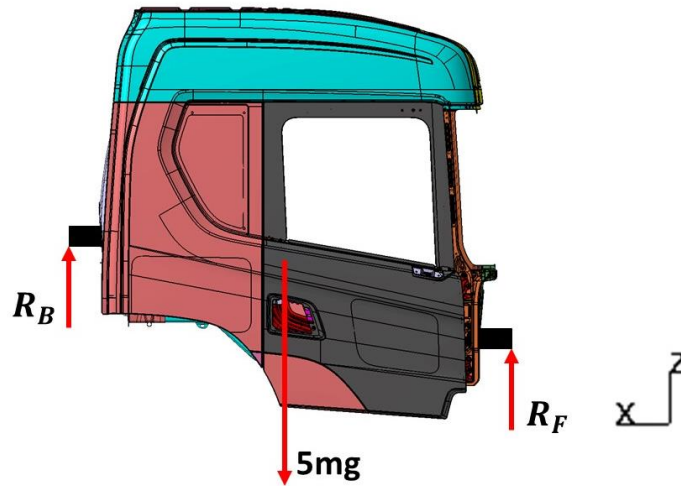


Figure 3.61 Picture of the LE cab from beside. The distribution of weight between back and front mounting plates.

Due to symmetry, only the half LE cab was calculated to obtain the force in only one mounting plate situated at the back. The total LE mass of 334kg was therefore divided by two, and later on multiplied with the safety factor of five, giving five masses, 5m, a total value of 835kg. Exact measurements used is not relevant for the reader to understand the following weight distribution procedure:

Force equilibrium:

$$\uparrow \sum F : R_F + R_B - 5mg = 0 \quad (3.38)$$

$$(3.38) \text{ gives: } 5mg = R_F + R_B \quad (3.39)$$

Moment equilibrium around R_F :

$$\sum M_{R_F} : 5mg(L_K + L_F) - R_B(2L_K + x_{mg} + L_F) = 0 \quad (3.40)$$

$$(3.40) \text{ gives: } R_B = \frac{5mg(L_K + L_F)}{2L_K + x_{mg} + L_F} \quad (3.41)$$

By obtained values the force distribution obtained were:

$$(3.41) \text{ in } (3.39) \quad R_F = 4653N$$

$$R_B = 3539N$$

R_B was the force for one mounting plate at the LE back. By multiply R_B with two, the total force at the back was obtained, i.e. $P_{Back} = 7078N$. The 45° position was calculated to give the most critical situation giving R_1 to be $7809N$, which during the simulations was divided into components in y and z direction. See Figure 3.62 for force descriptions. The safety factor is included meaning that the actual force, in real world, was one fifth of R_1 . Appendix E describes the calculations and obtained loads of the other load cases, which not were as critical.

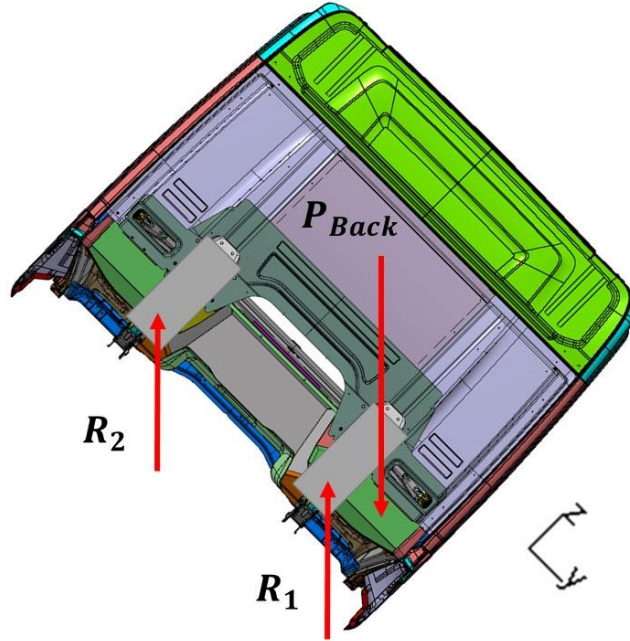


Figure 3.62 Picture of the LE cab from behind with forces R_1 and R_2 during the 45° rotation angle.

Force equilibrium in y- and x- direction:

$$\sum F_y : R_1 \cos(\alpha) + R_2 \cos(\alpha) - P_{Back} \cos(\alpha) = 0 \quad (3.42)$$

$$\sum F_z : R_1 \sin(\alpha) + R_2 \sin(\alpha) - P_{Back} \sin(\alpha) = 0 \quad (3.43)$$

$$\sin(45) = \cos(45) \quad (3.44)$$

$$(3.42), (3.43), (3.44): \quad P_{Back} = R_1 + R_2 \quad (3.45)$$

Moment equilibrium around R_1 :

$$\sum M_{R1} : P_{Back} \sin(\alpha) L_{ZQ} + R_2 \cos(\alpha) L_m - P_{Back} \cos(\alpha) L_{YQ} = 0 \quad (3.46)$$

$$(3.45) \text{ and } (3.46): \quad R_2 = P_{Back} \left(\frac{L_{YQ} - L_{ZQ}}{L_m} \right) \quad (3.47)$$

Obtained forces were:

$$(3.47) \text{ in } (3.50): \quad R_1 = 7809N$$

$$R_2 = -732N$$

3.5.2 Start point of optimization of K100

Starting from the construction shown in Figure 3.53 in section 2.3.6, a lighter construction was the goal. The four mounting holes were encastred, i.e. no rotation and translation were allowed, to act as the bolt connection onto the cab. Due to the complex geometry tetragonal mesh elements were used and were distributed in small sizes on critical areas such as radii or edges. A bigger mesh was applied on less critical areas, having thick material or no geometrical changes.

By simplify the hitch into a rectangular prism forces could be applied as pressures and still give a similar behavior as the spherical hitch. The whole plate was also assumed as one single metal piece. In real world, the hitch would be mounted at the plate, and therefore consist of two separate parts. Figure 3.63 gives the applied loads and their direction for the most critical load case, i.e. 45°. Observe that the load direction and magnitude differed between different load cases.

The initial part had a weight of 7.4 kg, when the rectangular hitch was included, and the whole construction consisted by aluminum. Young's modulus of 70GPa and Poisson's ratio 0.33 were used during the simulations [31]. Linear material strength behavior was used to simplify the model, i.e. using the yield strength, σ_{YS} , instead for ultimate tensile strength, σ_{UTS} , in Equation 2.1 shown in section 2.5.

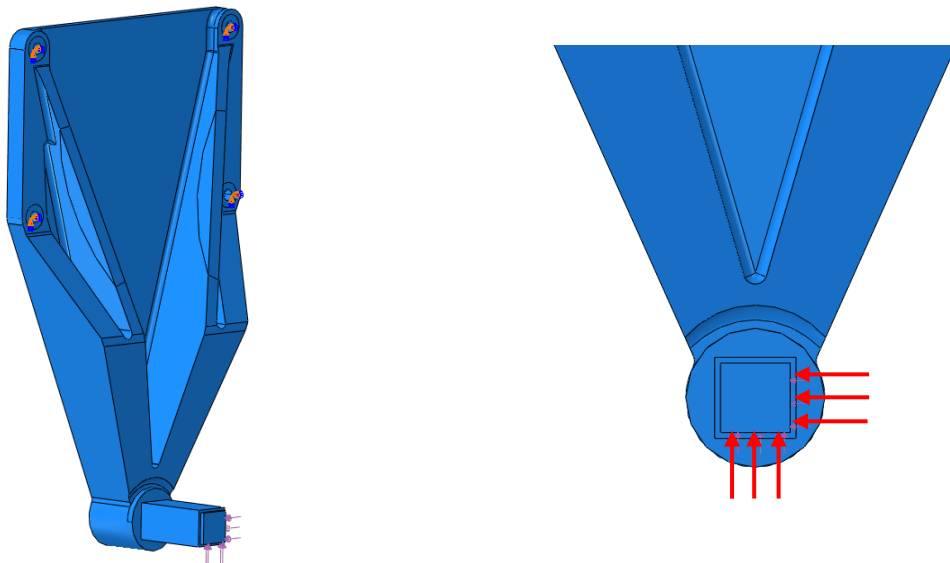


Figure 3.63 Simplified hitch with applied boundary conditions – left picture - and loads – right picture.

3.5.3 Optimization steps of K100

Material removal and construction changes were done during several steps, still using [24] as a guidance for force transition within the component. The result for the 45° degree rotation is shown in Figure 3.64, which shows the stresses obtained in the structure. Maximum stresses occur at the sharp 90° edge between the hitch rounding and the plate, reaching 480MPa, while the stresses at the right mounting hole reached 340MPa. These areas are shown with red arrows. The result was confirmed by computational testing using *CREO parametric 3.0*, shown in Figure 3.65.

A limit of 240MPa was used in the stress scale, due to the yield strength of aluminum 6082 T6 [31], given as a material alternative from the manufacturer. Other information obtained from the manufacturer was the minimum radius possible during milling, limited to 5.1mm. Appendix D show the results for each load case for the final optimization step.

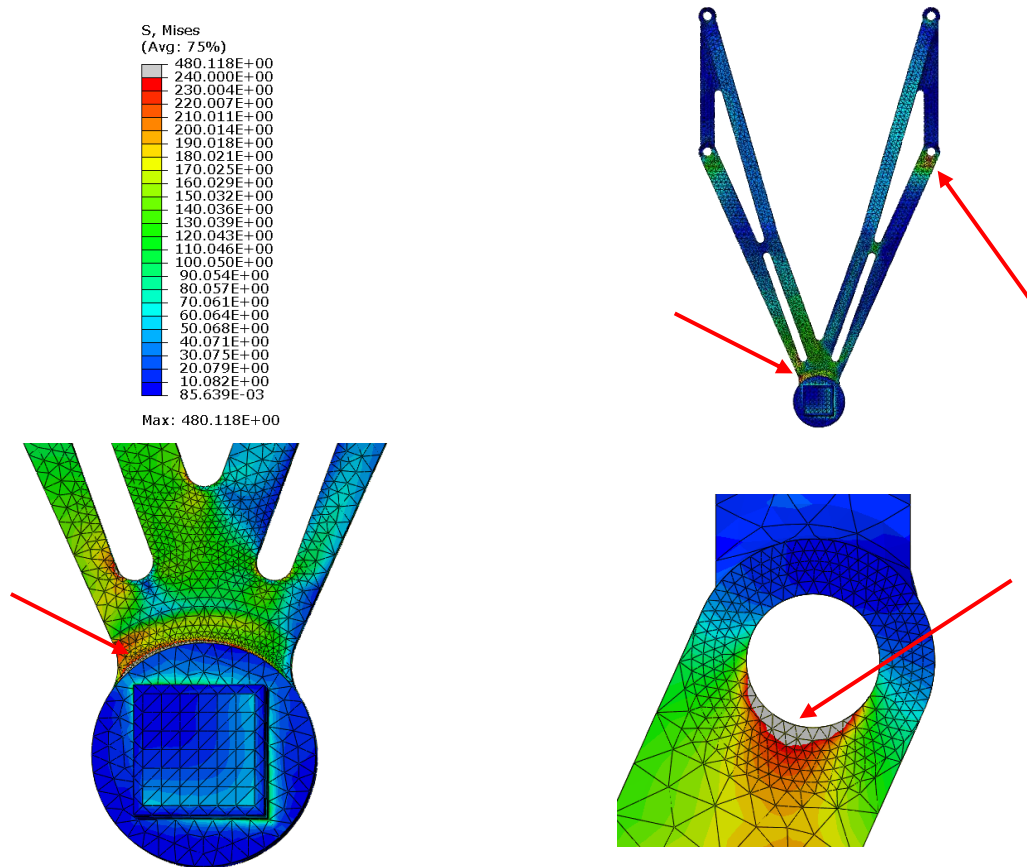


Figure 3.64 Stresses during the 45° mode. Upper left - stress scale, upper right - whole construction, lower left - stress concentrations at edge, lower right - stress concentrations at upper right hole.

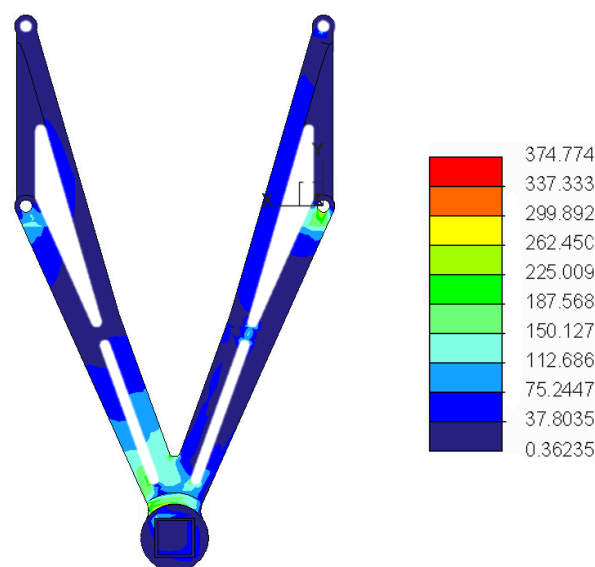


Figure 3.65 Validity check of the result using Creo Parametric 3.0. Stresses given in MPa.

The deflection obtained, shown in Figure 3.66, gave a total magnitude of approximate 2.96mm, shown with the red arrow. Movement in z-direction was the major part of the total deflection given the value of 2.91mm. The deflection of the rectangular prism was not taken into account because of probable use of other materials than aluminum. Steel was used in the original hitch, this would cause a stiffer behavior than shown in Figure 3.66. Observe that the deflection are overblown 10 times, in the right picture to show the behavior. The obtained results using *CREO Parametric 3.0*, validate the obtained result, Figure 3.67.

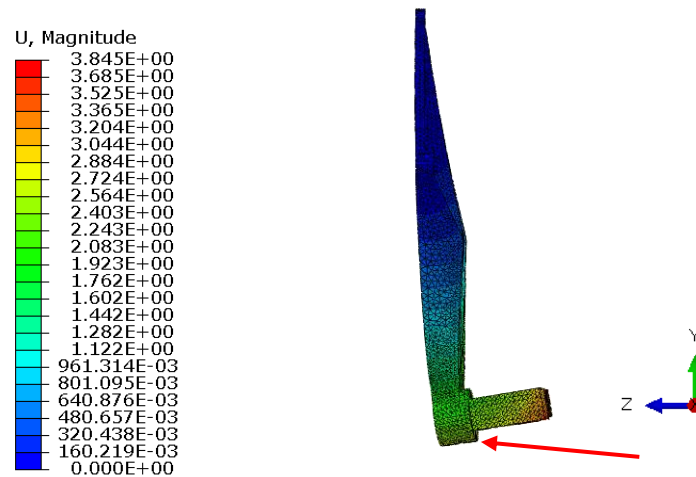


Figure 3.66 Deflections of load case 2 during 45° degree rotation. The deflection in the right picture was multiplied ten times to show the behavior.

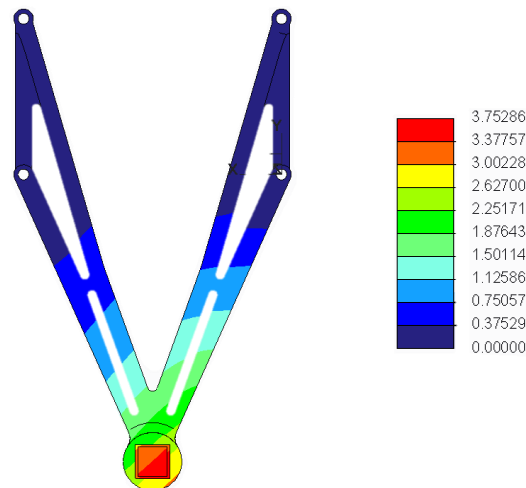


Figure 3.67 Validity check of the deflection, using *Creo Parametric 3.0*. Scale given in mm.

3.5.4 Final result of K100

After the optimizations the mounting plate shown in Figure 3.68 was obtained. Compared to Figure 3.53, this is a much more light weight design. By the iterative material removal the weight was reduced to 3-3.5 kg, which was less than half of the starting design.

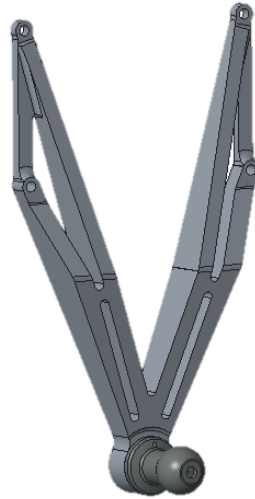


Figure 3.68 The optimized mounting plate, K100.

3.5.5 Load case identifications for K4

A rack with a CC31 upon was calculated to weight approximate 1500kg. This was divided by four, due to four wheels on the rack, assuming dividing the mass equally, causing a load of 375kg. Three load points were of interest depending on where the rack would be rolled over, shown in Figure 3.69. To distribute the force similar to a wheel, the load points were sketched as rectangles with the measurements 15mm wide and 40mm height, giving a total area of 600mm². Only the widest counter of 485mm was analyzed, giving the biggest moments possible between the middle support and the bend support.

3.5.6 Start point of K4 analysis

The weight was distributed as a pressure of 6.13MPa on the rectangular contact areas, called load point a), b) and c). During modelling only boundary conditions were used to imitate the counter behavior, which differed between the load cases. Exactly the same boundary conditions were applied at load case a) and b), shown in Table 3.15 and Figure 3.70, while load case c) differed at some points, shown in Table 3.16 and Figure 3.71.

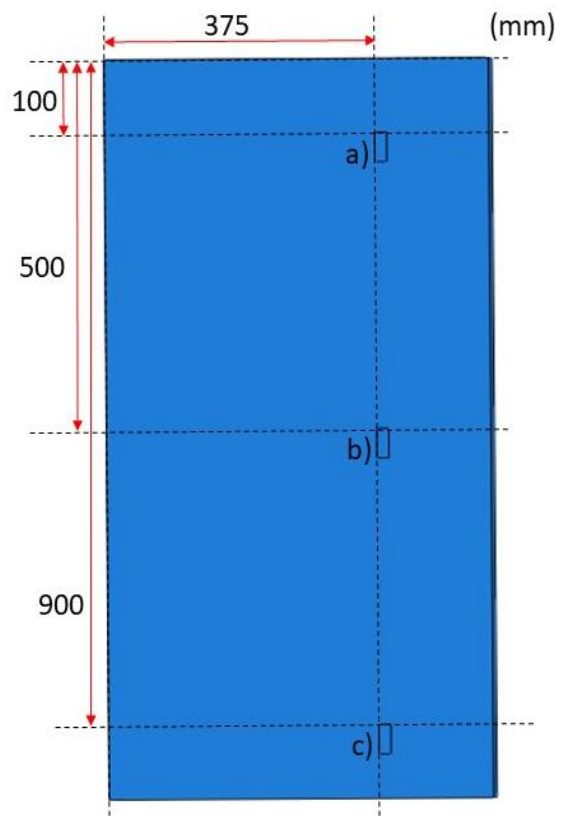


Figure 3.69 The K4 load points measurements given in millimeters originate from the hinge side b) was seemed as the most occurring load point.

Tetragonal elements were applied to the counter, simulated as a 3D solid and the areas around the load points were partitioned and given a smaller mesh size of 4mm while the global size was 10mm. Aluminum 5457 H114 was found as an alternative from a possible material provider [29], giving together with [31,51] a Young's modulus of 70GPa and poisons ratio to 0.33.

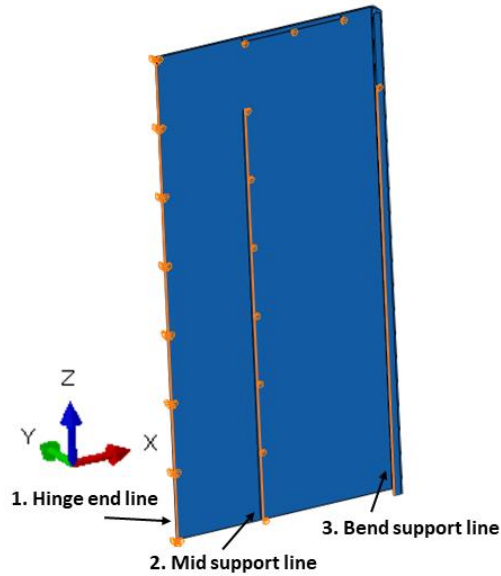


Figure 3.70 Boundary conditions for load case a) and b), connected to Table 3.15.

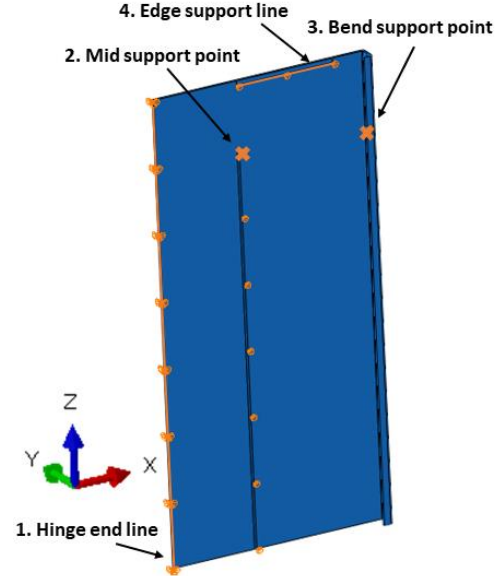


Figure 3.71 Boundary conditions for load case c), connected to Table 3.16.

Table 3.15 Boundary conditions for load case a) and b), connected to Figure 3.70

Counter placement	Boundary condition
1. Hinge end	Pinned – No translation allowed in x-, y- and z-direction
2. Mid support line	No translation in y-direction
3. Bend support line	No translation in y-direction

Table 3.16 Boundary conditions for load case c) connected to Figure 3.71.

Counter placement	Boundary condition
1. Hinge end line	Pinned – No translation allowed in x-, y- and z-direction
2. Mid support point	No translation in y-direction
3. Bend support point	No translation in y-direction
4. Edge support line	No translation in y-direction

3.5.7 Simulation results of K4

The simulation results from the most occurring load case b) is shown in Figure 3.72 and Figure 3.73, giving a total deflection of 4mm at the load point and maximum von Mises stress of 249MPa. These values did also agree with the case with a complete small global mesh of 4mm all over the plate for load case b). Further decrease in mesh size would therefore not have an effect on the result. Aluminum 5754 H114 had a yield strength of 190MPa and ultimate tensile strength of 240-270MPa [31]. At the center load point area the material was yielding and was also close to failure stresses. The five bar pattern, shown in Figure 3.50, was not included, which could contribute to the strength during use. Appendix E show the behavior of load case a) and c).

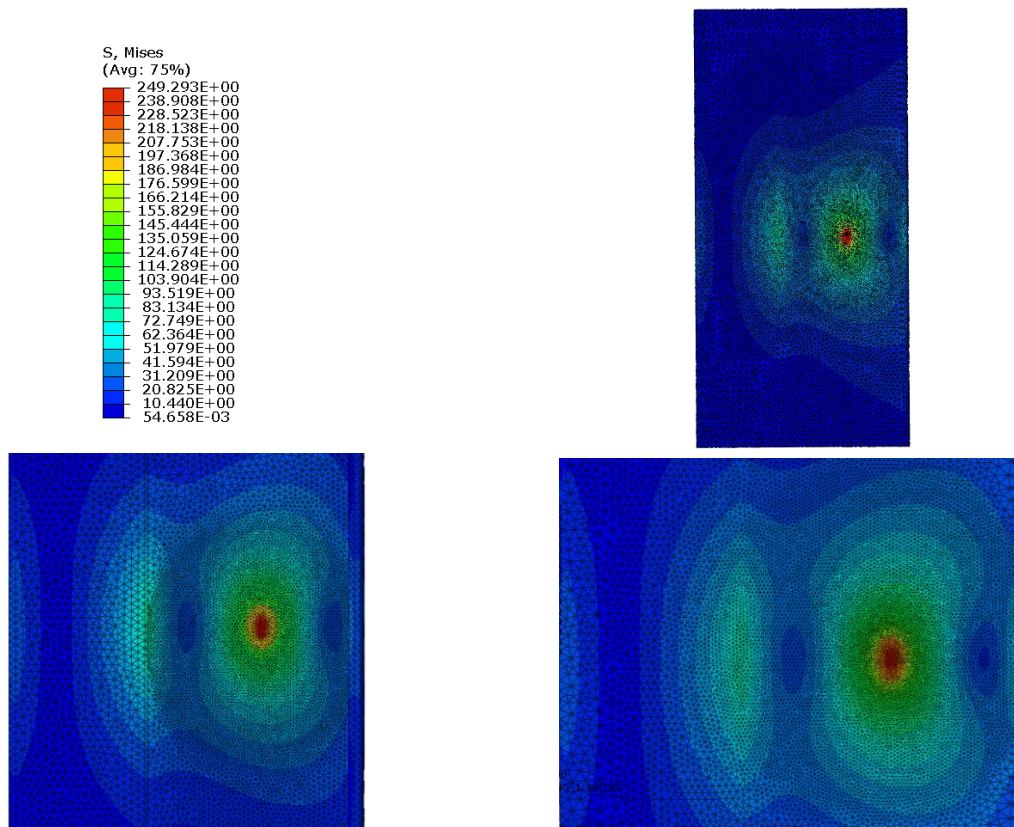


Figure 3.72 Von Mises stresses. Upper left – stress scale, upper right – whole plate top side, lower left – interesting area under side, and lower right – interesting area at top side.

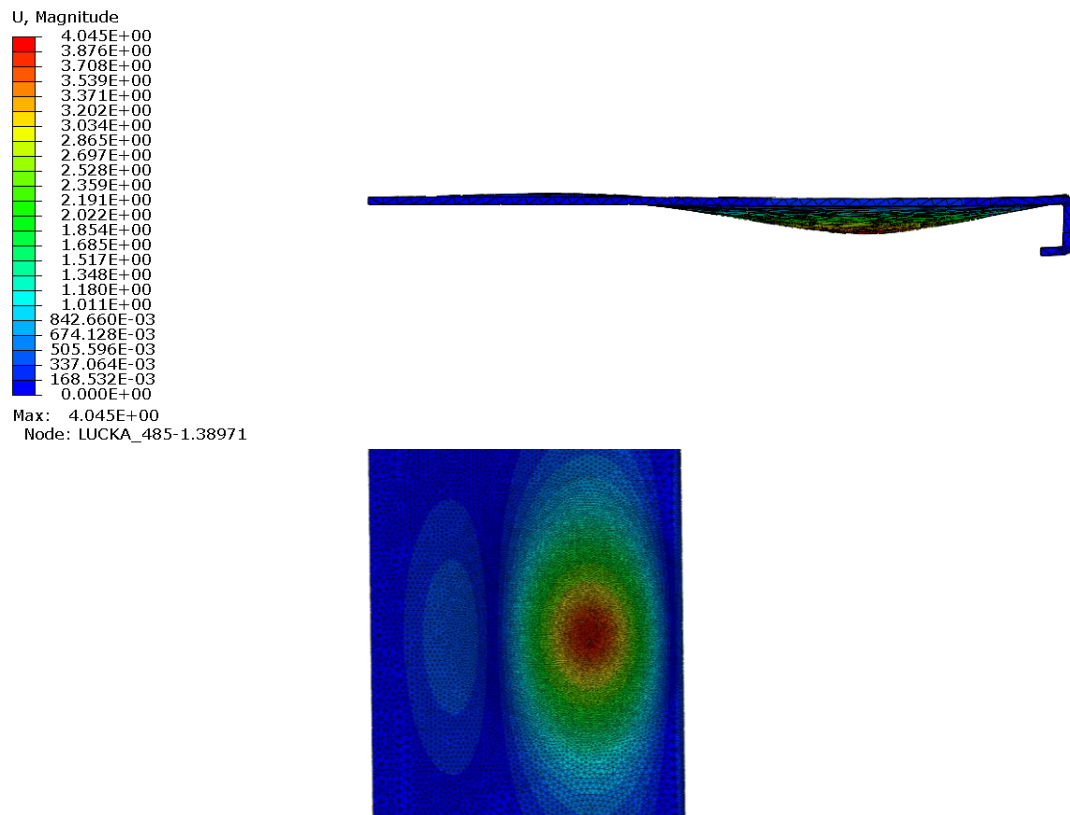


Figure 3.73 Deflections. Upper left – deflection scale, upper right – magnified deflection from side, lower – deflection from top side view.

3.5.8 Final results for K4

Without the middle support the weight of K4 made of 5mm aluminum was calculated to approximate 7,2 kg excluding the five bar pattern shown in Figure 3.50, using the density of 2.66kg/dm^3 for aluminum 5457 H14 from [31]. Finally, the weight would end at approximate 8-9kg, including the five bar pattern and the middle support. The 425mm counter weight, without the middle support, was calculated to 6.4kg. Figure 3.49 show the analyzed counter plate with 5mm thickness, without the middle support.

4 Discussion

Here the author gives his own point of view by analyzing the project performance and the systematic process itself. Step for step the five phases are discussed and eventual advantages, drawbacks and learning outcomes are given, important to have in mind if a similar development process would be done in the future.

4.1 Pre-study phase

Using the problem degradation approach shown in Figure 3.4, the problem could easily be divided into separate parts and possible attack points were exposed. This were important in respect of time and money, due to limiting the work into suitable degree. An example of too expensive changes was to lengthening the LE-cab, which also would reduce the cabs application areas. As stated, lengthening the LE-cab was not an alternative.

Another thing affected by the specified project time frame was the state of art. This phase could maybe be done better by visiting the Scania factory to broaden the cab handling process in a deeper and more concentrated sense. By looking at videos information could be obtained from Scania competitors, which was useful, but should been combined with a visit at Scania.

The final stage of the pre-study presented a requirement specification creating a foundation of the decision matrices in the upcoming concept phase. It was therefore important to investigate this deeply before the work was proceeded. By involving the job initiators, discussing the customer demands and wishes with its ratings, misunderstandings could diminished, and wrong decisions during use of the upcoming decision matrices avoided. One should have in mind that the requirement specification is a living document, therefore changes, which also occurred, could be reality.

The goal using a QFD was to connect the customer demands, given in the requirement specification, into functional means, such as layout, lengthening mechanism, material etc. This were done several times to understand the procedure and to get a reasonable result. In [52], ordinary QFD was said to be time consuming, ineffective and difficult to apply on complex systems, instead suggested usage of EQFD, extended quality functional deployment. This simplified QFD method was not tested during this development process, but would maybe give the same result as the one used and saving time. The result obtained from the QFD was seen rather obvious and had therefore limited effect on the project.

4.2 Concept generation phase

The function structure, given in Figure 3.10, was of major importance to attack the problem divided into smaller parts, giving good overview of the total problem and what to focus on. This was probably successful by combining the method and getting information from several sources [1,3,9]. This stage was followed by a concept generation from external sources, which only used [3] as a source, causing to too less information how this phase would be structured up. Much time was therefore spent alternating between searching between patent databases, benchmarking, etc. without any instruction how to do it in an effective way. If more sources were used, a more effective behavior and structure could probably be applied, maybe resulting in saved time. One thing learnt was to set a time limit for how long this unstructured work would propagate and when the work would proceed to the next phase.

According to time, the group generation did come a bit late during the concept phase. This was due to the master thesis students involved were located in another city than the work was sited. If this meeting would be taken into consideration during the planning phase in a greater extent, this mismatch between the concept phase and the group meeting could be avoided. Late changes of the requirement specification did also occur after the group meeting, which probably caused less concepts and ideas. Even if the group generation session was in some way miscalculated due to the planning and late changes, this activity gave new ideas and discussions important for the project to expand its views and deviate from the single man work.

It was uncertain if the morphological matrix really gave any advantage during this development process. Its intention was to combine the solutions from each sub function into a whole total concept, which was not done, due to assumptions of independent sub functions. But, even if this would take a lot of time, new solutions could have been obtained by doing this, not limiting sub function 2 to the tripod head and sub function 3 at the tripod tail. The morphological table, Table 3.2, did fulfill one purpose, giving an overview of proceeded concepts after the first elimination and first comparison.

Due to the work was done by one person the continuously meetings with the job initiators were of certain importance, both to be able to reflect thoughts and to get inspiration of what was possible or not. An example of this was concept 20a, which proceeded long way through the process, but was eliminated after discussions that revealed too complicated mounting at cab.

As told, the weight factors in the requirement specification can be a bit wrong, therefore there was important to discuss the outcome from these procedure and together choose the most suitable ones. The influence from the job initiators should be handled with some criticism. Discussions could limit the ability to think outside the box and generate revolutionizing ideas. The idea of from a job initiator should not be considered as a rule!

4.3 Embodiment phase

During the project it was known that it was a similar construction developed, which in some extent would fulfill the same function. This construction was not investigated before or during the concept generation phase, due to avoid bad inspiration and lock the thoughts to it, allowing better concepts to be generated. Even if the already developed construction shown in Figure 3.33, was chosen, the concept generation phase have proven that K100 was an effective solution. Extra time have been spent on developing unused concepts, but these can be used as inspiration in upcoming work where K100 not would be suitable.

When the safety factors were settled, a lot of research were done, obtaining values for different kinds of lifting equipment. This could involve wire and chains for example, which not were very similar to K100, but their safety factor of 4-5 seemed reasonable and acceptable by the job initiator. It was also confirmed by [26], showing that there was evidence for this assumption. Probably, the safety factor have good marginal, due to K100 consist of few and solid parts compared to chains and wires containing several part that can failure. The safety factor of K4 was settled to one, due to eventual failure would not risk any human injure in the same degree as for K100 failure.

During the function carrier comparison, the criteria used were found in [4], shown in Table 3.12. It can be discussed if these were relevant or if the demands and wishes from the requirement specification would be more suitable. What the outcome would be using these

instead is unknown, but the used criteria seems to be more suitable for products that will be developed and distributed on a market, which not was the case in this project and K4.

4.4 Material selection phase

The main thing to discuss is the best ranked materials for K100. These contained aluminum alloys with rather weak heat treatments compared to the ones obtained for K4, even if the strength of K100 was of greater importance. What this depend on was uncertain, but may been affected by the introduction of shape factor for K100. Probably the alloys with weaker heat treatment have higher ability to be formed in an effective shape and were therefore ranked higher in the material maps. Introducing buckling could have contributed to this strange result too. Maybe by using moment as only constraint would been enough.

None of the materials investigated would, with rather high certainty be used during manufacturing, due ordering a specific material for this purpose only would not be motivated. But, the material selection phase did prove that Aluminum was the best material family and also, in the case of K4, the best suitable aluminum series, i.e. 5000, 6000 and 8000-series. Information about possible manufacturing materials were obtained later on, during the optimization phase.

4.5 Optimization phase

The whole optimization phase was concerned by a limited time frame and too little knowledge. Initially when trying to use different kinds of interactions, especially during the K4 simulation, days were spent on just investigations of why the calculations didn't run through. The decision was therefore made to simplify the models, only using boundary conditions to obtain a result at all. Finally, there is impossible to say if these simplified results show a more realistic behavior or not than using interactions. Sure were that it went much quicker and the results seemed reasonable. Otherwise these would not be presented in the report.

K100 was simplified by using one single metal piece consisting of aluminum, as mentioned in the result, which caused shorter calculation times and eased the load applications. Drawbacks with this procedure could be that hitch connection plate adds some material thickness and therefore also add some total stiffness. But, the total deflection of approximate 3mm, shown in Figure 3.66, would probably not increase to critical values above 5mm.

Using one piece do also create stress concentrations due to the 90° edge caused between the hitch and the mounting plate. These would not occur in an equal way in reality. Similarly high stresses occurred at the mounting hole and may depend on the boundary condition. To get a more real case, using bolt loads would probably be a more effective way and give a more realistic stress around the holes.

For K4, using only boundary conditions some insight was needed to understand the deflection behavior. This was the reason different BC's were applied depending on load case. During the simulations the middle support was not covering the total length of the counter plate, but it was covering the whole length in Figure 3.51 and Figure 3.52. The reason to this inconsistency was how the gas cylinder would be applied, if this mid support would block a well functional cylinder behavior or not. But, applying the mid support would add stiffness to the plate, and the values obtained in Figure 3.73, could be interpret as the worst case.

The stresses for K4 were close to failure. The total load of rack and CC together, can be a bit overestimated, which would lowering the risk for failure. This weight can alternate depending on the type of equipment the CC contains too.

4.6 The overall process

The project time dependence can be discussed forever. There are always possible to do things more accurate and investigate these deeper. The project need to deliver a useful result and process, which forced the work in some extent to be shallow and using simplifications during some stages. Using boundary conditions instead for learning about interactions can be given as an example. Infinite of time could also be spent to optimize K100 during more steps. The product developer, did therefore often consider if further investigation was necessary or if the work would proceed to upcoming phases to give the project more value.

One thing to learn during upcoming systematic development processes would be to make a deeper investigation during an early stage. This would enable a more modern approach, maybe by a greater extent include the LPD or GPD approaches, compared to [4], which had its drawbacks, for example the QFD.

The systematic development process do probably seem straight forward, but this was not the reality. Several iterations back to earlier stages occurred, for example when the requirement specification were redone or when new information was obtained. Instead for waiting for information from, for example tilt manufacturer, the work proceeded to be time effective.

5 Conclusions

The systematic development process have been deeply described and performed to demonstrate the procedure, leading to a useful result according to the goals settled. A reflection regarding these goals, stated in section 2.1.1, are:

- By applying a longer rail plate and cover this foundation with K4, the length difference problem was solved. The developed K100 adjust, in a simple manner, the height difference between LE and CC.
- No big changes were needed since the tilt function was not affected by the solution. Nevertheless, some work will need to be done to implement this longer rail plate and make a longer foundation. K100 does not affect the current construction.
- The necessary changeover time between LE to CC and vice versa, will be sustained similar to the existing tilt layout. Movement of the tail tripod will occur in the same manner and K100 can be mounted at the LE cab before moving it into the tilt. Turning up and down K4 into the right position will be the only difference, which would need a small additional time compared to the original tilt.

6 Future work

Upcoming work needed to prepare for a final installation are following:

- The necessary length extension of the rail plate need to be settled, depending on the length difference between LE and CC28.
- Final small adjustments, making K100, even more suitable for the application and manufacturing process.
- Hinge-counter connection, for K4, need to be adjusted to some extent allowing approximate 90° opening. This could cause a smaller counter width, approximate with some millimeters.
- Shims may be needed between the mid support and the bend support against the rail plate, compensating for the floor that not is entirely flat.
- How the cylinder will be mounted is not exactly established, more than the broad set up in Figure 3.51.
- A handle should be applied to make the opening easier for the staff.
- Calculate necessary gas cylinder dimension.

7 Acknowledgments

Big thanks to Laxå Special Vehicles, for giving me the opportunity to make my master thesis project in Laxå, offering me workplace, a reasonable project and the necessary help. Thanks to Stefan Karlsson, the man on the opposite, for company and for giving me real engineering knowledge and inspiration during these months.

Thanks to Karlstad University and its teachers for these years, Leo de Vin, for the necessary feedback during this thesis work, and Jens Bergstöm, for interesting material courses and good guidance during the past two years.

Lastly, the greatest thanks to my grandmother and grandfather for letting me staying at their place, giving me accommodation and love during these months, catching up a lot of time from earlier years.

8 References

- [1] Johannesson H, Persson J-G, Pettersson D. Produktutveckling : effektiva metoder för konstruktion och design. 2nd ed. Stockholm: Liber; 2013.
- [2] Griffin A. PDMA research on new product development practices: Updating trends and benchmarking best practices. J Prod Innov Manag 1997;14:429–58. doi:10.1016/S0737-6782(97)00061-1.
- [3] Ulrich KT, Eppinger SD. Produktutveckling : konstruktion och design. Lund: Studentlitteratur; 2014.
- [4] Pahl G, Beitz W, Wallace K. Engineering design : a systematic approach. 2nd ed. Berlin: Springer; 1996.
- [5] Johansson G, Sundin E. Lean and green product development: two sides of the same coin? J Clean Prod 2014;85:104–21. doi:10.1016/j.jclepro.2014.04.005.
- [6] Tortorella GL, Marodin GA, Fettermann D de C, Fogliatto FS. Relationships between lean product development enablers and problems. Int J Prod Res 2016;54:2837–55. doi:10.1080/00207543.2015.1106020.
- [7] Yassine A, Braha D. Complex Concurrent Engineering and the Design Structure Matrix Method. Concurr Eng 2003;11:165–76. doi:10.1177/106329303034503.
- [8] Scania. Scania. Crew Cab - Nya Gener Scania 2017. <https://www.scania.com/se/sv/home/products-and-services/trucks/our-range/crewcab.html> (accessed May 20, 2018).
- [9] Liedholm U. Systematisk Konzeptutveckling 1999.
- [10] Cederlöf M. Retractable Boarding step for Scania Crew Cab. Södertälje: Karlstads Universitet; 2017.
- [11] Suh NP. The principles of design. New York: Oxford University Press; 1990.
- [12] Odhe J-E. Visual management 2016.
- [13] Ashby MF. Materials selection in mechanical design. 4th ed. Kidlington, Oxford, UK: Butterworth-Heinemann; 2011.
- [14] Scott. Safe Working Load Limits – What You Need To Know. Ind Wire Rope Supply Co Inc 2015. <https://industrialrope.com/safe-working-load-limits-what-you-need-to-know/> (accessed March 20, 2018).
- [15] What is safe working load (SWL)? Definition and meaning. BusinessDictionaryCom n.d. <http://www.businessdictionary.com/definition/safe-working-load-SWL.html> (accessed March 26, 2018).
- [16] Do you know the difference between SWL / WLL / MRC and when they should be used? Asset Manag Eng 2016. <https://asseteng.com.au/do-you-know-the-difference-between-swll-wll-mrc-and-when-they-should-be-used/> (accessed March 26, 2018).

- [17] Scania. Scania. -Serien - Nästa Gener Scania 2017.
<https://www.scania.com/se/sv/home/products-and-services/trucks/our-range/l-series.html>
(accessed May 28, 2018).
- [18] Scania Group. Scania Group - The cab factory of the future. 2016.
- [19] Brohmee J. Tilt unit for NGS. vol. 2017. Oskarshamn: n.d.
- [20] Bil TV. Man trucks assembly line. 2015.
- [21] DCP Cars. Mercedes Actros Production factory plant. 2016.
- [22] Svensk Standard SS-EN 349+A1:2008 2009.
- [23] Svensk standard SS-EN ISO 12100:2010 2011.
- [24] Sundström J, Bjärnemo R, Andersson P-E. Konstruktiv utformning, Del 1: Syntes. Lund: Lunds Universitet; 2000.
- [25] Aratron AB. Gasfjädershop. Beräkna Och Des Din Egen Gasfjäderapplikation Nu 2018.
<https://www.gasfjadershop.se/gasfjaderberakning/> (accessed May 1, 2018).
- [26] Arbetsmiljöverket. Maskiner - Arbetsmiljöverkets föreskrifter om maskiner samt allmänna råd om tillämpningen av föreskrifterna 2008.
- [27] Carlenskogs Byggvaruhus. Europrofil KANTJÄRN KJ50-4,0 50X3000MM.
Carlenskogs-Woody n.d. <https://carlenskogs.woody.se/europrofil-kantjarn-kj50-40-50x3000mm> (accessed May 11, 2018).
- [28] Specialbeslag. SVETSGÅNGJÄRN 120 MM. Specialbeslag n.d.
<https://www.specialbeslag.se/gangjarn/svetsgangjarn> (accessed May 14, 2018).
- [29] Alumeco Sverige AB. Durkplåt - EN AW-5754. Produkter Och Lösningar Inom Alum Och Rödmetaller n.d. <https://www.alumeco.se/aluminium/durkplaat/en-aw-5754/-x-2000--1000-mm/p/692/19723> (accessed May 14, 2018).
- [30] Lundh H. Grundläggande hållfasthetslära. Lund: Studentlitteratur; 2016.
- [31] Granta design Limited. CES Eduack 2017. Granta Design Limited; n.d.
- [32] AZO materials. Aluminium / Aluminum 5086 Alloy (UNS A95086). AZO Mater 2010.
<https://www.azom.com/article.aspx?ArticleID=6631> (accessed March 20, 2018).
- [33] MakeItFrom. 5086-H38 Aluminum. MakeItFrom 2018.
<https://www.makeitfrom.com/material-properties/5086-H38-Aluminum> (accessed March 20, 2018).
- [34] MatWeb. Aluminum 5086-H38. MatWeb Mater Prop Data 1996.
<http://www.matweb.com/search/DataSheet.aspx?MatGUID=90f530286ceb47a1b8d17b9323468765&ckck=1>.
- [35] AZO materials. Aluminum 5182 Alloy (UNS A95182). AZO Mater 2013_05-03.
<https://www.azom.com/article.aspx?ArticleID=8652> (accessed March 20, 2018).

- [36] MakeItFrom. 5182-H19 Aluminum. MakeItFrom 2018.
<https://www.makeitfrom.com/material-properties/5182-H19-Aluminum> (accessed March 20, 2018).
- [37] MatWeb. Aluminum 5182-H19. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/datasheet.aspx?matguid=9ef482b0015a483194bc3d53e2bf52> (accessed March 20, 2018).
- [38] AZO materials. Aluminium/Aluminum 6463 Alloy (UNS A96463) 2012.
<https://www.azom.com/article.aspx?ArticleID=6649> (accessed March 20, 2018).
- [39] MatWeb. Aluminum 6463-T6. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/datasheet.aspx?matguid=aa6090d830d2499f96fc2b2a094c06ac> (accessed March 20, 2018).
- [40] AZO materials. Aluminum 8090 Alloy (UNS A98090). AZO Mater 2013.
<https://www.azom.com/article.aspx?ArticleID=8789> (accessed March 20, 2018).
- [41] MakeItFrom. 8090 (AlLi2.5Cu1.5Mg1) Aluminum. MakeItFrom 2018.
<https://www.makeitfrom.com/material-properties/8090-AlLi2.5Cu1.5Mg1-Aluminum> (accessed March 20, 2018).
- [42] MatWeb. Aluminum 8090-T8151. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/datasheet.aspx?matguid=5cffe6f6f1f8445581572ea5f82a263e&ckck=1> (accessed March 20, 2018).
- [43] MatWeb. Aluminum 6463-T4. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/DataSheet.aspx?MatGUID=2f9c730a25cf4d9bb6a4f5169168cc27&ckck=1> (accessed April 10, 2018).
- [44] Leitel Brothers, inc. A/356 Aluminum Sand Castings. Leitel Brothers Inc Casr Brass Bronze Alum n.d. <http://www.lbfoundry.com/356-aluminum-sand-casting.html> (accessed April 10, 2018).
- [45] MakeItFrom. 5154-O Aluminum. MakeItFrom 2018.
<https://www.makeitfrom.com/material-properties/5154-O-Aluminum> (accessed April 10, 2018).
- [46] MatWeb. Aluminum 5154-O. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/datasheet.aspx?matguid=4232f533344d4cd0bd96eb07ae0bca02> (accessed April 10, 2018).
- [47] AZO materials. Aluminium / Aluminum 5454 Alloy (UNS A95454). AZO Mater 2012.
<https://www.azom.com/article.aspx?ArticleID=6655> (accessed April 10, 2018).
- [48] MatWeb. Aluminum 5454-H112. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/datasheet.aspx?matguid=865b278a047447699023b1ca7385600e> (accessed April 10, 2018).
- [49] AZO materials. Aluminium Alloys - Aluminium 5083 Properties, Fabrication and Applications, Supplier Data by Aalco 2005.
<https://www.azom.com/article.aspx?ArticleID=2804> (accessed April 10, 2018).

- [50] MatWeb. Aluminum 5083-H112. MatWeb Mater Prop Data n.d.
<http://www.matweb.com/search/datasheet.aspx?matguid=bd6317b19dd94faf8bff851e4f339e88> (accessed April 10, 2018).
- [51] Alumeco. Temper descriptions. Alumeco Be NO1 n.d.
<https://www.alumeco.com/knowledge-technique/aluminium-data/temper-descriptions> (accessed May 29, 2018).
- [52] Weiss MP, Hari A. Extension of the Pahl & Beitz Systematic Method for Conceptual Design of a New Product. *Procedia CIRP* 2015;36:254–60.
doi:10.1016/j.procir.2015.03.010.
- [53] Nordic fastening group AB. Hållfasthet(brottkraft och sträckkraft) för metriska grovgångor n.d. <http://nfgab.se/sv/teknik-kvalitet/tekniska-sidor/hallfasthet/metriska-grovgangor/> (accessed February 27, 2018).
- [54] Alfredsson B. Handbok och formelsamling i hållfasthetslära. Stockholm: Institutionen för hållfasthetslära, Kungl. tekniska högskolan; 2014.

Appendices

Appendix A – Pre-study

Appendix B – Concept generation

Appendix C – Embodiment design

Appendix D – Material selection

Appendix E – Simulations

Appendix A – Pre-study

The QFD obtained is shown Table A1, representing greatest dependence on the lengthening and height mechanism, while the layout did also have great importance. The concurrent comparison and the correlation triangle described in the method section were not performed.

Table A1 QFD diagram.

Functional requirements			Material	Manufacturing method	Lengthening mechanism	Height mechanism	Layout	Amount of components	Strength	Stiffness	Dock mechanism
Criteria number	Criteria statement	Weight									
31.	Cab docking at front and back	5			9	9	9		3		9
32.	fulfil standard SS-EN ISO 12100:2010	5	1		9	9	9		3		
33.	fulfil standard EN 349+A1:2008	5	1		9	9	9		3		
34.	Retain the automatic stop function by sensor	5			3	3	3				9
35.	Easy accessed cab-interior and -underbody	4			9	9	9				9
36.	Possible to fix other cabs than LE and CC	2			9	9	9				3
37.	Simple maintenance	2			3	3		9			
38.	Similar style as current	1	3	9	1	1	3	1			3
39.	Environmental friendly material	1	9	3							
40.	Avoid sharp edges	3	1	9							
41.	Minimize development cost	2	3	3	3	3	3	3			1
42.	Single part manufacturing possible	5		9							
43.	No unfriendly materials during manufacturing	5	9								
44.	Low weight on parts	1	3					9			
45.	Minimize manufacture cost	1	3	9							
46.	Possible to rotate both LE and CC	5			9	9					3
47.	Allow the two lengths of CC	5			9						
48.	Life length of a cab generation	5	3						9		
49.	Allow 360 degrees rotation of a normal roof cab	5			3	3					9
50.	Not deform plastically	5	3				3		9		
51.	Hold the cab tight	5			3	3					9
52.	No cab damage	5			9	9	9				3
53.	Short exchange time (Same cab type)	4					3				9
54.	Minimum maintenance	4									
55.	Limit deflection	3							3	9	
56.	Exchange time short (different cab type)	2			9	9					
57.	Ergonomic change between cabs	3									9
58.	Easy to understand	2			9	9	3				9
59.	Minimize amount of wearing parts	1			3	3		3			3
60.	Recyclable material	1	9								
Target value			Unharmful	Single manufacturing	Allow length of 3100, 2800 and 2000 (mm)	Height difference from 0 to 375 (mm)	Simple and understandable		Sustain static and rotation forces	As high as possible	
Weighted rating			121	99	421	376	337	37	144	9	341

Appendix B - Concept generation

B.1 Classification trees

B.1.1 Sub function 1 – Mounting connection

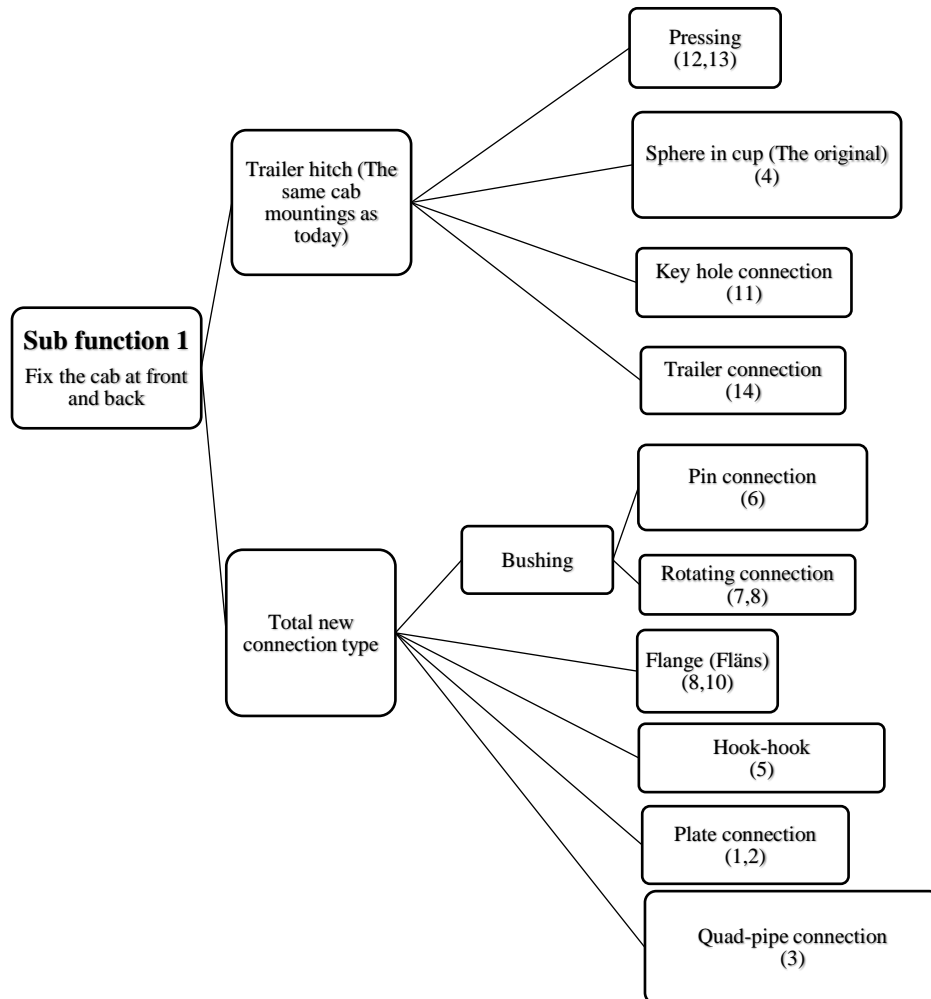


Figure B1 Classification tree for sub function 1 – Mounting connection

B.1.2 Sub function 2 – Length mechanism

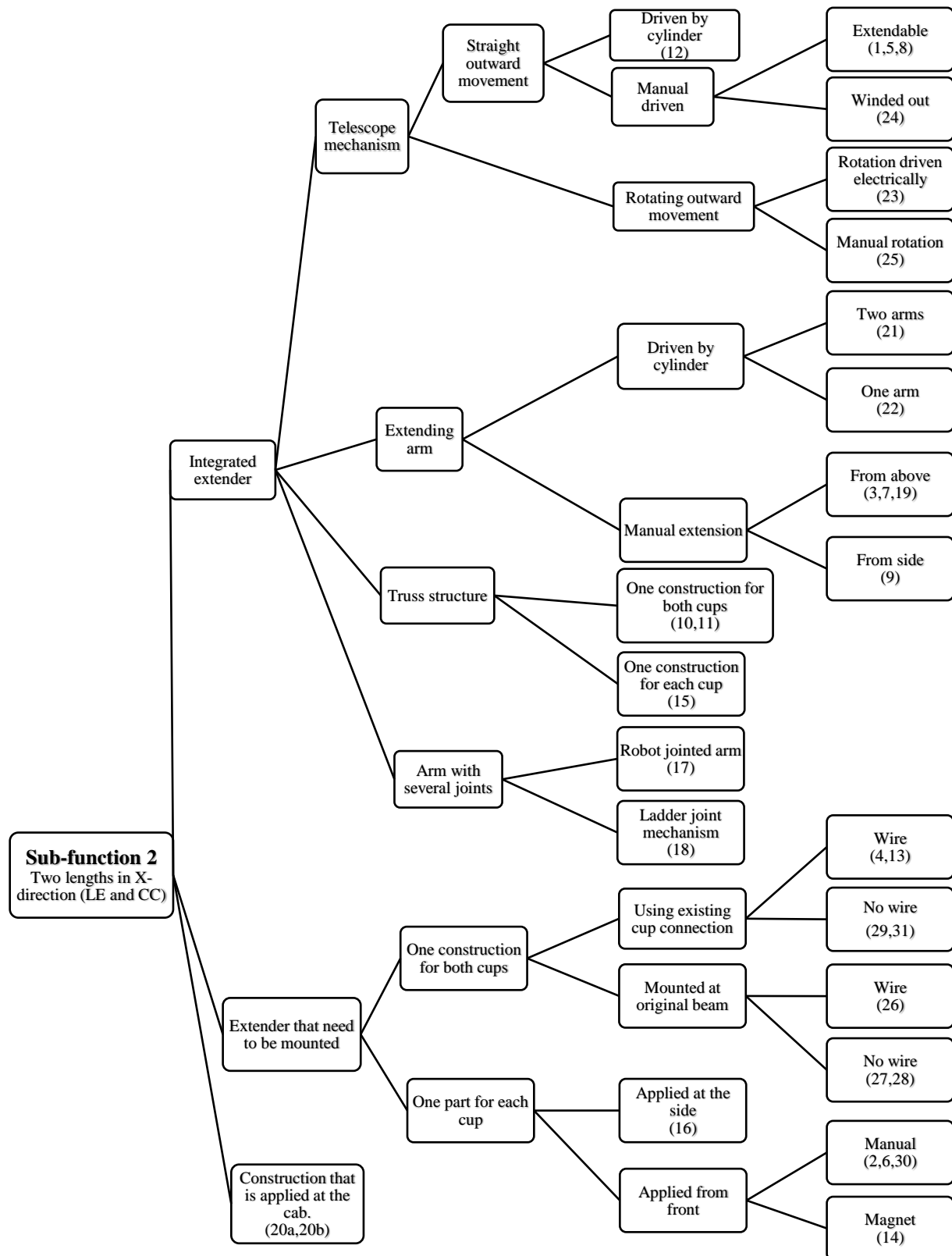


Figure B2 Classification tree for sub function 2 - Lengthening mechanism

B.1.3 Sub function 3 – Height mechanism

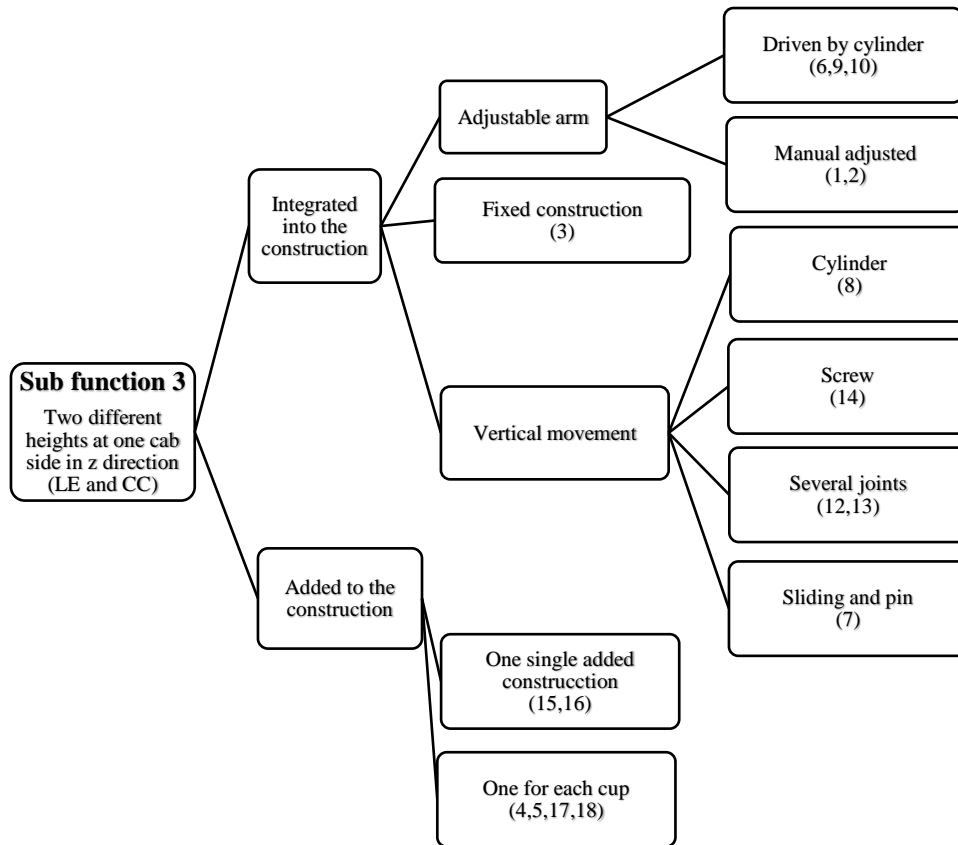


Figure B3 Classification tree for sub function 3 – Height mechanism

B.1.4 Sub function 8

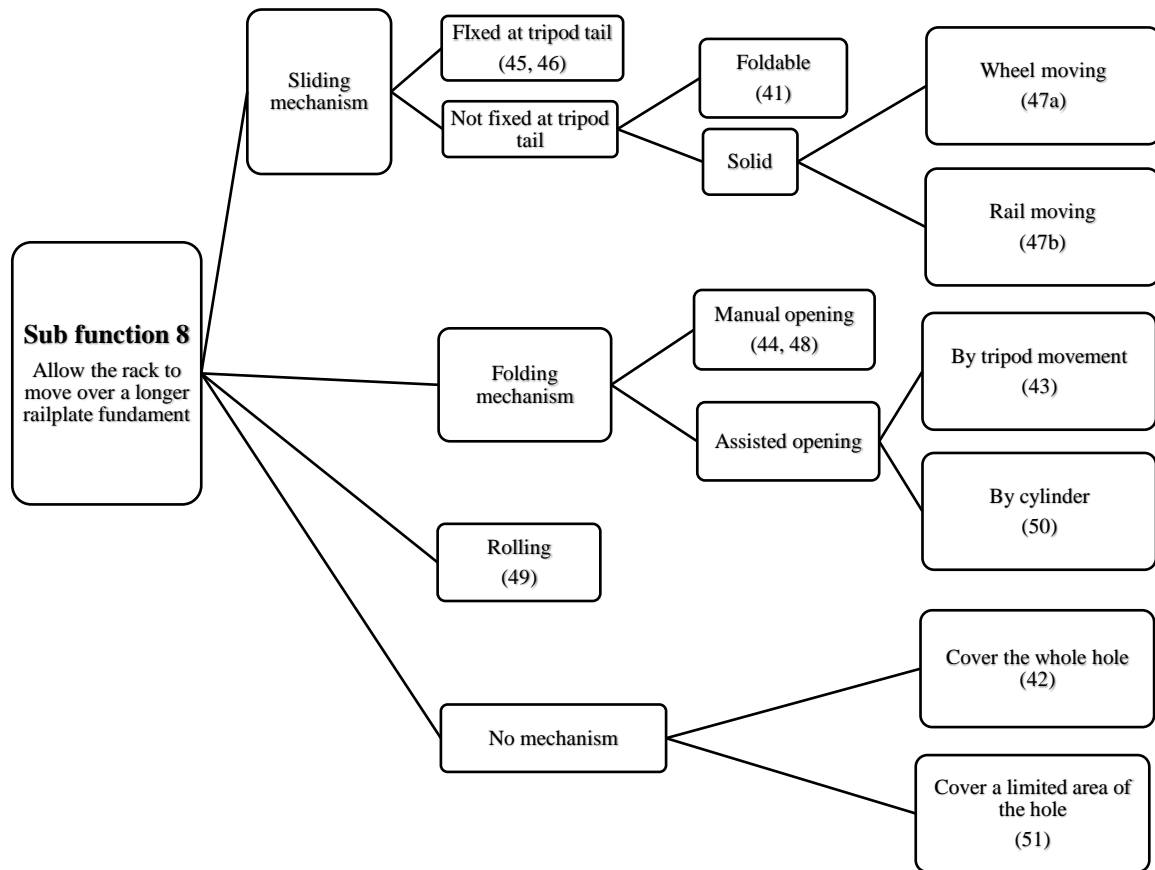


Figure B4 Classification tree for sub function 8

B.2 Systematic investigation – First eliminations

Criteria and decision description:

Table B1 Description of criteria and decisions.

Criteria	5 points = Do fulfil	1 points = Do not fulfil	>150 Proceed to total solution
Decisions	>150 Proceed to total solution	50<X<150 Proceed to total solution with drawbacks	<50 Eliminated

B.2.1 Sub function 1 – Connection mechanism

Table B2 First elimination of sub function 1 – Connection mechanism.

Concept solution	1. Solve the main problem (Yes/no)	2. Robust	3. Ergonomic	4. No complicated	5. Easy to understand	Total points (Aspect 2,3,4,5)	Comment
1.	Yes	4	5	4	4	320	Robust but pin need to be mounted in a right way, do not allow movement in horizontal
2.	Yes	4	5	4	4	320	Robust but pin need to be mounted in a right way, do not allow movement in horizontal
3.	Yes	4	5	5	5	320	Robust but pin need to be mounted in a right way, do not allow movement in vertical
4.	Yes	4	5	5	5	500	
5.	Yes	4	5	5	5	500	
6.	Yes	3	5	3	4	180	May fail because of the secure pin
7.	Yes	2	4	3	3	72	More parts that can fail, allow some movement
8.	Yes	3	4	2	2	48	Complicated, can be hard du manufacture and install in a proper way
9.	Yes	4	5	4	4	320	No movement allowed in any way,
10.	Yes	2	5	2	3	60	The screw and its connection is complicated, installing a bit complicated
11.	Yes	4	5	4	4	320	
12.	Yes	2	5	4	4	160	Insecure. Something need to stop movement out of the "key hole"
13.	Yes	3	4	3	3	108	Moving pressure device may fail or malfunction
14.	Yes	3	4	3	3	108	Moving pressure device may fail or malfunction

B.2.2 Sub function 2 – Lengthening mechanism

Table B3 First elimination of sub function 2 – Lengthening mechanism.

Concept solution	1.Solve the main problem (Yes/no)	2.Robust	3.Ergonomic	4. No complicated	5.Easy to understand	Total points (Aspect 2,3,4,5)	Comment
1.	Yes	3	5	3	5	225	
2.	Yes	4	3	4	4	192	
3.	Yes	3	5	2	5	150	
4.	Yes	3	1	2	3	18	
5.	Yes	2	5	3	5	150	
6.	Yes	2	3	2	2	24	
7.	Yes	3	4	3	4	144	
8.	Yes	4	5	3	4	240	
9.	Yes	3	4	2	3	72	The hinge can be critical and the necessary width
10.	Yes	0	4	2	3	0	
11.	Yes	3	4	1	3	36	
12.	Yes	3	5	0	5	0	Hydraulic cylinder not possible
13.	Yes	4	2	2	3	48	
14.	Yes	0	3	4	4	0	No robustness, because of the magnet may loosen
15.	Yes	2	4	2	3	48	Low robustness due to things that may fail. Complicated (Many components)
16.	Yes	4	3	3	4	144	No big drawbacks
17.	Yes	3	5	0	4	0	Robot arm very complicated
18.	Yes	2	4	1	4	32	Many components gives a high complicated construction
19.	Yes	4	4	3	4	192	No certain drawbacks
20.	Yes					0	
21.	Yes	4	5	0	3	0	Hydraulic cylinder not possible
22.	Yes	3	5	0	3	0	Hydraulic cylinder not possible
23.	Yes	2	4	1	4	32	Internal electric driven motor is complicated
24.	Yes	3	5	2	4	120	The mechanism may malfunction and is complicated to construct
25.	Yes	3	5	2	4	120	The rotation mechanism may be hard to manufacture in suitable size.
26.	Yes	4	2	2	3	48	Heavy, many parts (wires etc.) that need to be mounted. May fail due to wrong installation
27.	Yes	5	2	4	4	160	Heavy, do not connect in cups, easy and stable installation, simple construction
28.	Yes	5	2	4	4	160	Heavy, do connect the cups, simple installation, simple construction
29.	Yes	4	2	3	3	72	Heavy, the dock connection is critical
30.	Yes	4	3	4	4	192	Not integrated, need to be fastened correctly, simple construction
31.	Yes	4	2	4	4	128	Heavy, simple construction
32.	No					-	Not possible due to the arm extender won't fit during the CC mode. Tail in its way.
33.	No					-	No changes at the head and tail possible
34.	No					-	The solution won't fit during CC mode
35.	Yes	3	5	5	5	375	Will it give enough space when the long CC will be mounted. How to solve sensor issue?
36.	Yes	5	3	3	4	180	Need to be changed with the existing arm during each time change from LC to CC vice versa.
37.	No					-	Not possible at all.

B.2.3 Sub function 3 – Height mechanism

Table B4 First elimination of sub function 3.

Concept solution	1.Solve the main problem (Yes/no)	2.Robust	3.Ergonomic	4. No complicated	5.Easy to understand	Total points (Aspect 2,3,4,5)	Comment
1.	Yes	3	4	3	4	144	
2.	Yes	3	4	3	4	144	
3.	Yes	5	5	5	5	625	Fix and stable
3b	Yes	5	5	5	5	625	
4.	Yes	2	3	1	3	18	Insecure fastening mechanism
5.	Yes	5	3	3	4	180	Installation simple but needs to be done correctly each time.
6.	Yes			0		0	Hydraulic cylinder impossible
7.	Yes	3	5	3	4	180	Moving parts, but simple adjustment allowing, great amounts of heights by just drilling more holes into the vertical beam
8.	Yes			0		0	Cylinder impossible
9.	Yes			0		0	Cylinder 1 impossible
10.	Yes			0		0	Cylinder impossible
11.	Yes					0	
12.	Yes	1	5	1	3	15	Many moving part that can fail. Unstable
13.	Yes	2	5	2	3	60	More robust than 12, but still as many components
14.	Yes	3	5	2	3	90	Screws may fail, but is more stable than 13
15.	Yes	4	2	4	4	128	Need to be installed, fixed levels. May not be suitable for further mounting heights
16.	Yes	4	4	3	4	192	May be heavy to adjust but easier than mounting 16. Can be suitable for more heights
17.	Yes	4	4	4	4	256	Similar to 15 but more ergonomic due to individual mountings.
18.	Yes	3	3	2	3	54	Complicated and installation completely necessary between cabs
19.	Yes	2	4	2	2	32	Complicated and many things that seems to go wrong due mounting
20.	Yes	4	5	3	4	240	Similar to 3 but the cup is movable, which suitable for more heights. Sprint and moving part that may get stuck into the beam.
21.	Yes	4	5	4	4	320	Similar to 20 but the moving part is placed on the outer side of the "pipe"

B.3 Decisions made in morphological table

B.3.1 Sub function 1 – Mounting connection

- The original hitch-cup connection worked fine and was able to allow eventual movements and height difference during tilt use. To minimize the necessary construction changes and sustain the existing connection safety sensor, the decision was made to keep concept 4 for sub function 1.

B. 3.2 Sub function 2 – Lengthening mechanism

- Concept 1 and 5 contained the same mechanism, telescope, 1 proceed and 5 didn't.
- Concept 8 do looked a bit different to 1 and 5, but did not contain any certain advantages. 8 did therefore not proceed.
- Concept 9 was erased due its complexity, containing hinges and telescope function. The width was also limited by the cab width to not restrict the rotation. Concept 1 was better than concept 9 in all perspectives. Concept 9 did therefore not proceed.


- Concept 24 and 25 were erased due to the complexity of construction such as telescope mechanisms where the arm needed at least two extenders to have enough of space during CC-mode. Two extenders were too complicated using the mechanism of concept 24 and 25.
- Concept 3, 7 and 19 were arms in different configurations with one common problem; where should the arms take place during CC mode? Concept 19 seemed to be solve this in the best way. Therefore, concept 19 proceeded while 3 and 7 not.
- Concept 27, 28 and 29 were similar where 28 was evaluated as the best. 28 proceed, while 27 and 29 not proceeded.
- Concept 30 and 31 contain the same mechanism, but concept 30 was divided into two parts that made it much easier to handle during change from CC to LE cab. Concept 30 did therefore proceed and concept 31 did not.
- 16 proceeded to further investigation, because of unique solution mechanism compared to the other concepts.
- 20a was not similar to any other concept and seems to be useful and did proceed.
- Concept 35 and 36 proceeded because of individually unique solutions.


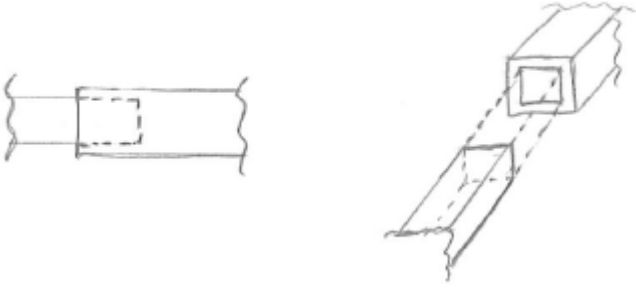
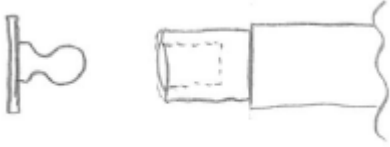


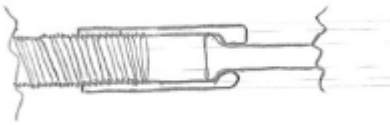
B.3.3 Sub function 3 – Height mechanism

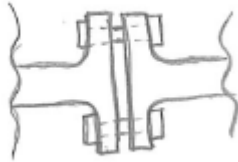
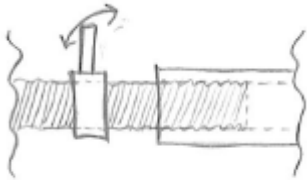
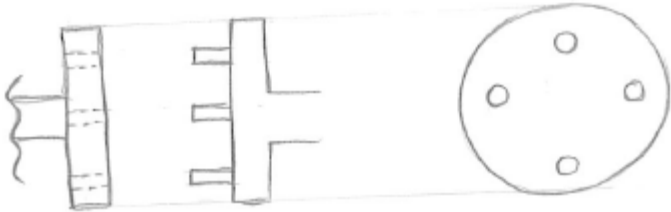
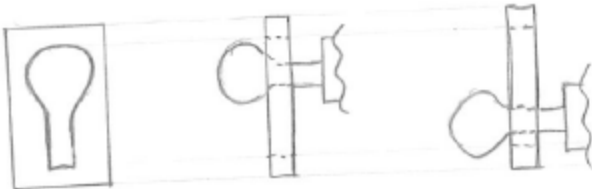

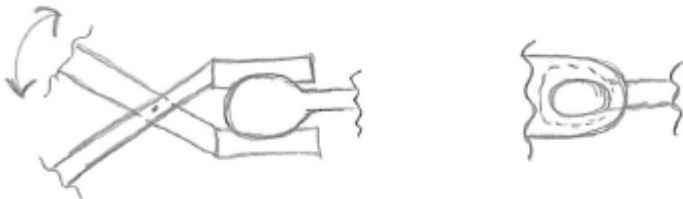
- Concept 1 was similar and had no advantages compared to concept 2 suitable in some combinations. Concept 1 did therefore not progress for further analysis.
- Concept 2, 3, 5, 15 and 17 solve the problem in an equal way. The space at the cab back did not need to be taken into consideration. Therefore, there were no advantages to have a construction like concept 2 that was turned into position or concept 15, which was mounded when necessary. Sub solution 3 was simplest possible fulfilling the expectations, and did therefore proceed. 2, 5, 15 and 17 did not proceed.
- Concept 7 and 16 was the same type of mechanism. The difference was that 7 consisted of one part that was simpler. Concept 7 did therefore proceed.
- Concept 20 and 21 were of unique character and mechanism.
- Concept 3b was developed originating from 3 but allowed easy height adjustment in vertical direction.

B.4 Generated concepts

B.4.1 Sub function 1 – Connection mechanism

Sub function 1 – Connection function	Description
	<p>Concept 1 – Left picture is shown from side. The connection is safe by using a pin.</p>

	<p>Concept 2 – Left picture is shown from above. The connection is safe by using a pin.</p>
	<p>Concept 3 – A quadratic beam is fixed into a quadratic pipe to restrict rotation and translation.</p>
	<p>Concept 4 – This is the original connection used at the current design.</p>
	<p>Concept 5 – A hook and a ring to connect to.</p>
	<p>Concept 6 – A bushing connect the pipe ends and is fixed by using pins.</p>
	<p>Concept 7 – One side is threaded where a threaded bushing can be turned on to secure the connection.</p>

	<p>Concept 8 – Flanges makes the connection using bolts.</p>
	<p>Concept 9 – The threaded beam can be rotated into a fixed bushing.</p>
	<p>Concept 10 – Similar to flanges, but one side has holes and the other has fixed bolts.</p>
	<p>Concept 11 – A key hole and a trail hitch as from the original. The hitch is put into the rounded part and moved down where it's fixed.</p>
	<p>Concept 12 – A clamp is used to connect to a trail hitch.</p>
	<p>Concept 13 – Similar to concept 12, both using clamps. But concept 13 has another type. Right image is above view.</p>

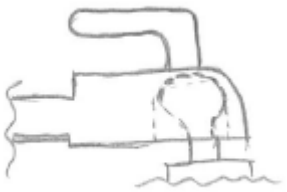
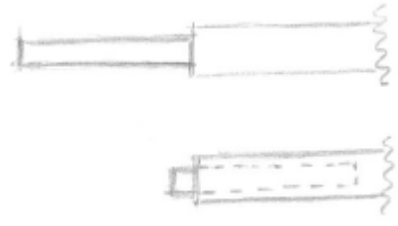
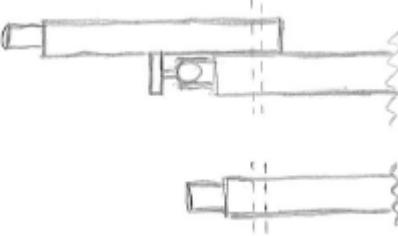
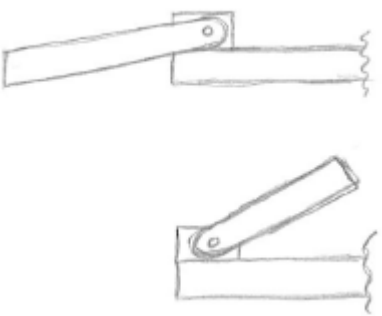
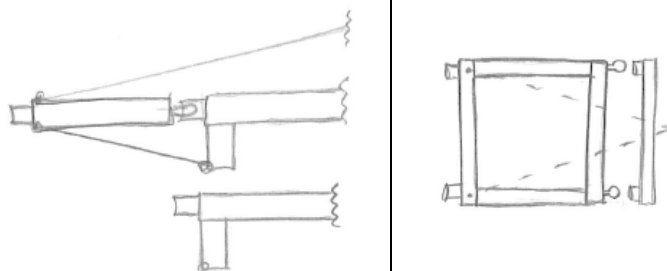
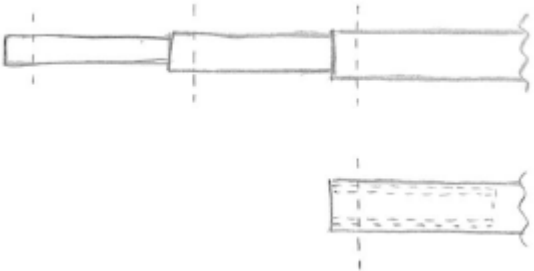
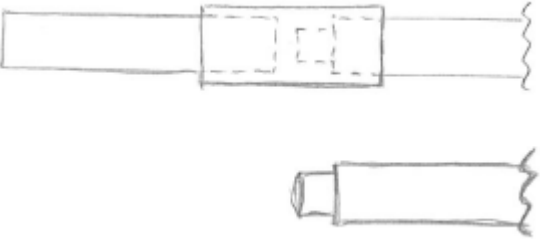
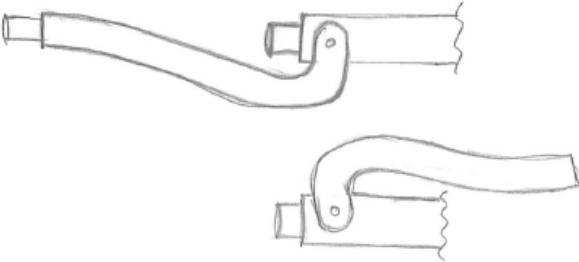
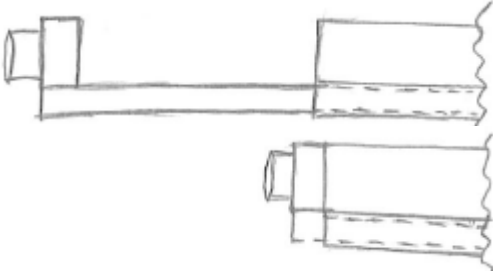
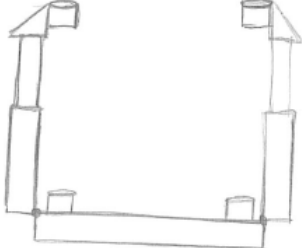
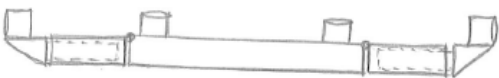
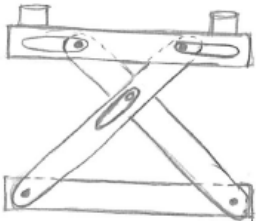

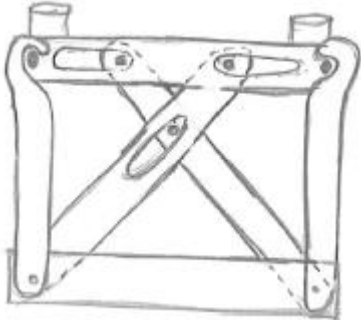
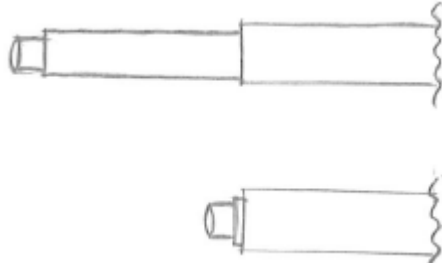
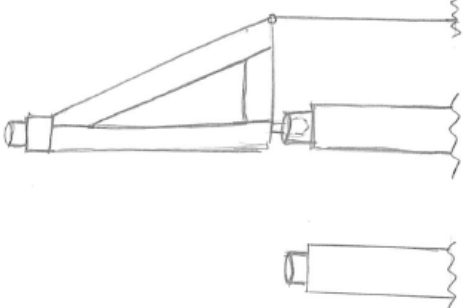
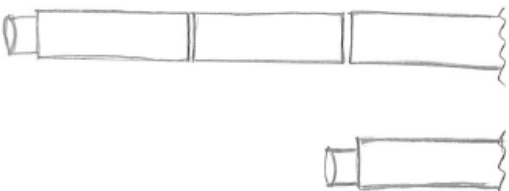

	<p>Concept 14 – A trial hitch connection similar to those found between cars and trailers.</p>
-----------------------------------------------------------------------------------	-------------------------------------------------------------------------------------------------------

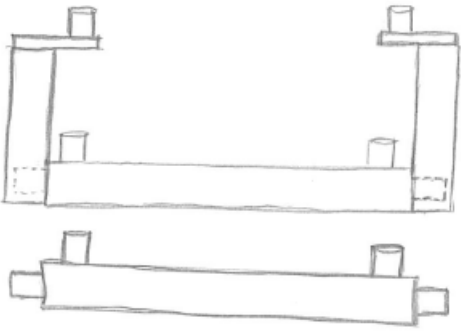
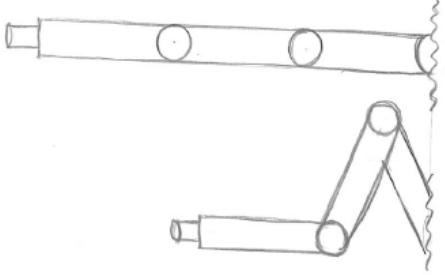
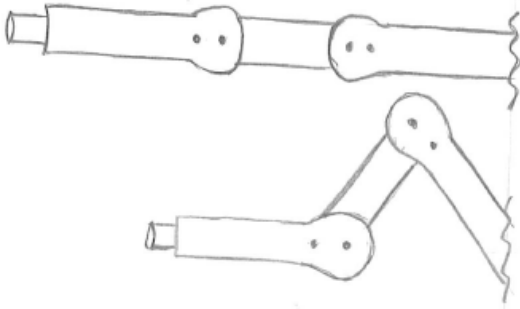
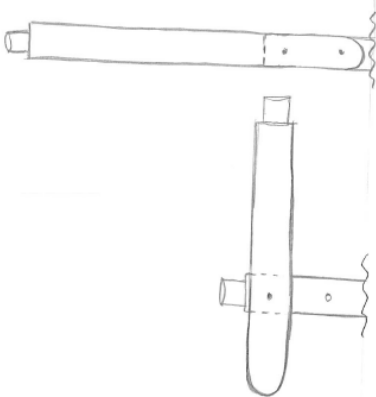

Figure B5 Proceeded concepts - Sub function 1.

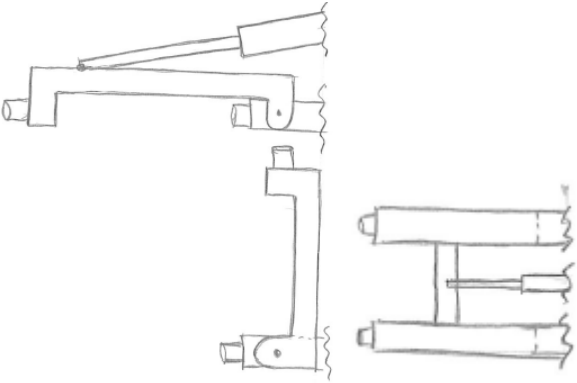
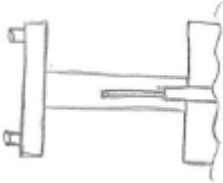
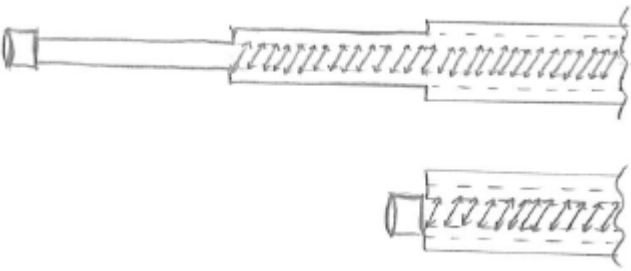
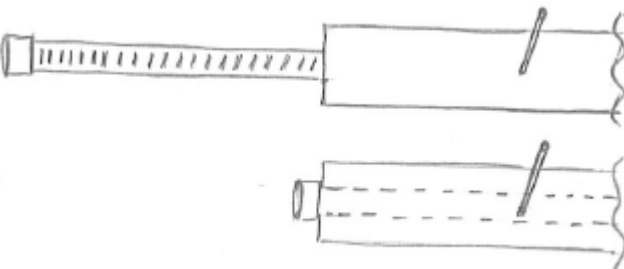
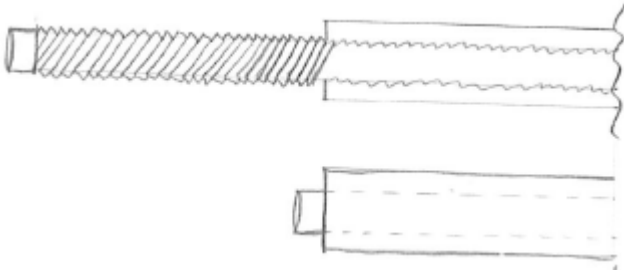
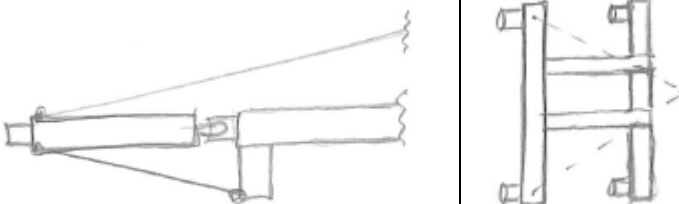
B.4.2 Sub function 2 – Lengthening mechanism

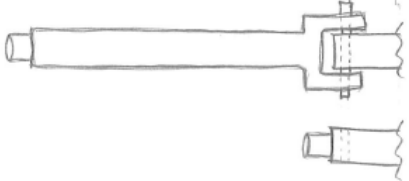
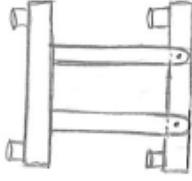
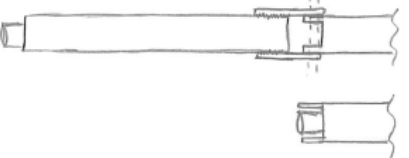
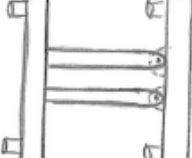
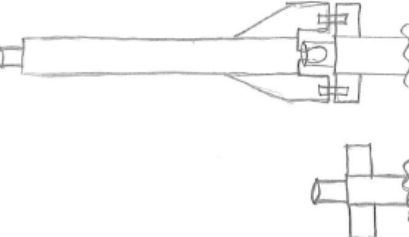
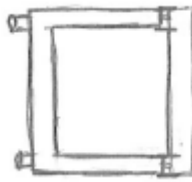
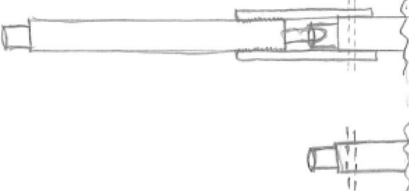
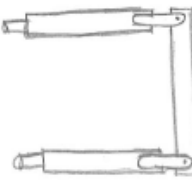
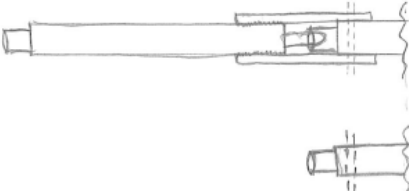
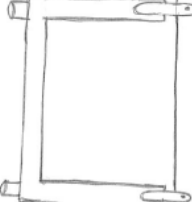
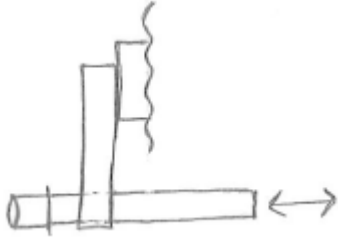
Sub function 2 – Length difference	Description
	<p>Concept 1 – The arm has an internal beam that can be drawn out during LE mode.</p>
	<p>Concept 2 – Extender beams are applied on and fixed with pins at the arm. The original hitch cup connection is also used.</p>
	<p>Concept 3 – A turning arm is turned down when needed. The joint is situated at the upper arm side.</p>
	<p>Concept 4 – A structure is applied using wires and the existing cup and hitch connection.</p>

	<p>Concept 5 – Telescope function. The extender arms are pulled out during LE mode.</p>
	<p>Concept 6 – A bushing is used to connect an extender arm to the existing arm.</p>
	<p>Concept 7 – An arm is jointed at the existing arm and is turned forward when needed.</p>
	<p>Concept 8 – The extender arm is drawn out, which is placed below the existing arm.</p>
	<p>Concept 9 – Arms are jointed at the original arm ends and are extended by telescopic function during LE mode.</p>
	

		<p>Concept 10 – Increased length is obtained by using a scissor function.</p>
		<p>Concept 11 – Similar as 10 but, stabilization arms are turned from the sides.</p>
		<p>Concept 12 – Hydraulic cylinder fulfil the lengthening procedure.</p>
		<p>Concept 13 – A structure is applied using the current cup and hitch, while using wires to stabilize.</p>
		<p>Concept 14 – Extenders are applied as magnets.</p>
		<p>Concept 15 – The lengthening is made by several crossed and coupled parts, which can be extended.</p>

	<p>Concept 16 – Extenders are applied at the side of the original arm</p>
	<p>Concept 17 – A robot arm is used to compensate the length.</p>
	<p>Concept 18 – A joint similar to those at folding ladders is used to allow the folding mechanism.</p>
	<p>Concept 19 – Arms are put down when the LE mode is used.</p>
	<p>Concept 20a – Extender arms are mounted at the cab and will compensate the length difference between LE and CC.</p>

	<p>Concept 21 – An arm is turned down with the help of a hydraulic cylinder.</p>
	<p>Concept 22 – Similar to concept 21 but other above view.</p>
	<p>Concept 23 – An arm can be turned out by rotating in several steps, driven by electrics. The arms are internal and external threaded.</p>
	<p>Concept 24 – By winding the handle the arm will be extended using an internal cog wheel and a rifflled extender arm.</p>
	<p>Concept 25 – Turned out manually. The arm is threaded.</p>
	<p>Concept 26 – Similar to concept 4. Structure is applied using wires and the existing cup and hitch connection.</p>

		<p>Concept 27 – Connection by pin is used through the existing arm.</p>
		<p>Concept 28 – Pins are used to connect at applied ears at the existing construction.</p>
		<p>Concept 29 – The construction is fixed using snaps at the upper and lower side of the existing arm.</p>
		<p>Concept 30 – Extenders are applied with pin similar as concept 1, but the cup will be at the same level as original arm height.</p>
		<p>Concept 31 – Similar to 30, but do only consist of one single part.</p>
		<p>Concept 32 – The existing arm is adjusted and will contain an extension, which can be drawn out when needed.</p>

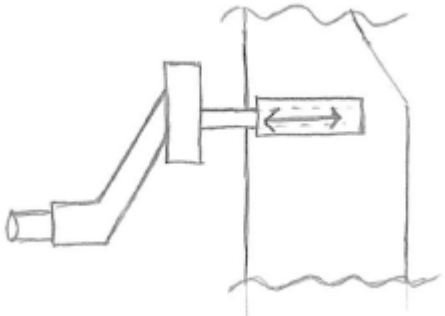
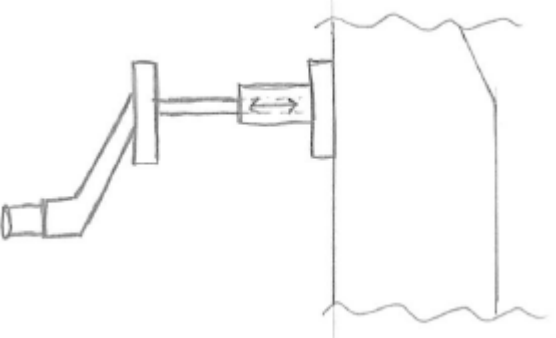
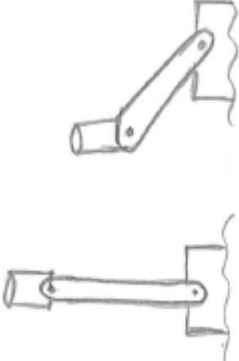
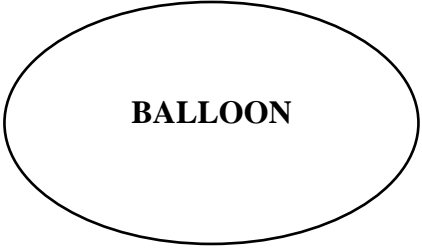

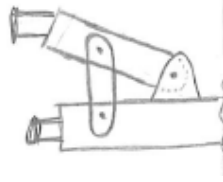


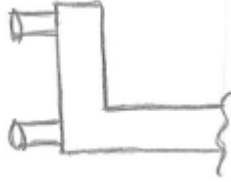
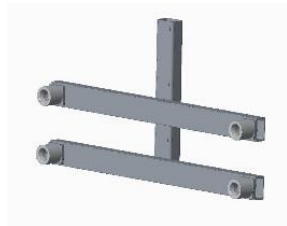
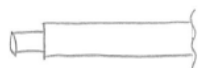

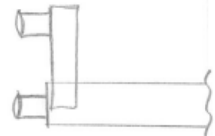
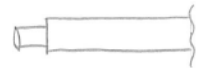
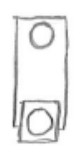
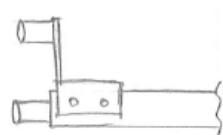
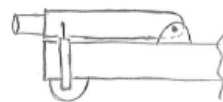
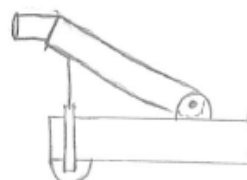
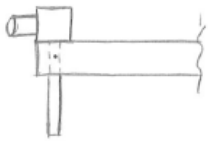
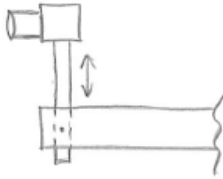
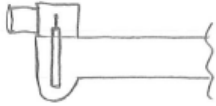
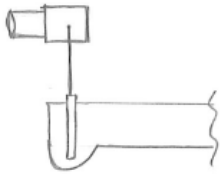
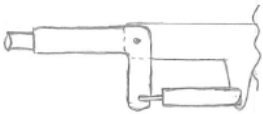
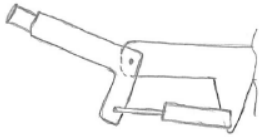
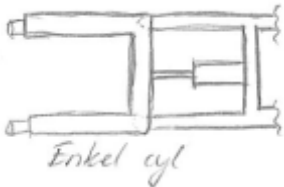
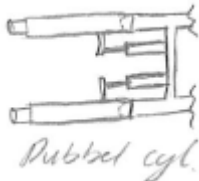


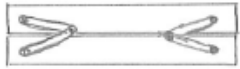
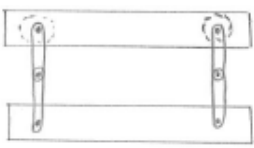


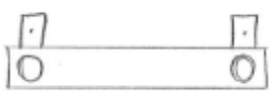
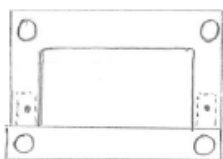
	<p>Concept 33 – Hydraulic cylinder within the tripod will compensate for the length difference.</p>
	<p>Concept 34 – The connection between the arm and the tripod contains a hydraulic cylinder compensating for the length.</p>
<p>No picture.</p>	<p>Concept 35 – Lengthening the tail tripod permanent and letting the possible movement of the tripod tail compensate the length difference between LE and CC.</p>
	<p>Concept 36 – A jointed arm is adjusting both the length by be turned up and down.</p>
	<p>Concept 37 – Using a balloon that is placed between the tripod tail and the LE cab.</p>

Figure B6 Proceeded concepts - Sub function 2.

B.4.3 Sub function 3 – Height mechanism

Sub function 3 – Height difference			Description
		Concept 1 – A turning arm, which has its rotation center a distance towards the tripod on the arm. Creating an angled arm during LE-mode.	
		Concept 2 – Turning arm jointed at the arm outset side. Is in straight horizontal direction in LE mode. Is turned backwards during CC mode.	
			Concept 3 – Two fixed position for compensating for cab mounting height difference.
			Concept 3b - Similar to concept 3 but consist of two horizontal beams. The upper beam can be movable if other heights than LE is needed.
			Concept 4 – A clamp is positioned on the existing arm when needed.
			Concept 5 – A construction is mounted on when needed.
			Concept 6 – Similar to concept 1, but a hydraulic cylinder is compensating the height difference. The cup of the adjusted arm is always used in this concept.

		Concept 7 – A thin pipe with the cup mounted on is moved up and down depending on cab mode.
		Concept 8 – A cup mounted on a cube is mounted on a hydraulic cylinder end, compensating for height difference.
9 and 10) 	9 and 10) 	Concept 9 and 10 – A 90 degree angled arm is adjusted using one or two hydraulic cylinders and rotate into the different cab modes.
9)  <i>Enkel cyl</i>	10)  <i>Dubbel cyl</i>	
		Concept 12 – The cup is mounted on a jointed bar, which can be folded.
		Concept 13 – Similar to concept 12 but the bars are connected by a beam to make the construction more stable.
		Concept 14 – Using big screws to allow height adjustment and at the same time become stable in all positions.
		Concept 15 – Two mounting places are mounted on the existing arm. A construction containing both cups are mounted on during LE mode.

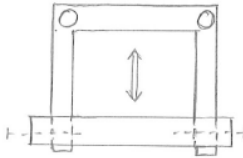
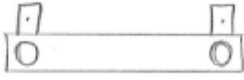

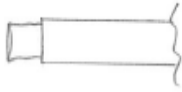
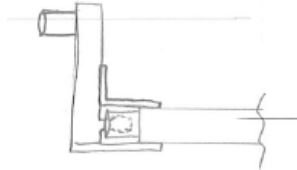
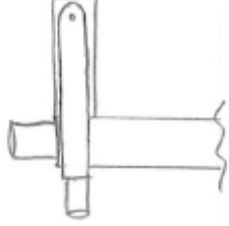
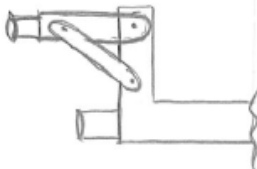

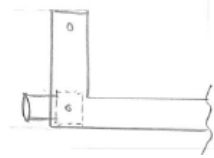
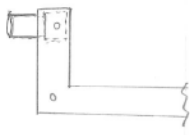
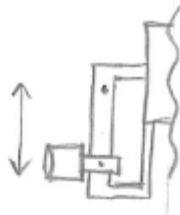

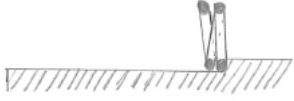
			<p>Concept 16 – Holes are made in the existing arm to allow a construction slide within these. Pins are fixing the positions.</p>
		<p>Concept 17 – Similar to concept 15, but one construction for each cup during LE mode.</p>	
		<p>Concept 18 – Using the original cup a construction can be fixed with supporting pin through the original arm.</p>	
		<p>Concept 19 – An arm is turned out during LE mode.</p>	
			<p>Concept 20 – A cup slides into the beam within a slit. Movement is stopped by pin.</p>
			<p>Concept 21 – A cub is fixed on a bushing that slides outside the beam. The movement is stopped using a pin.</p>

Figure B7 Proceeded concepts - Sub function 3.

B.4.4 Sub function 8 – Covering function

Sub function 8		Description
		<p>Concept 1 – Consists of several jointed plates that can be compressed together.</p>

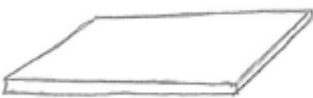
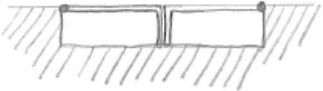
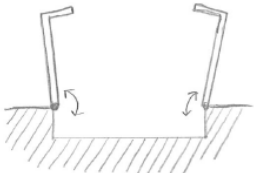

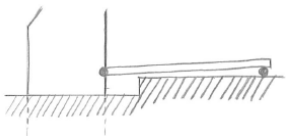
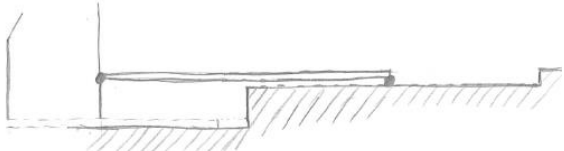
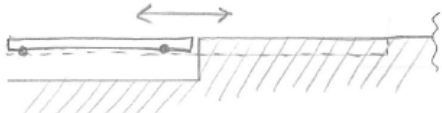
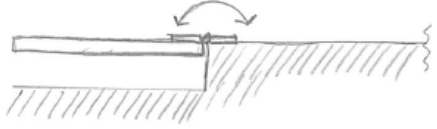

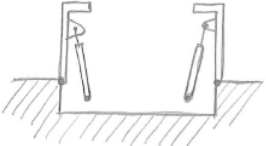
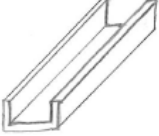
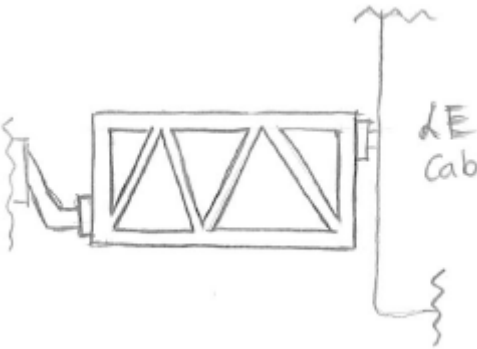
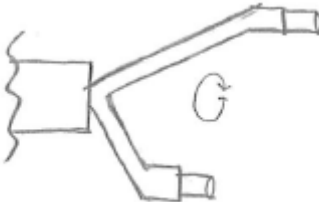
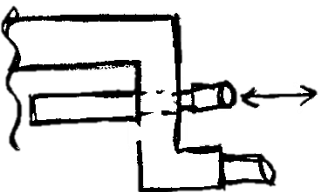
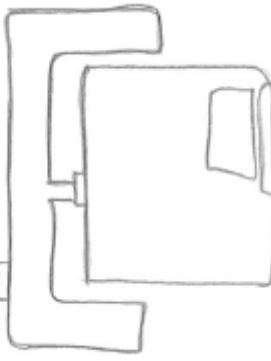
		<p>Concept 2 – One solid plate covering the foundation hole and will be removed manually by lifting</p>
		<p>Concept 3 – Counters are turned up automatically when the tripod is moved in the forward direction, because of construction on the tail tripod.</p>
		<p>Concept 4 – Counters are turned up manually by hand.</p>
		<p>Concept 5 – A plate is fixed at the tail tripod and follows its movement back- and forward.</p>
		<p>Concept 6 – A longer plate than concept 5 is fixed at the tail tripod and follows its movement, covering. This covers more situations than concept 5.</p>
		<p>Concept 7 – A plate has wheels or similar to be pushed forward when the rail plate need to be free during LE mode.</p>
		<p>Concept 8 – A plate is turned forward, not to the sides as in concept 3 and 4.</p>
		<p>Concept 9 – The covering is rolled up during LE mode.</p>
		<p>Concept 10 – Counters are turned up.</p>
		<p>Concept 11 – A narrow beam is placed over the rail plate at a suitable place to allow roll over. The width is similar to the CC rack, wheel.</p>

Figure B8 Proceeded concepts - Sub function 8.

B.4.5 Group generated concepts

Sub function 8	Description
	<p>Concept G1 – A frame construction is mounted between the tripod tail and the LE cab, compensating for both height and length.</p>
<p>No picture</p>	<p>Concept G2 – Add a rail plate to the tripod head, causing possible movement of both the tripod head and tail.</p>
<p>No picture</p>	<p>Concept G3 – Lengthening the existing rail plate for the tripod tail.</p>
	<p>Concept G4 – Another arm is used that is rotated 180° depending on the cab mode.</p>
	<p>Concept G5 – Both length and height compensated.</p>
	<p>Concept G6 – Construction added at cab back compensating for both height and length.</p>

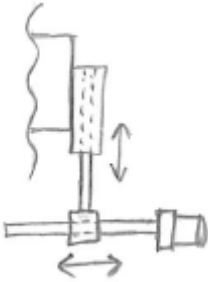

	<p>Concept G7 - The arm can be extended in both height and length depending on cab mode.</p>
	<p>Concept G8 – By turning the arm into different angles different height and lengths will be obtained.</p>

Figure B9 Proceeded concepts - Group generated concepts.

B.5 Systematic investigation – description of concept changes

B.5.1 Changes of sub function 2 – Different lengths

Concept 19 into 19b

For concept 19, the arm was not possible to fix in upward position because of the cab lip, shown in the Figure B10. This lip was 115mm long in x-axis compared to the mounting surface. A new concept was therefore constructed called 19b, where a movement of the joint pin was done in horizontal direction closer to the head tripod, still having the outer pin as rotation center.

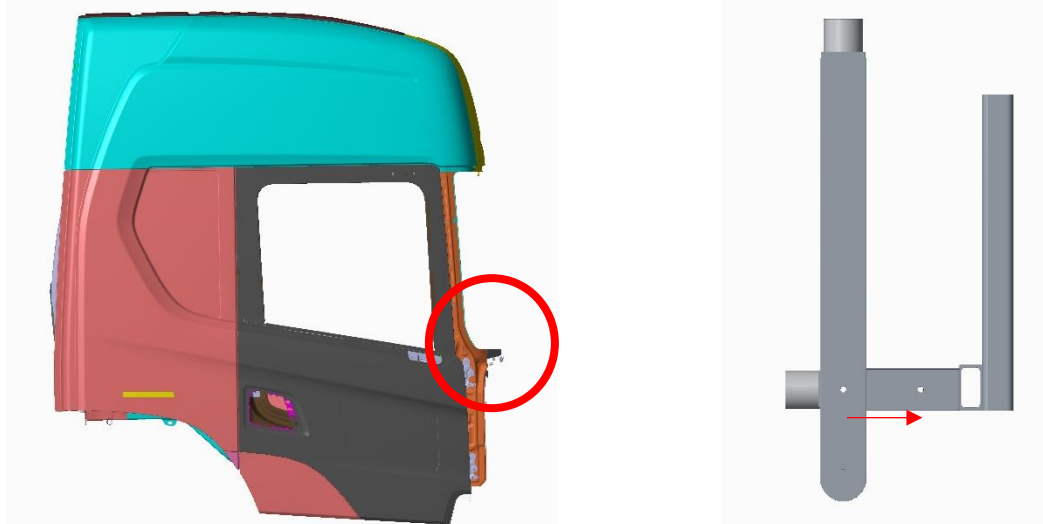


Figure B10 The lip that will block the arm in 90 degree position and the direction of construction change to obtain 19b.

Concept 19b into 19c

The turning arms would also take space in front of the front window frame. This was taken in consideration after the first decision matrix, showing a big drawback with respect to the space around the front window. The arms were approximately 1000mm from the center of the mounting points, therefore some area would be taken during the turned up position as shown with black arrows in Figure B11. 19c was therefore developed shown in Figure B11, using the inner pin as the rotation center.

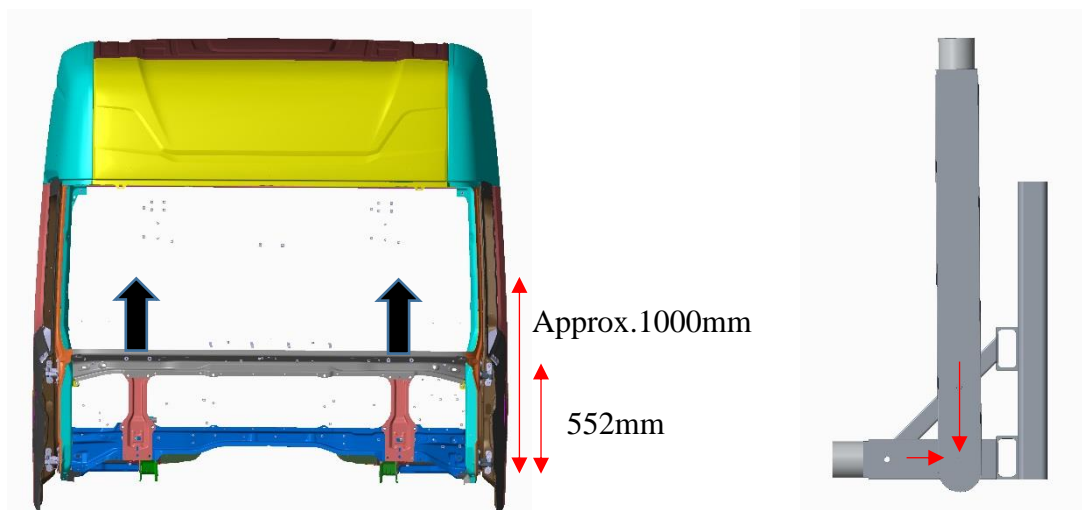


Figure B11 Left - cab front and its occupation of the arms. Right - construction changes to obtain more assembly space.

Concept 20a

This concept will be mounted fixed at the front of the cab. By using an extended arm of 800mm a moment will be created at the cab mounting point. The question was if the bolts used for the mounting plate would sustain the moment? The values given were approximate. The cab weight was approximately 400kg. This will be divided by four points, which means that F1 was 100g. L2 was the length between the bolt centers.

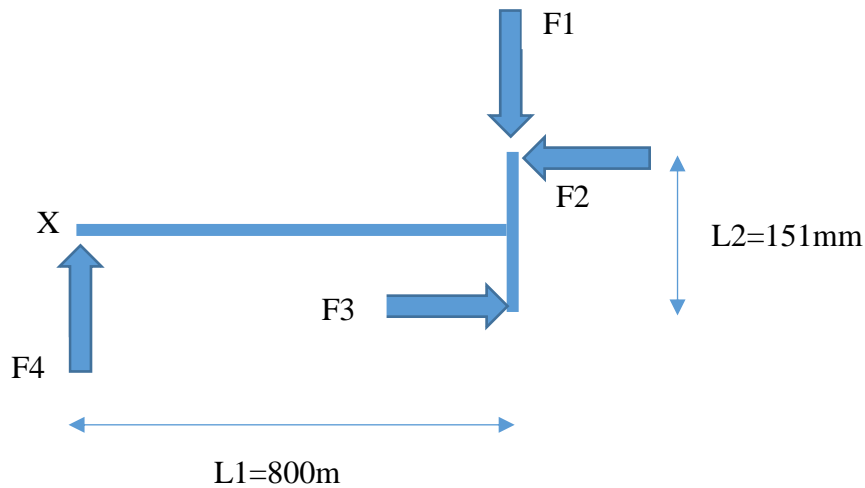


Figure B12 Description of the applied forces on concept 20a.

Force equilibrium: $F1 = F4$ (B.1)

$F2 = F3$ (B.2)

Moment equilibrium around X: $F1 \times L1 - F2 \times \frac{L2}{2} - F3 \times \frac{L2}{2} = 0$ (B.3)

(B.2) and (B.3) $F2 = \frac{F1 \times L1}{L2} = 5197\text{N}$

The current design contained one M8 bolt. Assuming “strength class” 8.8 its yield strength, $R_{p0.2}$, was 23,4kN, for one bolt. The biggest bolt possible to use through the cab mounting holes was M10. This had a yield strength, $R_{p0.2}$, of 37,1kN [53].

Instead of using two bolts it’s possible, in a point of security, to use four bolts. This would increase the security further to 46,8kN for the m8 and 74,2kN for M10. This was a safety factor of almost 10 and 14 respective, for strength class 8.8. No problems according to the bolt strength were therefore concluded.

Concept 35: Using constantly an extended arm at the back could lead to problems according to a too short tail tripod rail plate. How much space would be left during the long CC-mode? Would it be enough?

The rail was concluded too short to put the cab between the extended arms. The left space of 100mm(when the cab was mounted) during CC31 mode would be erased by the hitches at each

side, taking length space of a total approx. 100mm, 50mm on each side. The only possible mounting would be if mowing the cab straight into position. The place left will be +-0 between hitches and cups. Figure B13 give a description of the arrangement.

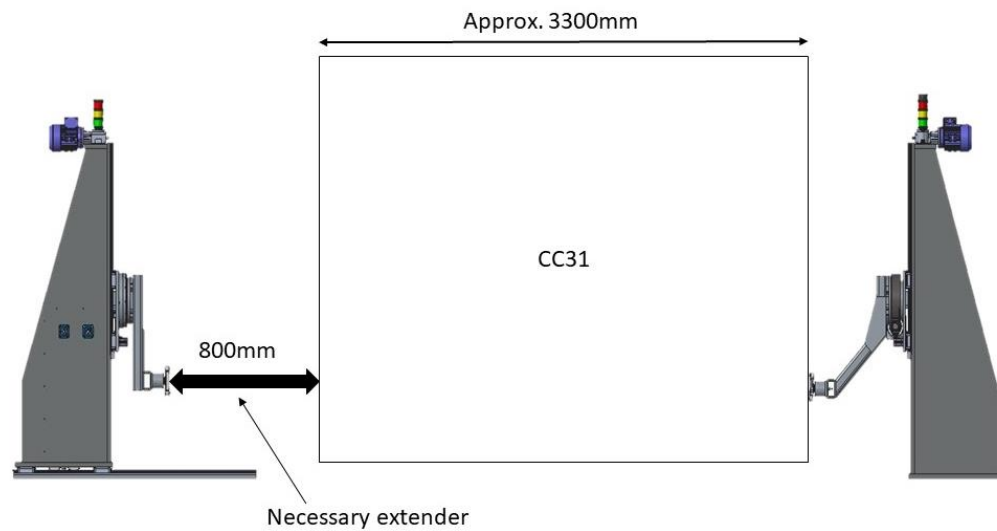


Figure B13 The critical arrangement including the tail tripod in its most backward position, the CC31 and the necessary extender to compensate the length difference.

Appendix C - Embodiment design

C.1 Critical measurements

C.1.1 K4

Distance between turned up counters and tripod arm (vertical distance):

The foundation wideness. If this would match the current width of 920mm, this was in some extent limited due the counters during turned up placement. Too broad foundation would cause broad counters ($920\text{mm}/2=460\text{mm}$), which movement will be limited by the arm in its lowest placement. The arm height measured from the rail plate upper side was approximate 572mm, exceeded the counter width with 110mm. In fact, that the rail plate upper side was situated a bit below the ground, approximate 50-55mm, the gap between arm and counter decreased from 110 to approximate 55-60mm shown in Figure C1.

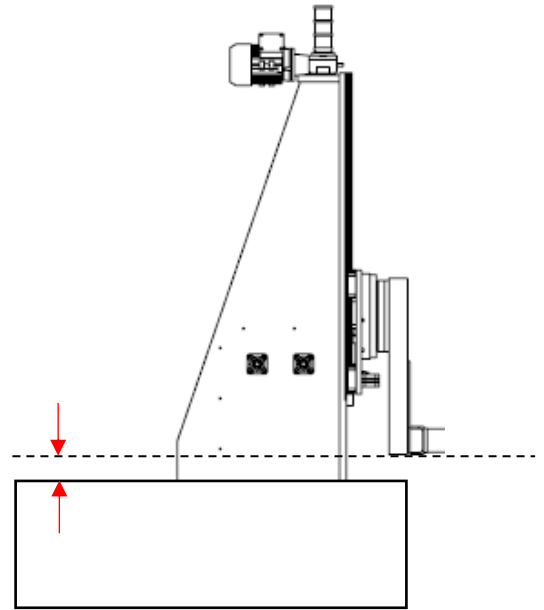


Figure C1 The free distance between the lowest part of the tripod arm and the turned up counters.

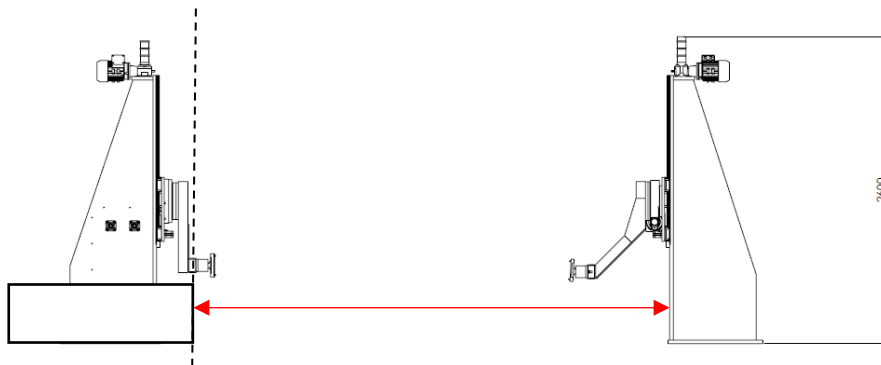


Figure C2 The distance between the counters turned up and the tripod head is bigger than the LE rack length.

- **Necessary lengthening of the rail plate and tripod driving chain**

The length difference between CC28 and LE, i.e. $3002-2048=954\text{mm}$, using the existing mounting plates. But the new one could differ in thickness and 954mm may therefore change.

- **Plunch cylinder hole position**

To obtain a functional lock mechanism for LE similar as for the CC cabs, it needed a plunch cylinder hole. The placement of this hole would be the same, measured from

the rail plate front side, as for the CC28 hole in the current rail plate, i.e. 420mm. This would simplify calculation during upcoming construction and installation.

C.2. Decisions made for function carriers.

The decisions made in the decision matrix for the function carriers, shown in Table 3.12, during the embodiment design phase were following:

C.2.1 The decisions made for frame:

Function: All fulfill the function

Working principle: All have a drawback. F1, F3 and F4 need exact holes. F2 was not fixed at concrete.

Layout: F2 would not have enough stability. F3 had not enough durability due to hinges mounting in concrete. F4 had the frame fixed directly into the hole, making the fixing most stable.

Safety: No differences due to safety if the frames will be fixed.

Ergonomics: Crushing possible in F2 due to stiffening beams at top of frame.

Production: F3 > F4 > easier > F1 > easier > F2 to construct

Quality control: Easy to identify the quality in all function carriers.

Assembly: F1 and F3, F4 easy assembly into hole if the hole is right. F2 will need adjustment for the perfect level and size.

Operation: Uncertain how F2 would react when load was applied and the construction was not fixed in the concrete. F4 was stable if the concrete was stable.

Maintenance: Same amount of maintenance necessary

C.2.2 The decisions made for covering function:

Function: C2 was limited by the thickness of approx. 20-25mm.

Working principle: Similar way of working

Layout:

Safety: No difference

Ergonomics: No difference in functional behaviour. Only by possible weight that not could be seen.

Production: Higher degree of freedom due construction using plate. The extruded profile may not be too thick to take place. Maximum 25mm.

Quality control:

Assembly: Both have consist of different parts.

Operation: Extruded profiles may have to thin upper layer plate to sustain the pressure from the wheel.

Maintenance:

C.2.3 The decisions made for gas cylinder function:

Function: Function in a similar way. G3 made it possible to get help of the cylinder to hold the counter down turned, therefore “+” was given.

Working principle: G1 had very limited space and could make it hard to obtain a functional working principle.

Layout: Similar stability and durability.

Safety: Similar

Ergonomics: Similar

Production: Similar

Quality control: The function was easier to check at G2.

Assembly: G2 was easier to assemble. G1 and G2 is hidden below the counter.

Operation: On cylinder may affect by unstraight load direction.

Maintenance: All cylinders were easily available when the counters were in turned up mode.

C.2.4 The decision made for hinge function:

Function: Similar

Working principle: could produce a small column between plate and floor/beam but it was better than having the hinges above due to wheel obstacle.

Layout: No effect

Safety: Similar

Ergonomics: Similar

Production: similar

Quality control: Similar. When turned up or down folded. Didn't matter.

Assembly: Similar

Operation: H1 may be more effective to absorb the forces.

Maintenance:

Appendix D - Material selection

D.1 Calculations for K4

The coarse calculations of the limiting yield strength and stiffness of K4 both were approximate and assuming the counter as a beam with point force.

Where:

- $P = 3679N$ – An approximate force from one of four wheels of the CC and its carrier with a total mass of 1500kg.
- $L = 0.46m$ – The counter width of one counter, from the foundation edge to the center above the rail plate.
- $b = 1m$ – An approximate length of the final counter solution.
- $h = 0.025m$ – The maximum thickness possible of the counter to fit above the railplate creating a smooth cover.
- $\delta = 0.005m$ – The maximum allowed deflection of the counter.
- $\alpha = \beta = 0.5$ – A length fraction of the counter width, L.
- $C_1 = 48$ Constant for this load case.
- $x = 0,230m$ – The width L divided by two

D.1.1 Limiting stiffness of K4:

The lower limit for the stiffness was calculated by equation (D.1) [54]. Describing the deflection of a freely submitted beam as in the case of K4.

$$E = \frac{12PL^3}{3bh^3\delta} \alpha^2 \beta^2 = 1.15GPa \quad (D.1)$$

D.1.2 Coupling line K4 – mass:

$$\frac{\sqrt[3]{\frac{12S^*}{C_1 b}} L}{\sqrt{\frac{6M}{b}}} M_{mass,1} = M_{mass,2} \quad (3.17)$$

Where: $M(x) = \frac{P}{2} x = 423N \quad (D.2)$

And: $S^* = \frac{P}{\delta} = 736 \frac{kN}{m} \quad (D.3)$

(D.2), (D.3), (3.17): $LogM_2 = LogM_1 + Log(0.519)$

D.2 Calculations for K100

Consisted of one case of buckling and one case of moment forces. Definitions used were following:

- $F_{crit} = 708N$. Force at one mounting plate placed at the cab back. No safety factor.
- $L = 0.295m$. Length from hitch connection to the lower mounting holes. See Figure 3.38:
- $n = \frac{3}{2}$ Constant for the given loadcase, obtained from [13].
- M_{crit} Moment force during 90° rotation
- S^* Minsta möjliga styvhet.
- $C_1 = 3$ Constant for the given loadcase, obtained from [13].

D.2.1 Coupling line K100 –buckling

$$\frac{\sqrt{\frac{12F_{crit}L^2}{n^2\pi^2}}}{F_{crit}L} M_{buckling,1} = M_{buckling,2} \quad (3.36)$$

(3.36) gives: $LogM_2 = LogM_1 + Log(0.018)$

D.2.2 Coupling line K100 – moment

$$\frac{\sqrt{\frac{12SL^3}{C_1}}}{(6M)^{2/3}L} M_{moment,1} = M_{moment,2} \quad (3.37)$$

$$M_{crit} = F_{crit}L = 708 \times 0.295 = 209Nm \quad (D.4)$$

$$S^* = \frac{F_{crit}}{\delta} = \frac{708}{0.005} = 141.6 \frac{kN}{m} \quad (D.5)$$

(D.4), (A.8), (3.37) gives: $LogM_2 = LogM_1 + Log(1.037)$

Appendix E - Simulations

Stresses are shown in von Mises stress and the deflections are the total magnitude, main consisting of deflection in z-direction according to the pictures. The stresses and deflections of the rectangular prism were not taken into account.

The abbreviations vertical and horizontal, should be read while looking at the mounting plate in normal position.

E.1 Load case 1 – 0° cab rotation

E.1.1 Force calculations

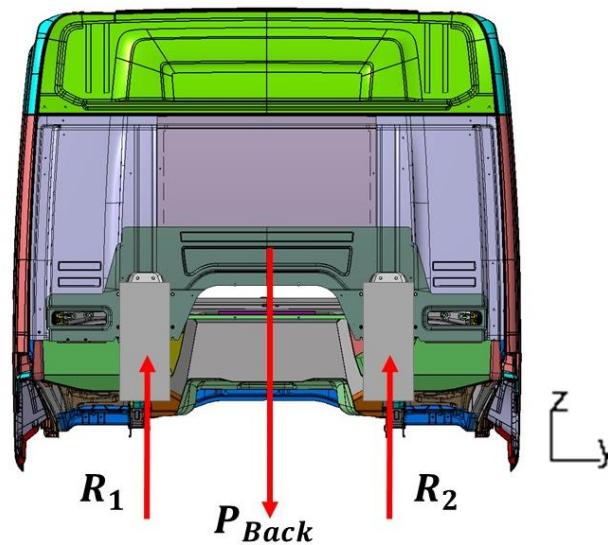


Figure E1 Picture of the LE cab from behind with forces R_1 and R_2 during the 0° rotation angle.

No cab rotation caused an applied force exactly like R_2 calculated in section 3.5.1, i.e. $R_1 = R_2 = 3539N$.

E.1.2 Simulation results

A vertical force of 3538.66N was applied as a pressure of 29.4888MPa on an area of 120mm². Maximum stress obtained was 188MPa. This stress levels occurred as stress concentration at the 90° edge at the hitch connection, and at the lower mounting hole edges shown in Figure E2. 88MPa was lower than the yield strength of 240MPa.

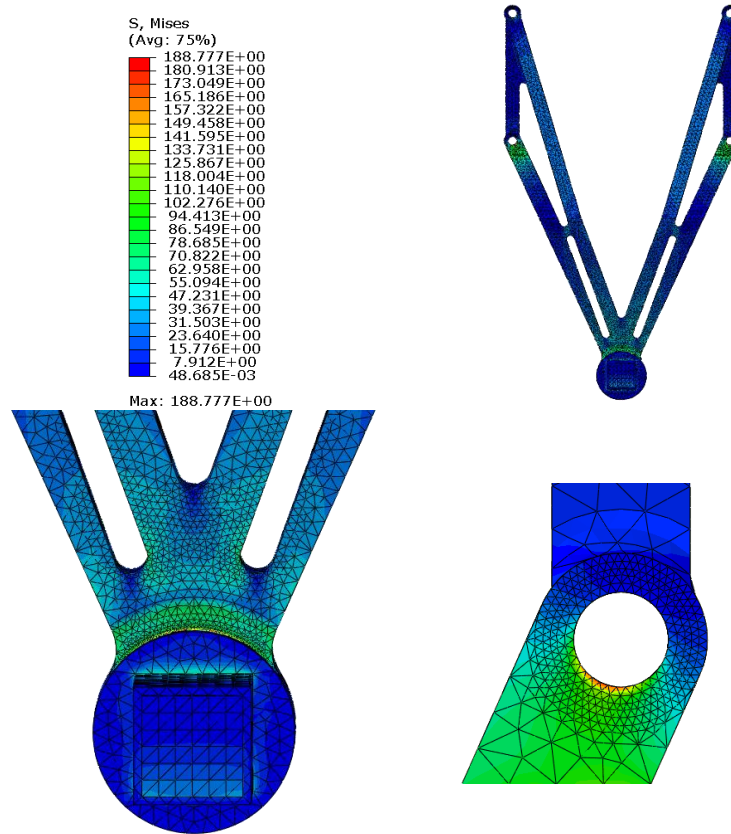


Figure E2 Stresses during the 0° mode. Upper left - stress scale, upper right - whole construction, lower left - stress concentrations at edge, lower right - stress concentrations at upper right hole.

Maximal deflection occurred was 1.87mm, which was of major correspondence of the deflection in z-direction, i.e. 1.85mm. See Figure E3.

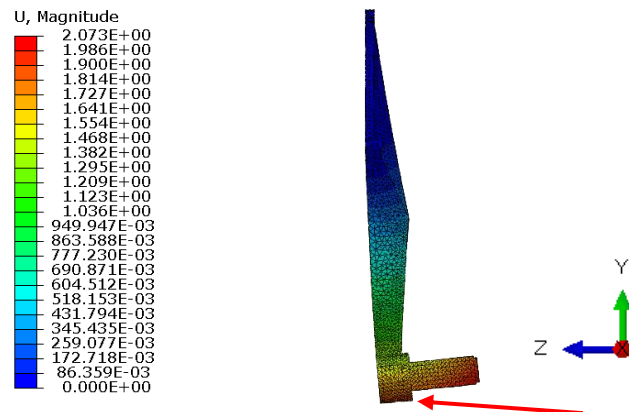


Figure E3 Deflections of load case 1 during 0° degree rotation. The deflection in the right picture was multiplied with 10 to show the behavior.

E.2 Load case 2 – 45° cab rotation

Consisted of two mounting plates with different levels of load. Only the mounting plate with the highest loads was investigated.

E.2.1 Force calculation

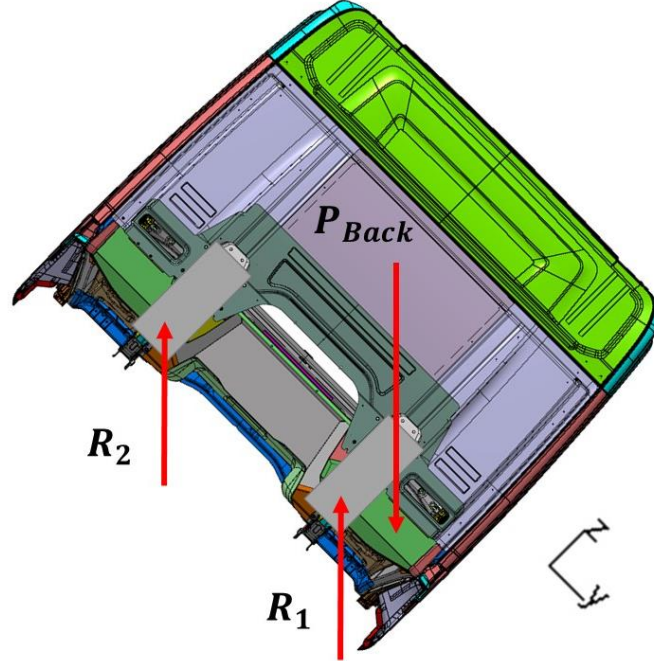


Figure E4 Picture of the LE cab from behind with forces R1 and R2 during the 45° rotation angle.

Force equilibrium in y- and x- direction:

$$\sum F_y : R_1 \cos(\alpha) + R_2 \cos(\alpha) - P_{Back} \cos(\alpha) = 0 \quad (E.1)$$

$$\sum F_z : R_1 \sin(\alpha) + R_2 \sin(\alpha) - P_{Back} \sin(\alpha) = 0 \quad (E.2)$$

$$\sin(45) = \cos(45) \quad (E.3)$$

$$(E.1), (E.2), (E.3): \quad P_{Back} = R_1 + R_2 \quad (E.4)$$

Moment equilibrium around R₁:

$$\sum M_{R1} : P_{Back} \sin(\alpha) L_{ZQ} + R_2 \cos(\alpha) L_m - P_{Back} \cos(\alpha) L_{YQ} = 0 \quad (E.5)$$

$$(E.4) \text{ and } (E.5): \quad R_2 = P_{Back} \left(\frac{L_{YQ} - L_{ZQ}}{L_m} \right) \quad (E.6)$$

By using values the force distribution obtained was:

$$(E.6) \text{ in } (E.4): \quad \begin{aligned} R_1 &= 7809N \\ R_2 &= -732N \end{aligned}$$

E.2.2 Simulation results

A vertical and a horizontal force of 5521.98N were applied as a pressure of 46.02MPa on an area of 120mm². The stresses of 480 MPa occur at the sharp edge at the hitch, this was seen as stress concentrations, pointed out with the red arrow in Figure E5. Stresses higher than 240MPa did also occur at the right lower mounting hole, which reached 340MPa.

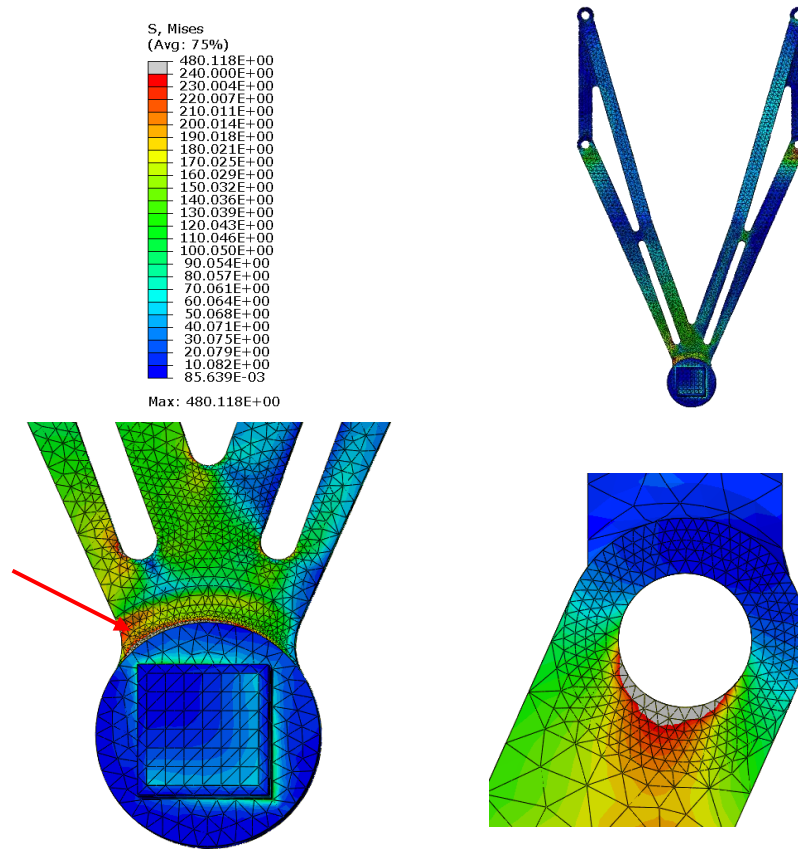


Figure E5 Stresses during the 45° mode. Upper left - stress scale, upper right - whole construction, lower left - stress concentrations at edge, lower right - stress concentrations at upper right hole.

Deflections shown in Figure E6 were measured in magnitude and obtained the value of 2.96mm at the lowest right point of the mounting plate. This value do almost correspond to the deflection in z-direction that was 2.91mm.

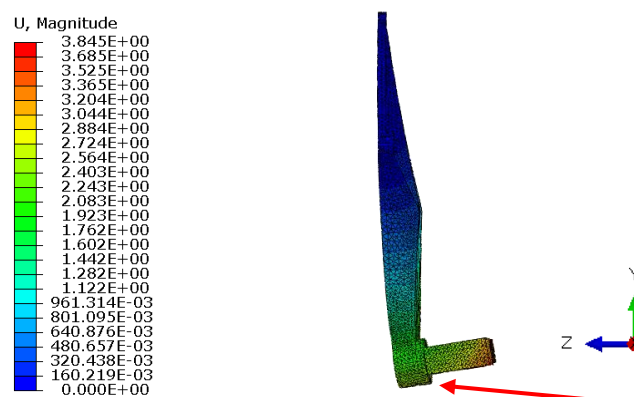


Figure E6 Deflections of load case 2 during 45° degree rotation. The deflection in the right picture was multiplied with 10 to show the behavior.

E.3 Load case 3 – 90° cab rotation

The two plates had forces of the same magnitude but the direction of R_3 and R_4 differed. Only the case when buckling occurred was investigated, i.e. compression of the mounting plate.

E.3.1 Force calculation

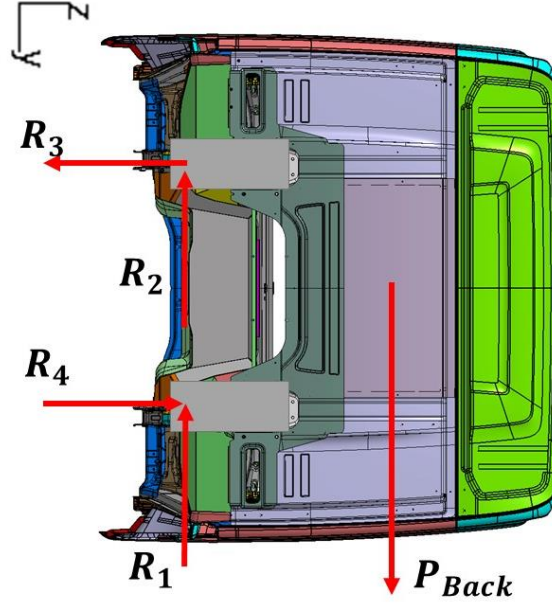


Figure E7 Picture of the LE cab from behind with forces R_1 and R_2 during the 90° rotation angle.

Force equilibrium in y- and x- direction:

$$\sum F_y : R_1 + R_2 - P_{Back} = 0 \quad (E.7)$$

(E.7) gives: $P_{Back} = R_1 + R_2 \quad (E.8)$

$$\sum F_x : R_4 - R_3 = 0 \quad (E.9)$$

(E.9) gives: $R_4 = R_3 \quad (E.10)$

Moment equilibrium around R_1 :

$$\sum M_{R1} : P_{Back} L_{ZQ} - R_3 L_m = 0 \quad (E.11)$$

(E.11) gives: $R_3 = P_{Back} \left(\frac{L_{ZQ}}{L_m} \right) \quad (E.12)$

Moment equilibrium around R_2 :

$$\sum M_{R2} : P_{Back} L_{ZQ} - R_4 L_m = 0 \quad (E.13)$$

(E.13) gives: $R_4 = P_{Back} \left(\frac{L_{ZQ}}{L_m} \right) \quad (E.14)$

By using simple static equilibrium it was impossible to obtain the magnitude of R_1 and R_2 , due to four unknown and three equations, (E.7), (E.9) and (E.11). An assumption was therefore made to use $R_1 = R_2 = 3539N$.

By using values the force distribution obtained is:

$$(E.12): \quad R_3 = 4259N$$

$$(E.13): \quad R_4 = 4259N$$

E.3.2 Simulation results

A vertical force of 4259N and a horizontal force of 3539N were applied as a pressure of 35.49MPa and 29.49MPa respective, on an area of 120mm².

Using the yield strength limit of 240MPa there were two area given stresses above this limit. Similarly to load case 2, it was the right mounting hole and the sharp edge between hitch and mounting plate, shown with arrows in Figure E8. The stresses at the hole is approximate 250MPa as a maximum, while there are stresses above 300MPa at the sharp edge.

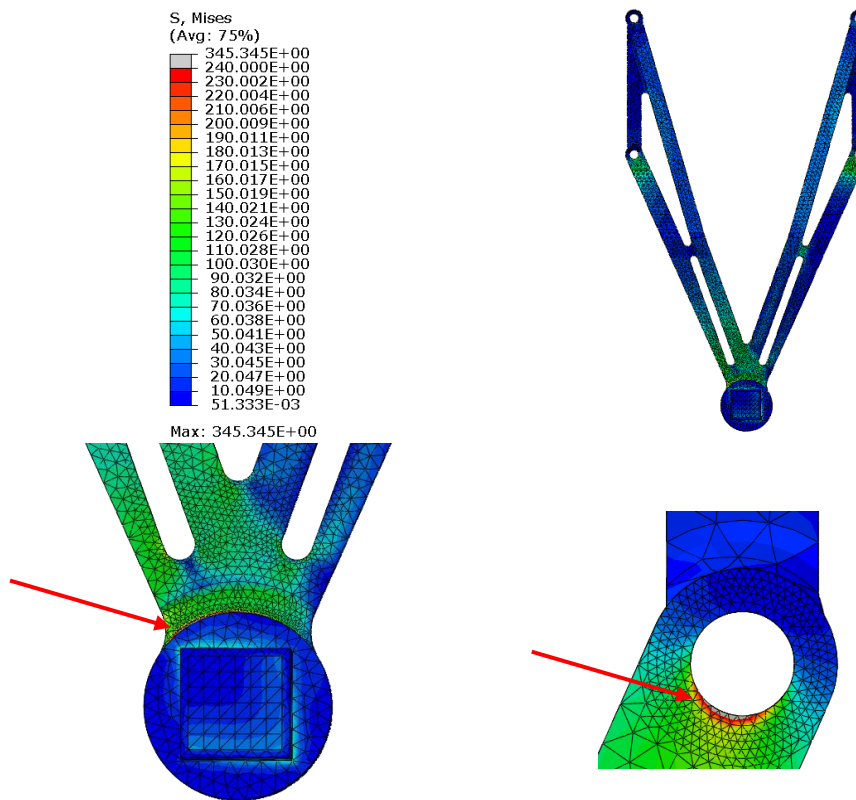


Figure E8 Stresses during the 90° mode. Upper left - stress scale, upper right - whole construction, lower left - stress concentrations at edge, lower right - stress concentrations at upper right hole.

Deflections obtained were of magnitude 2.27mm and in z-direction 2.24mm, as shown in Figure E9. The movement of the right hand side picture is multiplied with 10 to show the behavior.

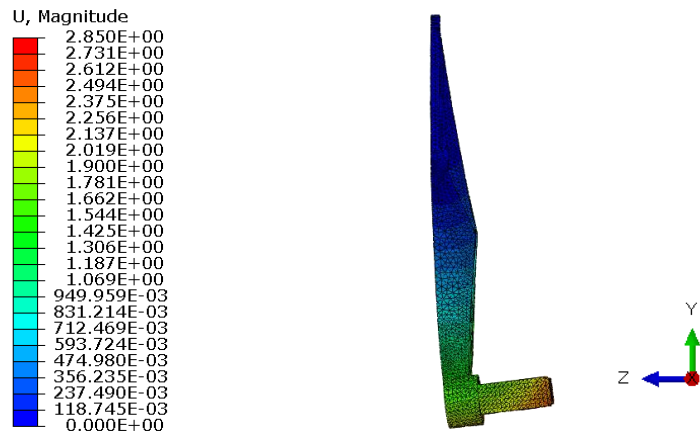


Figure E9 Deflections of load case 3 during 90° degree rotation. The deflection in the right picture was multiplied with 10 to show the behavior.

E.4 Load case 4 – 135° cab rotation

One of the mounting plates was subjected to very low loads and was therefore not analyzed, similar for the load case 3. The force will in the investigated case create a tensile situation and therefore create another way of deflection.

E.4.1 Force calculation

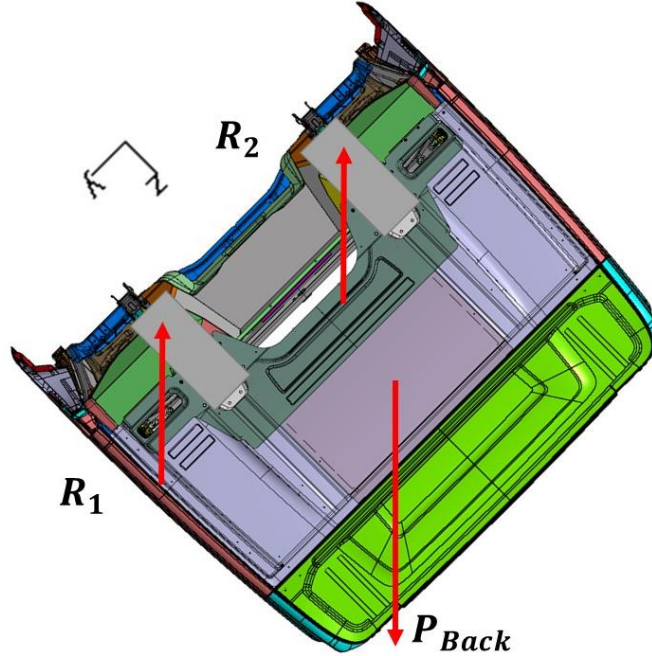


Figure E10. Picture of the LE cab from behind with forces R_1 and R_2 during the 135° rotation angle.

Force equilibrium in y- and x- direction:

$$\sum F_y : R_1 \sin(\alpha) + R_2 \sin(\alpha) - P_{Back} \sin(\alpha) = 0 \quad (E.15)$$

$$\sum F_z : R_1 \cos(\alpha) + R_2 \cos(\alpha) - P_{Back} \cos(\alpha) = 0 \quad (E.16)$$

$$\sin(135) = -\cos(135) \quad (E.17)$$

(E.15),(E.16),(E.17) gives:

$$P_{Back} = R_1 + R_2 \quad (E.18)$$

Moment equilibrium around R_1 :

$$\sum M_{R1} : -P_{Back} \sin(\alpha) L_{YQ} + P_{Back} \cos(\alpha) L_{ZQ} - R_2 \cos(\alpha) L_m = 0 \quad (E.19)$$

$$(E.17) \text{ and } (E.19): \quad R_2 = P_{Back} \left(\frac{L_{YQ} + L_{ZQ}}{L_m} \right) \quad (E.20)$$

By using values the force distribution obtained is:

$$(E.20) \text{ in } (E.18): \quad R_1 = 7785N$$

$$R_2 = -708N$$

E.4.2 Simulation results

A vertical and horizontal force of 5504.49N were applied as a pressure of 45.87MPa and -45.87MPa respective, on an area of 120mm². There were three areas succeeding the yield strength of 240MPa, the right hole, the sharp edge close to the hitch and at the radius to the outer left stiffening. The areas are shown with arrows in Figure E11.

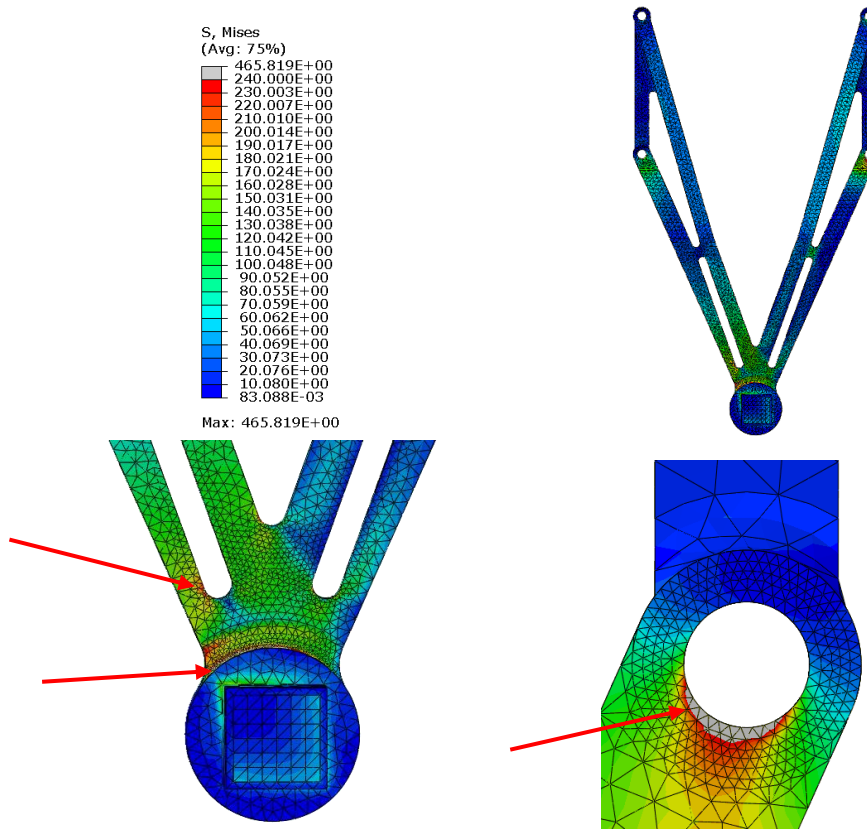


Figure E11 Stresses during the 135° mode. Upper left - stress scale, upper right - whole construction, lower left - stress concentrations at edge, lower right - stress concentrations at upper right hole.

The obtained deflection is shown in Figure E12, with a magnitude of 2.95mm, while 2.91mm in z-direction. Observe that the deflection was opposite compared to the earlier shown deflections. The movement of the right hand side picture was also multiplied with ten to show the behavior in a better way.

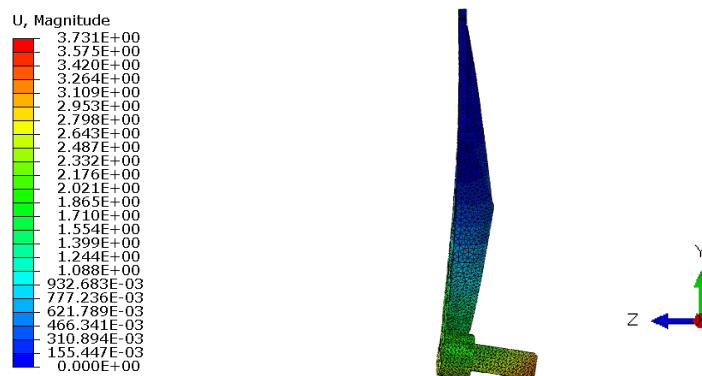


Figure E13 Deflections of load case 4 during 135° degree rotation. The deflection in the right picture was multiplied with 10 to show the behavior.

E.5 Load case 5 – 180° cab rotation

This load case was similar to the 0° load case but the force was in opposite direction creating a tensile load case.

E.5.1 Force calculation

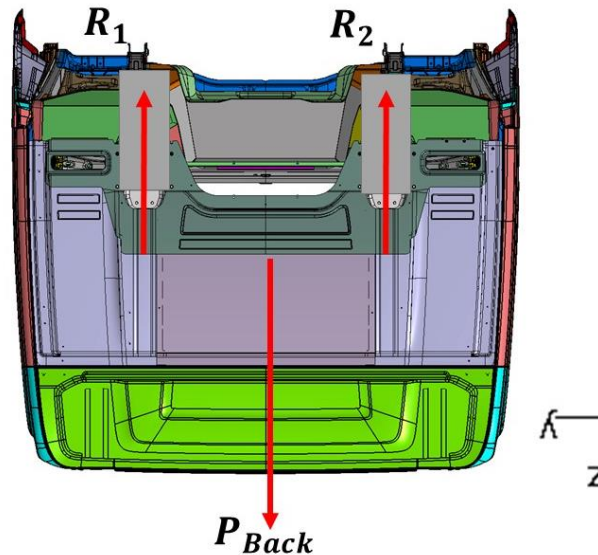
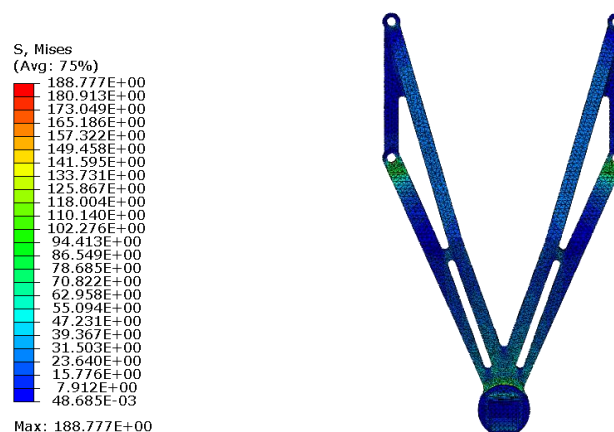


Figure E14. Picture of the LE cab from behind with forces R_1 and R_2 during the 180° rotation angle.

No cab rotation caused an applied force exactly like R_2 calculated in section 3.5.1, i.e. $R_2 = 3539N$, but in opposite direction, creating a tensile behavior.

E.5.2 Simulation results

A vertical force of 3538.66N was applied as a pressure of -29.4888MPa on an area of 120mm². As shown in Figure E15, the result obtained was similar to the one obtained for load case 1. The yield strength of 6082 aluminum was not exceeded anywhere in the structure.



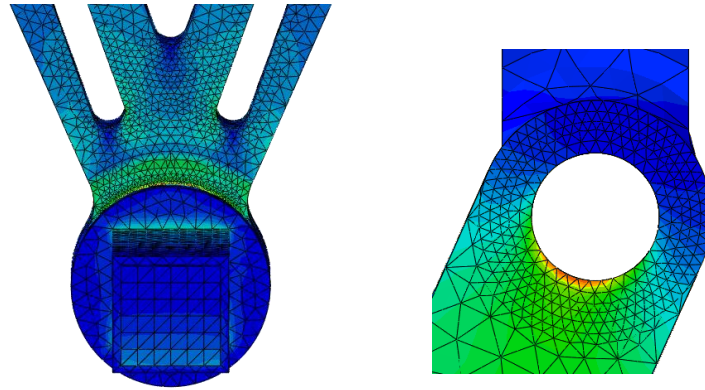


Figure E15 Stresses during the 180° mode. Upper left - stress scale, upper right - whole construction, lower left - stress concentrations at edge, lower right - stress concentrations at upper right hole.

Figure E16 show the deflection behavior, which was opposite to load case 1. Max magnitude of the mounting plate was 1.88mm while in z direction 1.87mm.

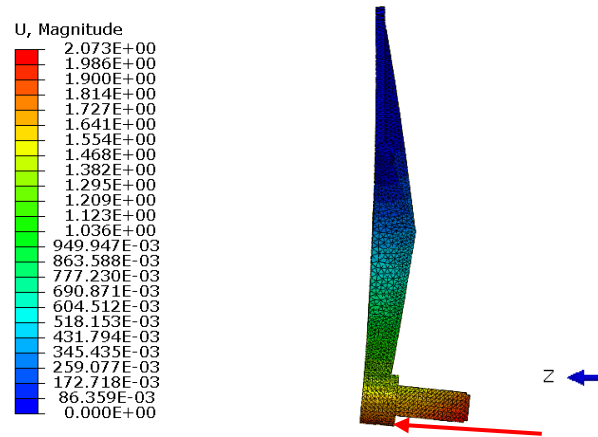


Figure E16 Deflections of load case 5 during 180° degree rotation. The deflection in the right picture was multiplied with 10 to show the behavior.

E.6 Load case a) – point closest to tripod

Max stress obtained was 254MPa, and max deflection 4.82mm, Figure E17 and Figure E18 show this result. The deflection was big out to the edge that depend on no support.

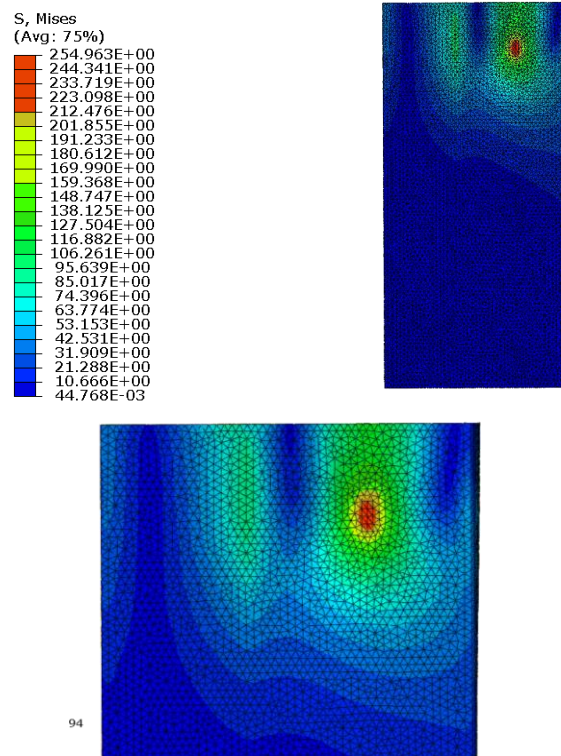


Figure E17 Von Mises stresses. Upper left – scale, upper right – whole plate top side, lower – interesting area at top side.

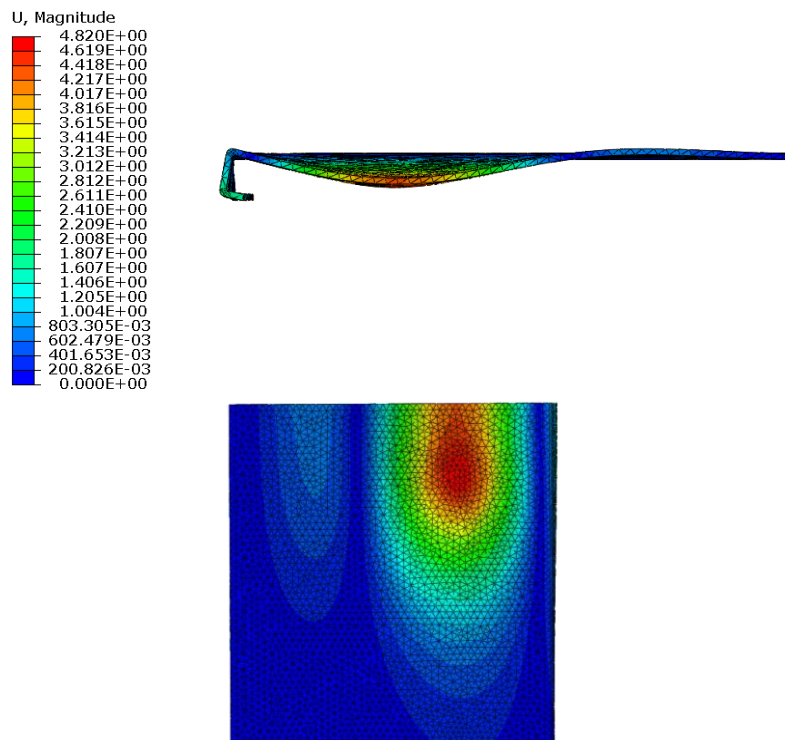


Figure E18 Deflections. Upper left – scale, upper right – magnified deflection from side, lower – deflection from top side view.

E.7 Load case b) – the most common load case

Max stress: 249MPa and max deflection approximate 4mm at the assumed most probably load case, shown in Figure E19 and Figure E20.

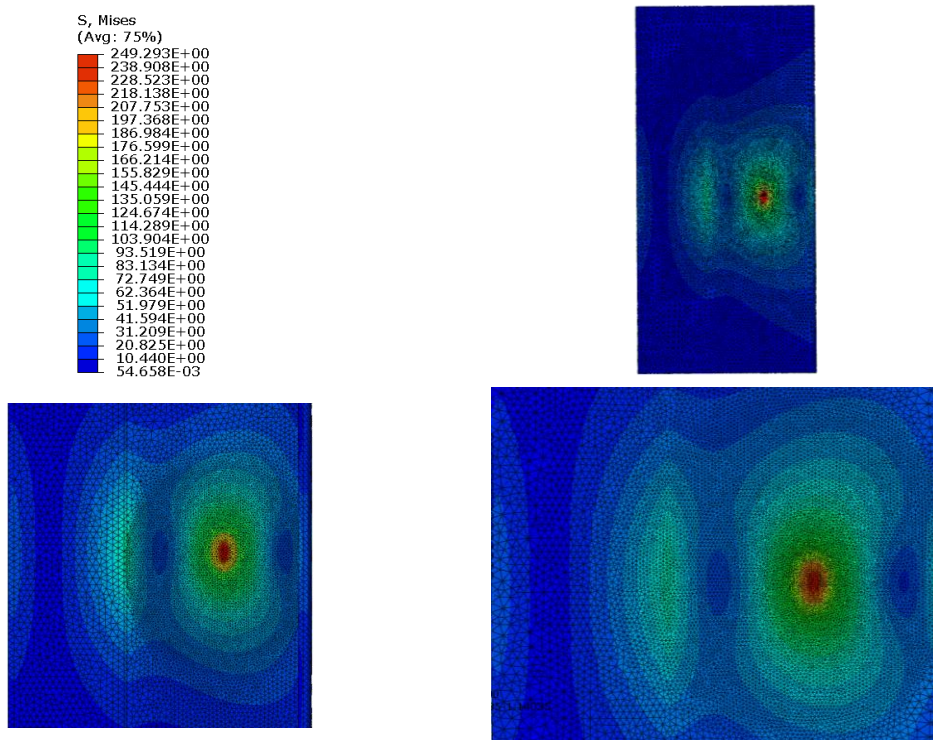


Figure E19 Von Mises stresses. Upper left – scale, upper right – whole plate top side, lower left – interesting area under side, and lower right – interesting area at top side.

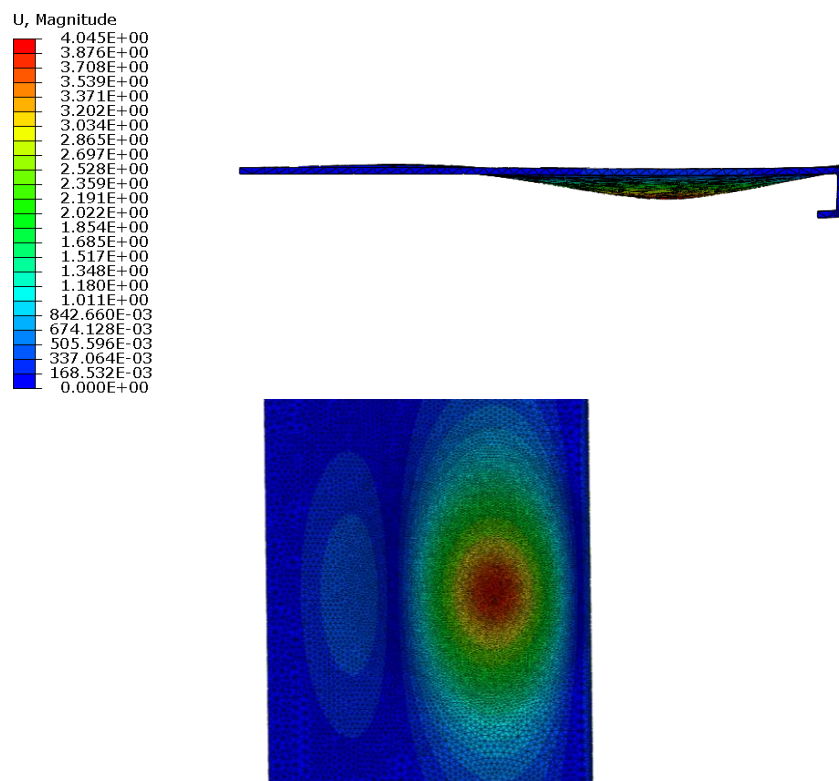


Figure E20 Deflections. Upper left – scale, upper right – magnified deflection from side, lower – deflection from top side view.

E.8 Load case c – point closest to the concrete edge

Max stress is 633MPa at some support point, probably stress concentrations. No area exceeded 260MPa at Figure E21. Max deflection was 2.62MPa. Figure E22. This was relatively small and depend on the edge support that was mounted at the concrete edge.

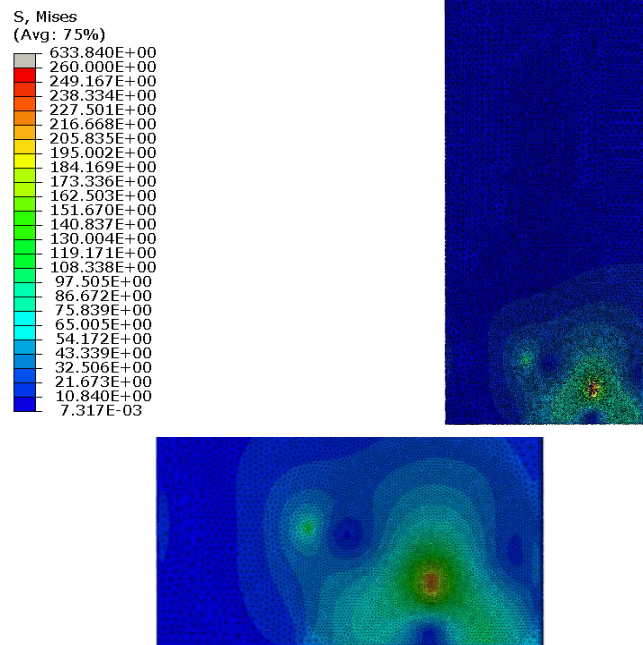


Figure E21 Von Mises stresses. Upper left – scale, upper right – whole plate top side, lower – interesting area at top side.

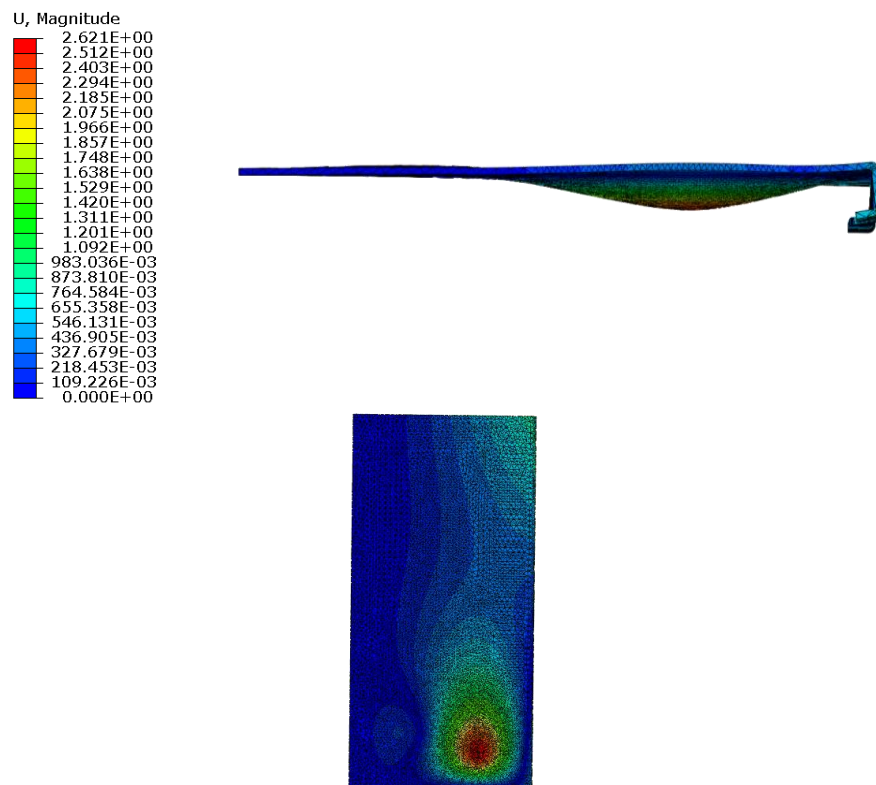


Figure E22 Deflections. Upper left – scale, upper right – magnified deflection from side, lower – deflection from top side view.