Design of Station for Calculating Centre of Gravity of Truck Cabin

A Product Design Project

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Abstract

As a part of Linköping University’s master program course curriculum, current thesis is performed at Tools and fixtures department (MPCT) of Scania, Oskarshamn. The aim of this master thesis project is to develop a complete construction of the station in CAD which calculates the weight and center of gravity of all the different cabs produced in Scania CV AB. To accomplish this project a generic product development process described in product development textbook by Ulrich and Eppinger (2012), fifth edition and The mechanical design by David G Ullman, fourth edition were extensively used. The whole function from a black box is decomposed into several sub functions and different solutions were identified for these individual functions. By using morphology matrix and proper combinations from these solutions five different concepts were developed and presented to Scania CV AB.

The team along with technical design experts in the MPCT department evaluated all the concepts and one concept was chosen for further development. Protecting the weighing scales during loading of cab from forklift onto the station and safety for the cab during tilting are the two main challenges faced during detail design phase. We were able to achieve these operations by incorporating a lifting table into the station design. Thanks to the custom made multi-tasking lift table which is manufactured and supplied by HYMO.

With the help of sensors, speed of the lifting table can be controlled with two operating speeds-High & Low. Lifting table moves in its lowest speed whenever it approaches the weighing scales. Incorporation of Jacob safety into the lifting table allows the table to always operate in low speed when the lift link is in action. These sensors ensure high safety for the cab and weighing scales. Apart from this, an emergency stop has been provided to stop the entire operation in case of emergencies.

In this proposed design, the center of gravity values will be determined in two stages and the weight readings are recorded in computer during these stages. For determining the longitudinal and transverse distances of CG, weight readings from all the weighing scales is essential once the cab is loaded on the station from the forklift. For determining the vertical distance of CG, two weight readings and measured tilt angle is required. A calculation module will allow the user to enter these values and obtain the result in no time.

This developed 3-D CAD model with 2-D drawings are presented to Scania and the obtained results of this work fulfilled the set of requirements set for this master thesis.

Key words: CAD, Cabin, Center of Gravity, Sensors, Tilting.
Acknowledgement

This master thesis project was conducted in MPCT department at Scania’s technical center in Oskarshamn in co-ordination with department of management and Engineering(IEI) at Linköping university between January 2018 – May 2018. This journey was challenging and paved the way to model our career. We would genuinely like to acknowledge everyone who helped us in this project work.

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Suppliers play a major role in this project and worth mentioning about the contributions of two major suppliers involved in this project. Weighing platform supplier Oscar from Vetek contributed a lot with his innovative ideas for this project. Providing detail information about the accuracy of the platforms and sharing their physical dimensions to eliminate many uncertainties in the measurements.

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Regards

Shiva & Srinivas
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Notations and abbreviations used in this current report writing are listed here

**Abbreviations**

CG  
Centre of Gravity

CGx, CGy, CGz  
Centre of Gravity values in respective directions

MPCT  
Tools and Fixtures Department-Scania CV AB, Oskarshamn

GF  
Gauge factor

SI  
System International

CATIA  
Computer aided three-dimensional interactive application

MATLAB  
Matrix laboratory

R&D  
Research and Development

GM  
General Motors

NHTSA  
National Highway Traffic Safety Administration

CAB/cab  
Cabin

UMTRI  
University of Michigan Transport Research Institute

DFMEA  
Design Failure Mode Effect Analysis

CAD  
Computer Aided Design

DFM  
Design for Manufacturing

DFA  
Design for Assembly

FS  
Full Scale

**Notations**

a  
Acceleration (m/s²)

b  
Average track length of axles (mm)

g  
Acceleration due to gravity (m/s²)

F  
Force (N)

m  
Mass (Kg)

Fx, Fy & Fz  
Force components in respective directions

Mx, My & Mz  
Moment components in respective directions

l  
Length of the skid (mm)

Wtot  
Total weight of skid and cabin (kgs)

W1, W2, W3 & W4  
Weight readings in horizontal condition (kgs)

W1’ & W2’  
Weight readings in tilted condition (kgs)
Nomenclature

Useful definitions related to the current project are covered in this section.

- **Centre of Gravity:** It is the point through which the resultant of the weight of all the particles of the body acts. It is the balance point of an object and about this point all the gravity moments will be balanced.

- **Weighing Platform:** It is a device which measures the weight of an object by placing on the surface of the platform.

- **Load Cell:** It is a force transducer which converts energy from one form to another. Load cell measures the force by creating an equivalent magnitude of electrical signal.

- **Gauge factor:** It can be defined as a measure of sensitivity of the material or its resistance change per unit applied strain as: \( \text{GF} = \frac{dR/R}{\varepsilon} \) (Kyowa, 2016)

- **Galvanometer:** It is an electrical instrument used for measuring electric current of small magnitudes.

- **Skid:** A skid is basically a steel supporting structure used in assembly lines where the cabs are mounted and let move on the assembly conveyor belt to perform assembly operations on different stations.

- **% of Full Scale accuracy of a measuring device:** The error in the reading in this case is constant for any reading on the device within its maximum limits.

- **% of Reading accuracy of a measuring device:** The error in the reading in this case not constant. But, is the % of the reading on the device within its maximum limits.

- **Anthropometry:** Finding a right physical fit by measuring the size and proportions of the human body.

- **Cab-0:** It is a global reference position point in CATIA V5 within Scania CV AB.
1 Introduction

In this chapter, a detailed background is provided pertaining to the Master thesis project “Design of station for calculating Centre of gravity of truck cabins”. This project is carried out at Scania CV, Oskarshamn at Scania Trucks Cabin department in cooperation with the Machine Design Department of Linköping University.

1.1 Background Concerning Scania Oskarshamn

Scania’s Production unit in Oskarshamn is responsible for producing truck cabins and is the largest private employer in Kalmar County, Sweden. The Production unit in Oskarshamn have solid experience in cabin manufacturing and have developed world-class technology products for over sixty years. Truck cabins are manufactured with great care to deliver premium products to Scania’s customers. A number of cabins produced in Oskarshamn on daily basis is approximately 300 units. These finished cabins are dispatched to Scania’s final assembly divisions in Södertälje in Sweden, Zwolle in Holland and to Angers in France. (Scania, 2016)

The cabin production work in Oskarshamn is done in four different workshops: Press workshop, Body workshop, Painting and Assembly Workshops. Heavy pressing operations and base body of cabins are carried out at Press and Body workshops. Most of the painting work is automatized with robots and is carried at a painting workshop. In the assembly workshop, all the individual components like control panel, windshield, side doors, mirrors etc. are assembled together to make the finished cabin product. Kindly refer Appendix 1 for more detailed classification of different types of cabs produced by Scania.

1.1.1 MPCT

MPCT provides service to all departments and workshops in Oskarshamn with technical support, the design of production equipment and packaging. MPCT is also responsible for manufacturing prototypes. This Master thesis falls under this department which is responsible for all detail drawings that describes the production equipment used in workshops. MPCT serves as a guiding tool in issues concerning CE marking of equipment related to Assembly and Body divisions in Oskarshamn. (Scania, 2017)

1.2 Project Purpose

Centre of gravity not only plays an important role in defining the dynamics of the vehicle but also in the design of equipment to manufacture the vehicle itself. Knowing the location of the centre of gravity of the truck cabin is very crucial in different stages of production. As per the definition of centre of gravity, by calculating the position of CG of the cabin, the average location of all the weights of the cabin is obtained. This will assist the designer to describe the forces relative to the cabin during the design of any fixture or equipment.

Since all the cabs vary in heights, during assembly operations the cabin body in one particular line where the side doors are assembled, the entire cabin has to be lifted in order to adjust the height of the skid. Once the height of the skid is adjusted to the required height by means of a mechanism, the cabin is locked in this position and is ready to assemble the side doors. Also, a number of rotating robot arms are used in assembly lines for fixing windshields to the cabins which involve rapid lifting and rotating mechanisms. It is extremely important for all these mechanisms and fixtures to be robust during any assembly operation.
In order to design these mechanisms and fixtures in the assembly line, the reaction forces and moments acting on it from the cabin has to be estimated. Since, Scania has very limited knowledge about measuring Centre of gravity of the whole cabin, to design any new production equipment will become an iterative process. This is because of the unknown reactive forces, moments and torques to compare and use that data in the design of new production tools. Therefore, Scania identified a need of developing a station which calculates the CG and weight of the cabin on the transport skid (See Figure 1). So, measuring CG and weight of cabins forms a basic purpose of this project.

Scania\'s vehicle is designed in CATIA V5 at the production facility in Oskarshamn. Besides the large computing capacity, calculating the centre of gravity by using CAD models are difficult for various reasons. Additionally, it is very time-consuming to prepare a cab model according to a specific assembly extent. The cab model consists of thousands of parts with different materials. First of all, not all of the parts have the right density. Parts that are modelled with surfaces will not have the right volume and thus not the right weight. Many parts/assemblies from the suppliers do not have a homogenous density as they include several components. All these factors together with inaccuracies from measuring devices adds certain amount of error in the final measured CG values. CATIA V5 cannot determine the position of components like cables in control panels. The way cables are routed inside the panel will change CG position considerably. Also giving the accurate amount of weight to the paint and manufacturing tolerances from the suppliers will add up a large number of uncertainties to the CG position.

Apart from the need to measure centre of gravity mentioned in the previous section, the centre of gravity height is an important parameter in the automotive industry that determines the dynamics of the vehicle. Lower the centre of gravity, higher is the stability of truck. This is also one of the reasons why R&D department in Södertälje is also curious about this project and interested to know the CG measuring equipment.
1.3 Research Questions
This chapter deals with the main research questions pertaining to this master thesis.

The research questions that will be dealt with are as follows:

- How must the station be designed so that work becomes intuitive and rational?
- Which parameters are needed to be measured and which calculations are required to determine the centre of gravity?
- How should the values be read and measured?
- How accurate are the measured values?
- How safe is it both for the operator and the cabin during measurement?
- How is the cabin mounted on the station rigidly?

1.4 Project Goals and Deliverables
The work can be divided into a number of intermediate goals. Following outputs should be generated by the end of this project work.

- A complete CAD construction of the Station which calculates CG.
- Detail Drawings of station.
- A calculation module with a user-friendly interface to the user.
- An instruction manual to the station which clearly describes how the work in the station is to be performed.

1.5 Delimitations
Developing a sample prototype model which tests the final selected concept is a good idea to learn and understand the practical implications involved in this project. This would not be possible to achieve because of the time frame. Due to the evolving customer needs throughout this product development process, finding technical solutions to the needs and construction of station in CAD with complete instruction manual is the primary focus of this project. Time span of this project is 20 weeks and all the technical solutions concerning the minute details of construction is answered within this given timespan. So, during this project timeframe not constructing a prototype and obtain results from a physical model is regarded as limitation of this thesis.
1.6 Report Outline
How the structure of the report has been organized is presented in this section. A short overview of each section is described in this section so that the reader can clearly understand the outline of this report.

➢ Chapter1: Introduction

In this section an introduction about Scania’s Oskarshamn Production unit followed by MPCT division (Tools& Fixtures department) is presented briefly. Simultaneously other relevant topics covered in this section are purpose of the project, research questions, problem statement, project goals & deliverables, delimitations, and an outline about the structure of the thesis work.

➢ Chapter2: Theoretical Frame of Reference

All the relevant theory and concepts that are required for implementing this project is presented in this section. This section covers also the basic definitions so that any reader who don’t have any prior knowledge regarding technical background can understand this project work with the help of mentioned theory in this section.

➢ Chapter3: Method

How the project is taken forward and the choice of method used to accomplish the goals and deliverables of this project is explained more elaborately in this section.

➢ Chapter4: Implementation

How the above-mentioned method is implemented and selection of all the key decisions involved during different phases of this project are explained in this chapter.

➢ Chapter5: Results

Output of the method and obtained results will be presented in this section. This section also answers the desired project goals and deliverables mentioned in chapter1.

➢ Chapter6: Discussion

This section deals with the detailed description of the presented results in previous section. Technical interpretation, Logical reasoning and arguments on the results will be followed by referring to concerned literature.

➢ Chapter7: Conclusions

Based on the developed discussion important conclusions should be drawn in this section. Brief technical solutions will be recommended to the project statement in this section.
Chapter 8: References & Appendix

In these sections all the references that have been used in the current project work will be provided. The appendix consists additional information concerning the project so that the reader can refer to it to get a holistic idea about the project.
2 Theoretical Frame of Reference

During the course of the project, research was conducted on some particular theoretical aspects to ensure that all standards and requirements that are valid for the station to be designed is considered. These aspects are discussed in the following chapter to help the reader to understand basic knowledge about the technical aspects of this project.

2.1 Methods to Determine Centre of Gravity

To enhance knowledge on the station under development, a study on existing techniques with similar functionality is done. This section gives a brief description of the methods that were used or currently being used to measure the CG values.

2.1.1 Plumb Bob Method

In this method, CG value can be determined at the intersection points of all the plumb lines drawn from different positions of holes. A plumb line is just a string with a bob attached to the end of it and used specially to determine verticality. By hanging the object at hole 1, draw a vertical line with the help of plumb line. Repeat this process at other positions too and locate the intersection point of all the vertical lines (see Figure 2). This method is pretty much straightforward for implementing in 2-D planar objects, but for 3-D objects one has to project the intersection point of the planar CG location onto the third principal axis. (Elfick, 2015)

2.1.2 Tilting Method

Type 1: Tilt around transverse axis of the vehicle

This is one of the common method used to determine the CG in an automobile. From this method CG values can be obtained in two steps. In the first step longitudinal direction of CG position can be determined by using static equilibrium equations (see Figure 3) using the reaction weights measured beneath the 4 tyres of the vehicle with the help of a weighing platform. Using the same reaction weights, transverse direction of CG can also be determined. In the second step, in order to determine the vertical height position of the CG, the vehicle should be lifted to a certain height above the ground level (either front or rear of the vehicle) and the 2 reaction weights from 2 of the weighing platforms are noted down again. Following values have to be measured in this experiment: wheelbase, weights on scales and height into which vehicle is lifted (see Figure 4). (Rektorik, 2017)

![Figure 2: Plumb Bob Method](source: Elfick, 2015)
The calculations used to determine CG are presented below.

**Step1-Calculating CG:**

Vehicle wheel base = L  
Mass of front left wheel = \( m_1 \)  
Mass of front right wheel = \( m_2 \)  
Mass of back left wheel = \( m_3 \)  
Mass of back right wheel = \( m_4 \)  
Mass in front= \( m_1 + m_2 = m_f \)  
Mass in back= \( m_3 + m_4 = m_r \)  
Mass of vehicle = \( M_v = m_f + m_r \)

One can express the forces acting under each axle and the weight of the vehicle as follows:

\[
R_f = m_f \times g = (m_1 + m_2) \times g  \\
R_r = m_r \times g = (m_3 + m_4) \times g  \\
W_t = M_v \times g = (m_f + m_r) \times g
\]

The longitudinal position of the centre of gravity of the vehicle is then determined from the following two equilibrium moment equations relating either to rear or front axle.

\[
W_t \times b = m_f \times L  \\
W_t \times a = m_r \times L
\]

By simplifying the above equations one can get the longitudinal CG values as follows:

From rear end, \( b = \frac{(m_1 + m_2) \times L}{m_1 + m_2 + m_3 + m_4} \)

From front end, \( a = \frac{(m_3 + m_4) \times L}{m_1 + m_2 + m_3 + m_4} \)

Calculations involved to determine the value of CGv is similar to the above calculations except that the moments are taken on the loads on the other 2 wheels into the paper.
Step2-Height above the ground CGz:

From the below figure, one can represent the distances as follows:

Rear distance $l_1 = b \cos \alpha$, $l_2 = h_o \sin \alpha$ and $l_3 = L \cos \alpha$.

Then the equation of static torque equilibrium relative to the rear axle axis has the form:

\[
R_{rea} \cdot l_3 = W_t \cdot (l_1 + l_2)
\]

\[
R_{rea} = \frac{W_t \cdot (l_1 + l_2)}{l_3}
\]

\[
R_{rea} = \frac{W_t \cdot (b \cos \alpha + h_o \sin \alpha)}{L \cos \alpha}
\]

\[
R_{rea} = \frac{b}{L} \cdot W_t + \frac{W_t \cdot \tan \alpha \cdot h_o}{L}
\]

After further simplifying the above equation $CG_z(h_o)$ can be written as follows:

\[
\left\{ h_o = \frac{R_{rea} \cdot L}{W_t} - b \right\} \quad \text{(Rektorik, 2017)}
\]

Type 2: Tilt around longitudinal axis of the vehicle

The test object shall be placed parallel to the tilting axis on the tilting platform. First on a levelled plane by using reaction forces one can calculate CG using Newton’s second law as described above. This can be achieved by using weighing platforms or load cells or force transducers at the base of the object to measure reaction loads at desired positions (Winkler, et al., 1991). Then the tilting shall be done very slowly until desired angle is reached and the CG vertical height can be determined by using the same formula derived above (see Figure 5).
To determine the vertical position of CG, Motor Vehicle Manufacturers Association assessed the current practises of measuring CG height of light vehicles. Ford, GM, Chrysler and NHTSA participated in the study by demonstrating their own CG height measuring techniques on same test vehicles. More detailed descriptions about the techniques adopted by different companies can be found at (Winkler, et al., 1991).

2.1.3 Multi Point Weighing Method
The CG of test platform is determined by placing three or more load cells. CG in longitudinal and lateral directions can be calculated from the force measurements readings at these points (see Figure 6). Weight is nothing but the sum of force readings at these three transducers.

\[ W = A + B + C. \]

By taking moments at x and y we get the following expressions (Groover, 2013).

\[
\sum M_x = (B+C)L - WX = 0
\]

\[
\sum M_y = \frac{CD}{2} - \frac{BD}{2} - WY = 0
\]

\[
\Rightarrow \frac{D}{2} (C-B) - WY
\]

\[ X = \frac{(B+C)L}{W} ; \quad Y = \frac{(C-B)D}{2W} \]
In the second step one needs to tilt the test object to a certain angle on multiple weighing modules and determine the vertical Component of CG in the same way as explained in the tilting method.

2.1.4 Instability Method

Step1: On a flat horizontal surface, the longitudinal and transverse parameters (CG\(_X\) & CG\(_Y\)) can be measured by the same principle as explained in tilting method. For more detailed description refer the paper Determination of vehicle’s CG position. (UN, 2000)

Step2:
Main principle behind this method is to place the test object parallel to the tilting axis on the tilting platform. The tilting shall be done gradually till the instability position of the vehicle is reached (see Figure 7). This step has to be repeated three times and the average value of the three tilting angles should be used for the calculation of CG height. This tilting test should be made on both the directions and CG\(_Z\) height can be calculated from the below derived formula.

\[
CG_{zi} = \frac{b \pm 2CGY}{2 \times \tan \alpha_i}.
\]

\(\alpha_i\) & \(CG_{zi}\) are values corresponding to left and right tilting tests.

By taking average of both the directions final CG\(_Z\) value can be obtained. For detailed method descriptions and formulas refer the concerned paper. (UN, 2000)
2.2 Force Measurement
A brief description and working principle of Industrial weighing scales are mentioned in this section.

2.2.1 Platform Weighing Scales
Compact platform weighing scales are widely used to measure weight with weighing capacities from 1000kgs to 10000kgs, (see Figure 8). To ensure consistent performance, high sensitive load cells are placed at the heart of platform which are specifically designed for high resolution and production environments. A typical platform weighing scale consists of a platform of desired dimensions and the output can be read in digital indicator as shown in below figure. (Vetek, 2016)
2.2.2 Load Cell

Load cells are used in many weighing applications in various installation configurations. Load cells are generally a typical strain gauge type, electromagnetic type or piezoelectric type. The electromagnetic and piezoelectric type of load cells are highly accurate, very expensive and are mostly used in aerospace industries or where accurate prediction of dynamic loads are required. Strain gauge load cells are the most common type of load cells and has numerous applications. Strain gauge load cells work on the principle of Wheatstone bridge network. This working principle is explained in the next section.

Depending on the type of application, load cells can be classified into following categories see Figure 9. (Collins, 2013)

![Figure 9: Classification of Load Cells](source: (Collins, 2013))

One component load cells measures load in vertical direction, whereas two component and three component cells reads values in other two directions. In addition to the readings in three directions, six component load cells give measurements of moments in respective directions. One can find much information about load cells in the following journal (Collins, 2013).

2.2.2.1 Strain Gauge

Strain gauge is one of the most important sensor of the electrical measurement techniques applied to the measurement of mechanical quantities. It is a device used to measure strain on an object and can be measured by measuring the change in its resistance (Kyowa, 2016). If a metal conductor is stretched or compressed, its resistance changes because of its change in length and diameter changes. This phenomenon where in the resistance of material changes because of its resistivity changes is called piezo resistive effect.

Resistance of wire can be expressed as \( R = \frac{\rho L}{A} \). \( L \) is length of wire, \( \rho \) is resistivity of material and \( A \) is cross sectional area. Wheatstone bridge is used to measure this change in resistance and related to the strain by gauge factor.
Wheatstone Bridge

General arrangement of Wheatstone bridge is shown in below Figure 10. It consists of four arms AB, BC, DC and AD with respective fixed resistances P & Q, S is variable resistance and R is the unknown resistance. A sensitive galvanometer is connected across the terminals B and D. A battery is connected across terminals A and C. This circuit is said to be balanced when no current flows in galvanometer. That means voltage difference between points B and D is zero. At this condition current flowing through resistances P and Q is i₁ and current flowing through resistances R and S is i₂. Because voltage drop from point A to Point B is equal to Point A to D then  \( i_1 \cdot P = i_2 \cdot R \). Similarly, in the next case \( i_1 \cdot Q = i_2 \cdot S \). By dividing these two equations the unknown resistance R can be determined in terms of other known resistances of the bridge as \( R = \frac{P}{Q} \cdot S \) (Kyowa, 2016).

![Figure 10: Wheatstone Bridge](Source: Kyowa, 2016)
3 Method

In this section, the method used during this thesis is described. This method is comprised of identifying the needs, where specific information pertaining to the requirement of the product is gathered. Target specification, where required targets are set with respect to the needs prior to the concept generation phase. Various concepts are developed during concept generation stage and finally concepts are evaluated to proceed with the detailed design. The phases after detailed design, does not fall under the scope of this thesis and hence will not be presented. Generic product development process described in (Ulrich & Eppinger, 2012) is used as a reference to develop the following work flow for this project.

![Figure 11: Product Development Process](image)

3.1 Identify Customer Needs

Identifying the needs of the customer is the foremost step prior to any product development to ensure the product is customer focused. It establishes a connection between the designer and the customer’s requirement. According to Karl. L. Ulrich and Steven. D. Eppinger, the process of identifying the customer needs is an integral part of the product development process and is closely related to the concept generation, concept selection and the establishment of product specifications.
3.1.1 Interviews
Here one or more team members discusses the needs with the single customer. It is usually conducted in the customer's environment and typically lasts one or two hours (Ulrich & Eppinger, 2012).

3.1.2 Questionnaire
Structured questionnaires can be electronic, or paper based. It helps to collect information in a form of written document stated directly from the customer. The questions designed should seek information in an unbiased, unambiguous, clear, and brief manner. The best questions ask about attributes, not influences. Attributes express what, where, how, or when. Why questions should lead to what, where, how, or when as they describe time, quality, and cost (Ullman, 2010).

3.2 Product Specification

Product specifications gives precise descriptions of what the product has to do or in more technical terms which describes the Engineering Characteristics (Ulrich & Eppinger, 2012). These specifications which define the product technically, are set early in the product development process to proceed with the design. These specifications are directly the solution to the product that links the requirements from the customer. It is very important to set the right targets at this stage of the project as it is less expensive to change in beginning rather than in the later stage of the project.

3.2.1 List of Metrics
Metrics bridges the gap between the need and the final product. They have a measurable characteristic of the customer’s needs. According to (Ulrich & Eppinger, 2012), a good way to generate the list of metrics is to contemplate each need in turn and to consider what precise, measurable characterises of the product will reflect the degree to which the product satisfies that need.

3.2.1.1 Set Ideal and Marginal Acceptable Target Values
Two types of target values are useful for setting the values of the metric: an ideal value and a marginal value. The ideal value is the best result the team could hope for and marginal value corresponds to the value of the metric that would just barely make the product commercially viable (Ulrich & Eppinger, 2012).

There are five ways to express the values of the metric:

- At least X: a minimum bound
- At most X: a maximum bound
- Between X and Y: Upper and lower bound
- Exactly X: No bounds and this type of metric should be avoided if possible.
- A set of discrete values: several discrete choices

The specifications set in the beginning of the product development process are not always the final specifications. However, these specifications will be revisited during the entire course of the development process as it is extremely difficult to set the final specifications in the initial stage of the project and trade-offs frequently occur between different technical performance metrics and almost always occur between technical performance metrics and cost.
3.3 Concept Generation:
The main purpose of concept generation is to establish several possible solutions to the problem. According to (Ulrich & Eppinger, 2012), the product concept is an approximate description of the technology, working principles and form of the product. The degree of customer satisfaction is directly proportional to the quality of the underlying concepts. The technical basis to the concept generation phase are the needs and the target specifications. If the needs are well acquired and the target specifications are well defined, the risk to avoid very good solutions will be considerably lowered.

3.3.1 Black box
The first step in the concept generation process would be establishing a black box. Black box provides a visual representation of the overall function of the product. It is a technique used to investigate the essential requirements to convert the control input to the desired output. Once the overall basic function is identified, it will be easy to build a morphology from this step. A basic representation of a black box is shown in the Figure 12.

![Figure 12: Physical Representation of Black Box](image)

3.3.2 Building a Morphology
Building a morphology is one of the most powerful methods to generate concept ideas. Generally, this technique is carried out in following three steps (Ullman, 2010).

- Decompose the function
- Develop concepts for each sub functions
- Combine concepts

Listing all the decomposed functions that needs to be accomplished and finding technical solutions to all the sub functions list in step one will simplify the whole design process. Because most of the design challenges are too complex to solve as a single problem and the product development process can be simplified by dividing them into several simpler sub problems. The resulting table from this morphological method is called as morphology which means “a study of form or structure” (Ullman, 2010). An example of such table on design of one handed bar clamp is shown in the following Figure 13.
### Morphology

**Product:** One-handed bar clamp  
**Organization Name:** Irwin Tools

<table>
<thead>
<tr>
<th>Subfunctions</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collect grip force and motion from user</td>
<td>One trigger</td>
<td>Two triggers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transform grip force and motion to bar</td>
<td>Jam plate</td>
<td>Ratchet</td>
<td>Rack and pinion</td>
<td>Linkage</td>
</tr>
<tr>
<td>Move bar</td>
<td>Free sliding</td>
<td>2 speed system</td>
<td>&gt;2 speed system</td>
<td></td>
</tr>
<tr>
<td>Amplify force</td>
<td>Short stroke</td>
<td>Long stroke</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 13: Example of Morphology*  
*Source:* (Ullman, 2010)
3.4 Concept Selection:
According to (Ulrich & Eppinger, 2012) concept selection is the process of evaluating concepts with respect to the needs of the customer and other criteria’s, comparing the relative strength and weaknesses of the generated concepts. Here the concepts are evaluated to narrow down to one or two of the many alternating concepts with regards to the value and quality with respect to the needs from the customer.

3.4.1 Concept Scoring
Concept scoring technique will provide a thorough differentiation among the selected concepts. The team first identifies all the criteria based on which the scoring and selection can be made. A selection matrix is prepared with all the listed criteria’s and all the concepts are rated with respect to a reference concept. An example of scoring matrix is shown in below Figure 14.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Weight</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
<th>Weighted Score</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of handling</td>
<td>5%</td>
<td>3</td>
<td>0.15</td>
<td>3</td>
<td>0.15</td>
<td>4</td>
<td>0.2</td>
<td>3</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Ease of use</td>
<td>15%</td>
<td>3</td>
<td>0.45</td>
<td>4</td>
<td>0.6</td>
<td>4</td>
<td>0.6</td>
<td>3</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Readability of settings</td>
<td>10%</td>
<td>3</td>
<td>0.75</td>
<td>3</td>
<td>0.75</td>
<td>2</td>
<td>0.5</td>
<td>3</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Dose metering accuracy</td>
<td>25%</td>
<td>3</td>
<td>0.3</td>
<td>5</td>
<td>0.75</td>
<td>4</td>
<td>0.6</td>
<td>3</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td>15%</td>
<td>2</td>
<td>0.3</td>
<td>5</td>
<td>0.6</td>
<td>4</td>
<td>0.4</td>
<td>2</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Ease of manufacture</td>
<td>20%</td>
<td>3</td>
<td>0.6</td>
<td>3</td>
<td>0.6</td>
<td>2</td>
<td>0.4</td>
<td>2</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Portability</td>
<td>10%</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

Total Score
Rank
2.75
1
3.45
4
3.10
2
3.05
3

Continue? No
Develop No
No

Figure 14: Example of Concept Scoring
Source: (Ulrich & Eppinger, 2012)
3.5 Detailed Design

The purpose of detail design is to furnish the complete engineering description of the tested product. The arrangement, form, dimensions, tolerances, and surface properties of all individual parts along with materials to be used, manufacturing processes to be adopted are decided in this section.

3.5.1 Detail Construction

Entire 3-D model of this station is built in CAD. CAD is a computer program which is used to create two or three-dimensional graphical representation of physical objects. It enables the users to test and learn more about existing products and parts. With the help of CAD any designing flaws can be rectified before the creation of physical prototype. In addition, CAD allows for use of all the standard symbols required for technical drawings and schematics. Better visualization of final products, sub-assemblies and constituent parts in a CAD system speeds the design process. (Ulrich & Eppinger, 2012)

3.5.2 Bill of Materials

BOM or product structure is a list of raw materials, sub-assemblies, sub-components, parts, and the quantities that are needed to manufacture the final end product. BOM often tied to production ordering. For example, if the manufacturing department is making 1000 parts each use four Y type screws then the purchasing department knows to order 4000 Y screws based on BOM. A typical example of BOM is shown in the below Figure 15. To shorten the assembly parts of bigger components a separate BOM list is used for each assembly. Usually BOM list consists of 5-6 columns of information. Each column gives information about number of components needs to be manufactured, material needs to used, part numbers and dimensions of the workpiece. (Ullman, 2010)

![Bill of Materials](image)

*Figure 15: Example for Bill of Materials*
*Source: (Ullman, 2010)*
3.5.3 Product Evaluation for Performance:

In this section one can compare the performance of the designed product to the target specifications developed earlier in the initial stages of the project. In this way one can comprehend the total functional behavior of the product and how much error it produces due to inaccuracies. Comparison between performance of product and specifications should be done in terms of tangible numerical values and even coming up with a rough values are better than no values at all (Ullman, 2010). In addition to error estimation, performing sensitivity analysis provides information about the effect of changing one variable or more variables on the outcome result. By doing so one will get powerful insights into the design problem and can judge the relative importance of influencing parameters on the final results.

3.5.4 Design for Assembly

Provided enough time, money and resources it is possible to manufacture most things that are designed. Simultaneously it is more cost effective to design a product with quality and efficient manufacturing practices.

Maximizing ease of assembling components and designing a product that can be easily operated by inept customers is another crucial step in product development process. Following design principles suggested by Boothroyd and Dewhurst (Ulrich & Eppinger, 2012) are considered in developing this station.

- Minimizing the parts count.
- Designing parts with self-aligning features like chamfers to reduce the total assemble time.
- Reducing securing operations like tightening, curing while designing parts so that they will fit properly upon insertion.
- Part introduction from top of assembly/ Z-axis assembly.
- Integration of the parts/part which solves multipurpose operations.
- Standardizing the parts as much as possible.
- Giving priority to modular architecture.

3.5.4.1 Ergonomics and Usability

Ergonomics is about matching products and tasks with people. More work can be done by an operator if the working equipment is easier and safer to use. Many gadgets and appliances have highly impressive features, but some are difficult to figure out even if you still have the instruction manual. This is frustrating, and it means many features are wasted, because the users stick to the simplest tasks. While designing any new products one needs to understand the way people think and interpret the information. It can be as simple as using red for stop and green for go. It is that what people are used to. Also designing a product so that the people can do the obvious is the important parameter for designing any new product (Brinkerhoff, 2009).

Because humans by nature are of different shape and size and in order to match this working station to people physically, one need information about people's characteristics. During handling objects and equipment's, one need to use a certain amount of force. To find out how much force people comfortably exert in different situations designers needs information about the biomechanics of the human body. For designing a pedal mechanism, one needs data that tell us how hard people can push their legs at different angles. For turning a knob or handle one can look at how people’s turning strength is effected by the handle diameter.
This all information comes from the field of anthropometry. A careful study of anthropometric data is considered while designing this station. This station is designed in complete cooperation with the ergonomic information aspects of the design that are important for the people during operating the station.
4 Implementation

This chapter presents how the work of this thesis is carried out using the method described in chapter 3 and discusses about why certain choices that has been made.

4.1 Identify Customer Needs

The main purpose in this phase was to identify and receive as much information as possible. This phase is crucial, if the needs are not properly understood in the very beginning, the desired expectations cannot be met. Almost a week was spent to gather all the preliminary information’s both within the department and the workshop where prototypes are tested. All the possible information’s pertaining to this project were collected by means of having a person to person interviews, questionnaires and finally some of the additional needs were also captured from the thesis description document.

4.1.1 Interviews

Planned Interviews were conducted with the designers within the MPCT department in Scania CV AB. These interviews gave the insights about the background, the need to establish the station and understand the project in detail. The details of the interviews are presented in Appendix 2.

4.1.2 Questionnaire

The team prepared a list of questions to get a better understanding of the requirement. This process was quick and a hand-written document which enabled to retrieve few needs which were unstated during the interviews. See Appendix 3.

4.1.3 Needs List and its Relative Importance

A list of needs was prepared based on the information gathered from the previous section. All the stated needs and unstated needs are interpreted and translated into specific needs of the customer. The set of needs that falls under a common category were identified and named after them.

After the preparation of the needs list, their relative importance was ranked in a team of 4, including the project supervisor and the Manager of MPCT department at Scania CV AB.

Relative importance of the needs was established based on the scale rating from 1 to 5 with each scale representing the following (Ulrich & Eppinger, 2012).

- Scale rating 1: Feature is undesirable. I would not consider a product with this feature.
- Scale rating 2: Feature is not important, but I would not mind having it.
- Scale rating 3: Feature would be nice to have but is not necessary.
- Scale rating 4: Feature is highly desirable, but I would consider a product without it.
- Scale rating 5: Feature is critical. I would not consider a product without this feature.

The output of this phase is a matrix with stated & latent needs of the customer and its relative numerical weightage of the needs. This matrix was carefully evaluated to ensure a customer focused product. The needs table is presented in Figure 16.

Upon termination from this stage, it was evident for the team that measuring CGX or CGY value for the cabin is pretty straight forward as described in the theory. But, for determining the
vertical height $CG_Z$ the cabin has to be tilted to a certain angle. $CG_Z$ value of the cabin can be obtained with full accuracy of the machine when it is tilted $90^\circ$. But, the cabin cannot be tilted to complete $90^\circ$ because of the following practical issues.

- Entire outside surfaces of the cabin are considered as A-surfaces. Which means those surfaces should be free from dents and surface finish quality must be very high.
- For the cab to tilt $90^\circ$ almost $50\%$ weight of the cabin must be removed for this purpose. Otherwise, it will cause damages to some of its parts like mirrors, head lights and cause dents to its surface.
- Hard to find flat surfaces for holding in this position.
<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Need list</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The station accurate in measurement</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>The station measures weight of the cabin accurately</td>
<td>5</td>
</tr>
<tr>
<td>1.2</td>
<td>Measure centre of gravity of the cabin accurately</td>
<td>5</td>
</tr>
<tr>
<td>1.3</td>
<td>The station is stable during measurement</td>
<td>5</td>
</tr>
<tr>
<td>1.4</td>
<td>The station is robust in design</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>The station is versatile</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>The measurements are done with the transport skids</td>
<td>5</td>
</tr>
<tr>
<td>2.2</td>
<td>The station measures weight and CG for all New gen cabs</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>The station is safe and ergonomical</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Skid is completely rigid on the station</td>
<td>5</td>
</tr>
<tr>
<td>3.2</td>
<td>Cabin is safe on the station when tilted</td>
<td>5</td>
</tr>
<tr>
<td>3.3</td>
<td>The station has sound ergonomics</td>
<td>4</td>
</tr>
<tr>
<td>3.4</td>
<td>Less impact on the measuring device</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>The station is easy to operate</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>The station comes as a complete unit with user instructions</td>
<td>5</td>
</tr>
<tr>
<td>4.2</td>
<td>The assembly is intutive on station</td>
<td>4</td>
</tr>
<tr>
<td>4.3</td>
<td>The dis assembly is intutive on station</td>
<td>4</td>
</tr>
<tr>
<td>4.4</td>
<td>Station has a calculation module with user friendly interface</td>
<td>5</td>
</tr>
<tr>
<td>4.5</td>
<td>Easy to read the values on the station</td>
<td>5</td>
</tr>
<tr>
<td>4.6</td>
<td>Measurements are made in less time</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>The station is economical</td>
<td></td>
</tr>
<tr>
<td>5.1</td>
<td>Cost effective</td>
<td>4</td>
</tr>
<tr>
<td>5.2</td>
<td>Simple design</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Maintainance</td>
<td></td>
</tr>
<tr>
<td>6.1</td>
<td>The station is easy to maintain</td>
<td>4</td>
</tr>
</tbody>
</table>

*Figure 16: Customer Needs list*
4.2 Product specification

Prior to the execution of the concept generation phase, the technical product specification was established after spending a great deal of time in identifying the needs. A list of metrics was listed that defines the CG measuring station.

Metrics are established based on the need list and each need should correspond to one of the metrics. The importance of the needs was given based on the relative importance established in the identifying the need phase. The ideal and marginal values are set based on the literature review, Scania’s specific need and the existing specifications in Scania CV AB.

These metric specifications were refined several times during the entire course of design phase. For the product specification list, refer Figure 17.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Corresponding need</th>
<th>Importance</th>
<th>Unit</th>
<th>Marginal value</th>
<th>Ideal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy of load measuring device</td>
<td>1.1,1.2.5.1</td>
<td>5</td>
<td>% Full scale</td>
<td>±0.05</td>
<td>±0.01</td>
</tr>
<tr>
<td>Tolerances on linear measurements</td>
<td>1.2</td>
<td>5</td>
<td>mm</td>
<td>±1</td>
<td>±0.01</td>
</tr>
<tr>
<td>Resolution of the angle measuring device</td>
<td>1.2</td>
<td>5</td>
<td>deg</td>
<td>0.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Station tilt angle</td>
<td>3.2,1.2</td>
<td>5</td>
<td>deg</td>
<td>20-30</td>
<td>90</td>
</tr>
<tr>
<td>Range of weight measurement device</td>
<td>2.1,2.2</td>
<td>3</td>
<td>Kg</td>
<td>0-800</td>
<td>0-2000</td>
</tr>
<tr>
<td>Flatness of the surface</td>
<td>1.1, 1.2, 1.3</td>
<td>5</td>
<td>mm</td>
<td>±1</td>
<td>±0.01</td>
</tr>
<tr>
<td>Material properties</td>
<td>1.4</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Counter balance force</td>
<td>1.3</td>
<td>4</td>
<td>N</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Scania’s Ergonomic standard</td>
<td>3.3, 3.4</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>User instruction manual</td>
<td>4.1, 6.1</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cabins that the station can accommodate</td>
<td>2.1,2.2</td>
<td>4</td>
<td>-</td>
<td>All new gen cabs</td>
<td>All</td>
</tr>
<tr>
<td>Time to assemble on station</td>
<td>4.2</td>
<td>4</td>
<td>Minutes</td>
<td>&lt; 10</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Time to dis assemble from station</td>
<td>4.3</td>
<td>4</td>
<td>Minutes</td>
<td>&lt; 10</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Time to operate on station</td>
<td>4.4,4.5,4.6</td>
<td>4</td>
<td>Minutes</td>
<td>&lt; 10</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>Overall cost</td>
<td>5.1,5.2</td>
<td>3</td>
<td>SEK</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Figure 17: Product Specifications*
4.3 Concept generation
This phase focuses on the generation of the concepts. Concepts were generated purely based on the experience of the team members and the following procedure were followed to generate distinct concepts.

4.3.1 Black box
To start with, a simple functional analysis was done using the concept of black box before jumping into actual concept generation. This enabled the team to understand and create a solid base to list out all the sub functions. Refer Figure 18 for the back box.

![Diagram of Black Box](image.png)

4.3.2 Building a Morphology
After understanding a bigger picture by means of a black box, the team decided to decompose the function and list out all the sub functions involved to determine the required output. All the sub functions were listed out which also describes the procedure to conduct the experiment. After a brainstorming session, large amount of ideas was generated. These ideas were sorted out to fit into each sub functions. This produced many concept ideas for each sub function. The resulting table is presented in Figure 19.
## Morphological Matrix

**Product:** Station to calculate the weight and centre of gravity of a truck cabin

<table>
<thead>
<tr>
<th>Sub functions</th>
<th>Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td>A</td>
<td>Stabilize platform</td>
</tr>
<tr>
<td></td>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td>B</td>
<td>Position the skid with mounted cabin onto the platform</td>
</tr>
<tr>
<td></td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
<tr>
<td>C</td>
<td>Grip the skid rigidly onto the station</td>
</tr>
<tr>
<td></td>
<td><img src="image11" alt="Diagram" /></td>
</tr>
<tr>
<td>D</td>
<td>Measure the reactions forces</td>
</tr>
<tr>
<td></td>
<td>Platform weighing</td>
</tr>
<tr>
<td>E</td>
<td>Tilt the platform</td>
</tr>
<tr>
<td></td>
<td><img src="image16" alt="Diagram" /></td>
</tr>
<tr>
<td>F</td>
<td>Measure the angle of tilt</td>
</tr>
<tr>
<td></td>
<td><img src="image21" alt="Diagram" /></td>
</tr>
<tr>
<td>G</td>
<td>Measure the reaction forces</td>
</tr>
<tr>
<td></td>
<td>Platform weighing</td>
</tr>
<tr>
<td>H</td>
<td>Tilt the platform back to the initial position</td>
</tr>
<tr>
<td></td>
<td><img src="image26" alt="Diagram" /></td>
</tr>
</tbody>
</table>

*Figure 19: Morphological Matrix*
4.3.3 Concept combination

The morphological matrix prepared yielded too many possible solutions which are practically impossible to generate, and some results obtained did not make any sense. Moreover, each concept can work with all the concepts of a sub function. For example, even though a concept was chosen a bubble inclinometer to measure the angle, this does not mean that other instruments listed in the sub function cannot measure the same angle. This also depends on how the station is going to be constructed. A good idea was to perceive an overall picture of the station. Sensible combination’s yielded five good concepts that can be practically implemented. The actual combinations are presented in the beginning of each of the concepts in Appendix 4.

4.4 Concept Selection

All the concepts presented in the previous section differs only in the measurement of CG\(_Z\). Whereas, the principle involved in the measurement of CG\(_X\) and CG\(_Y\) is the same. The values of CG\(_Z\) in all the concepts is measured either by taking the reaction force when tilted or by tilting the cabin till the instability point occurs. And the reaction loads were either measured using a simple weighing scale which is cheap or with the help of highly accurate load cells which can measure forces in all the 3 directions. Apart from these, each concept differs in its construction.

All the concepts were presented to the Manager and the Supervisor at MPCT department in Scania CV AB. The first impression was that all the concepts were unique and from a broad perspective, all these concepts work to fulfil all the desires needs. Since it was very hard to pick a concept at this point, the team decided to compare every concept with some criteria based on which selection can be made. Some of the key feedbacks were recorded and are presented below.

- Concept 1 looks simple in design
- They liked the idea of clamp design over the platform weighing.
- Concept 4 seems very accurate because of the use of load cells.
- Need for a protection for the load measuring device
- Other concepts are also very interesting
- It’s a good idea to list out some criteria before selection
- It’s good to involve other designers in the department during concept selection

Since all the concepts were interesting to evaluate, the team decided to proceed to compare all the concepts by assigning certain weights to each of the criteria’s.

4.4.1 Preliminary cost estimation

For all the developed concepts, a preliminary cost analysis is made on the important working components of respective concepts. Estimation of manufacturing costs and parts of the station is not considered in this preliminary cost estimation. In this way one can save time and directly get an overview of the costs involved in each of the concepts. As the needs of the customer evolved, Cost became an important factor at this stage. This cost estimation is one of the crucial parameter in concept ranking and selection phases of this project. Estimated costs for all the concepts are shown in Appendix 5.
4.4.2 Concept Scoring

The concepts were evaluated by using the concept scoring matrix in order to evaluate every individual concept and to eliminate the concepts that does not fulfil certain criteria’s. A list of criteria were listed based on the need list and was further developed and mutually agreed by the team.

The scoring in the matrix was established by including a team of 5 design experts at Scania CV AB. All the needs that fall under a specific category was carefully scrutinized for each concept before assigning the weights.

Concept 2 was set as datum and the relative performance was rated to the other concepts based on the following as defined by (Ulrich & Eppinger, 2012).

- Scale rating 1: Much worse than reference
- Scale rating 2: Worse than reference
- Scale rating 3: Same as reference
- Scale rating 4: Better than reference
- Scale rating 5: Much better than reference

This evaluation was done over 3 times with different datum and were evaluated for the best. Concept 1 still scored the highest net score and finally, one concept solution was chosen which weighed higher than the other concepts to proceed with the detailed design phase. The decision matrix is presented in the Figure 20.

<table>
<thead>
<tr>
<th>Selection criteria</th>
<th>Weights</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of measurement</td>
<td>20</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Versatility</td>
<td>15</td>
<td>3</td>
<td>0.45</td>
<td>3</td>
<td>0.45</td>
<td>3</td>
</tr>
<tr>
<td>Safe and ergonomical</td>
<td>20</td>
<td>4</td>
<td>0.8</td>
<td>3</td>
<td>0.6</td>
<td>4</td>
</tr>
<tr>
<td>Ease to use / Operate</td>
<td>15</td>
<td>5</td>
<td>0.75</td>
<td>3</td>
<td>0.45</td>
<td>3</td>
</tr>
<tr>
<td>Economical</td>
<td>15</td>
<td>3</td>
<td>0.45</td>
<td>3</td>
<td>0.45</td>
<td>3</td>
</tr>
<tr>
<td>Easy to maintain</td>
<td>5</td>
<td>5</td>
<td>0.25</td>
<td>3</td>
<td>0.15</td>
<td>4</td>
</tr>
<tr>
<td>Durability</td>
<td>10</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>Net score</td>
<td>4</td>
<td>3</td>
<td>3.25</td>
<td>3.65</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Continue?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Figure 20: Concept Scoring Matrix

Apart from the decision made through the matrix, the working procedure followed in Concept 1 is similar to the experiments which were previously conducted by Scania CV AB to measure the CG values. This is also one of the reason to take a firm decision to proceed with the development of Concept 1. Refer Appendix 6 for discussion details of concept scoring.

After concluding to proceed with the first concept, a safe angle to which the cab can be tilted in order to determine CGz value was set to around 20⁰ based on the previous experience and to ensure the safety of the cabin since the cabin is mounted on the transport skid during the experiment.
4.5  **Detail Design**  
This section presents the complete specifications of geometry, materials, and tolerances of all the individual parts in the product. Outcome of this phase is identification of standard parts, materials selection and production costs.

4.5.1  **Construction**  
It was important at this stage for the team to investigate further on the development of the chosen concept to resemble a measuring station which is simple and easy to operate. Based on the analysis from the decision matrix, the chosen concept is to be developed further and constructed in detail. Before proceeding with the CAD construction, some research was made on few of the assembly and measuring stations within Scania CV AB in Oskarshamn to have a basic idea of how a station looks like and how the operators are working on the station.

This station is constructed with reference to another already existing measuring station at Scania CV AB which is mainly used to measure all the geometric dimensions and form of the cabin at different stages of manufacturing. Figure 21 shows the entire CG measuring station.

![Figure 21: Complete 3-D Model of Station](image-url)
The construction of the station can be explained in 3 major sub-assemblies.

4.5.1.1 Base construction

The base construction consists of a very stout weldment structure which primarily consist of standard rectangular beams, square plates and stiffeners to have good rigidity to the structure. The standard beams used in this structure is 150x100x10 mm and the plate thickness is of 20 mm.

The longitudinal and transverse beams in the centre which forms a rectangle is constructed to take all the loads from the lift table and support the lift table assembly. The four ends of the structure have a square plate at the top which is welded to the beams. Each of this square plate has 4 M16 threaded holes to mount the pillars during the final station assembly. This entire structure in mounted on the concrete floor at 10 different positions with the help of M28 bolts as shown in the Figure 22. This type of mounting enables the station to be adjusted to obtain the required flat surface at the top surface of the weighing platform. Achieving this flatness on top of all the four pillars is crucial since it adversely affects the accuracy of the measured values. This also means that, provisions are made to calibrate the station easily.

In addition, provisions are made to access the forks of the fork lift to make the station mobile. Two C shape openings are provided under the bottom surface of four beams as shown in Figure 22. Two flat rectangular plates are welded into these two C cuts so that forks will get a complete planar surface while lifting and transporting from one place to another.

This structure was refined several times by varying the dimensions of the plate and adding reinforcements to attain a stable and rigid structure. Since the station is used to measure very sensitive parameters, it is paramount to have a very stiff structure so that the readings taken from the station are close to actual.

Figure 22: Base Weldment Structure
4.5.1.2 Pillar assembly

The pillar assembly can be divided into front pillar assembly and back pillar assembly shown in Figure 23. The only difference between these two assemblies is the length of the beam. A single pillar assembly typically consist of a standard rectangular beam of 200x100x10 cross section which is welded to a 20 mm thick square plate in the top and the bottom. The structure is made stiffer by means of adding ribs.

Above the pillars are the weighing platforms mounted by means of 4 M8 screws (per platform) onto the top surface of the pillar assembly. The weighing platforms in the front has 2 support components mounted on top of it. These components ensure safety for the skid during operation. Apart from this, safety cover plates are installed in the front pillars for the safety of the weighing platforms in the front during operation. This can be understood in the section 5.3 where the operating procedure is discussed.

Figure 23: Pillar Assembly
4.5.1.3 Lift table assembly

The lift table assembly mainly consist of lift table, front guides, side guides, back guides, support pillar and lift link assembly shown in Figure 24. The lift table is a custom made bought out part from the supplier HYMO. It is specifically designed to assemble the required parts and perform the intended operation. The main purpose of the lift table in the station is to position the cabin, eliminate the impact from the fork lift truck onto the weighing platform and tilting operation. All these operations are explained in detail in the section 5.3.

The back guides are equipped with dampers (Not shown in figure) to take up the impact load from the fork lift. The calculation involved in damper selection can be found in Appendix 7.

The support pillar has an index pin which holds the lift link assembly and one more index pin is used in the lift link assembly to hold the clamp in its position. In addition, rubber sheets are glued in the face of support pillar to avoid metal to metal contact from the lift link assembly.

Figure 24: Lift Table Assembly
and a chain is connected from the support pillar to the lift link assembly to avoid the risk of lift link assembly fall free towards the front. All these acts as safety accessories during experiment.

Static FE analysis performed on all the components and sub-assemblies. FE Analysis reveal that all the stresses and displacements are well within acceptable limits. The results from the FE Analysis are presented in Appendix 8. After the completion of the detailed construction of the CAD model, BOM and detailed drawings are generated. These information’s are available only with Scania CV AB and is not circulated.

The theoretical weight estimation is done by properly assigning materials in CAD. Refer Table 1.

<table>
<thead>
<tr>
<th>Component/ Assembly</th>
<th>Quantity</th>
<th>Weight per piece(kgs)</th>
<th>Combined Weight(Kgs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Construction</td>
<td>1</td>
<td>701</td>
<td>701</td>
</tr>
<tr>
<td>Front Pillar Assembly</td>
<td>2</td>
<td>117,727</td>
<td>235,454</td>
</tr>
<tr>
<td>Back Pillar Assembly</td>
<td>2</td>
<td>119,059</td>
<td>238,118</td>
</tr>
<tr>
<td>Weighing Platform</td>
<td>4</td>
<td>14.5</td>
<td>58</td>
</tr>
<tr>
<td>Support component</td>
<td>2</td>
<td>8,458</td>
<td>16,916</td>
</tr>
<tr>
<td>Side Guide</td>
<td>6</td>
<td>4,683</td>
<td>28,098</td>
</tr>
<tr>
<td>Back Guide</td>
<td>2</td>
<td>20,788</td>
<td>41,576</td>
</tr>
<tr>
<td>Safety Cover Plates</td>
<td>2</td>
<td>3,399</td>
<td>6,798</td>
</tr>
<tr>
<td>Lift link assembly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beam</td>
<td>1</td>
<td>28,427</td>
<td>28,427</td>
</tr>
<tr>
<td>Clamp</td>
<td>1</td>
<td>21,206</td>
<td>21,206</td>
</tr>
<tr>
<td>Clevis Joint</td>
<td>1</td>
<td>7,071</td>
<td>7,071</td>
</tr>
<tr>
<td>Shaft housing</td>
<td>4</td>
<td>1.09</td>
<td>4.36</td>
</tr>
<tr>
<td>Support pillar</td>
<td>1</td>
<td>6,643</td>
<td>6,643</td>
</tr>
<tr>
<td>Dampers</td>
<td>2</td>
<td>1.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Lift table</td>
<td>1</td>
<td>1400</td>
<td>1400</td>
</tr>
</tbody>
</table>

Total Weight: 2795,867

Note: These weights are excluding fasteners, shafts, cables and all the other accessories.

Table 1: Station weight

4.5.1.4 Weighing module setup

The entire weighing module set up solution is provided by the company, Vetek. The weighing module consist of 4 weighing platforms of capacity 1.5T with an accuracy of 0.03% of Full Scale. Each of these weighing platforms is connected to a Stainless steel digital weight indicator which can display 4 channels at the same time. All the 4 weighing platforms are connected to the indicator by means of cables or Wi-Fi enabled and the output is transferred to the computer through another cable. The circuit connection is shown in the Figure 25.
The values read by the weighing platform are recorded directly in the computer by means of a software called Wei monitor. Wei monitor is a software for managing the weights obtained from the weighing platforms. This PC program allows to monitor and record real time data’s from the connected weighing platform and stores the values in a text or excel file for further processing (Vetek, 2018). The user interface in this software program is extremely simple and easy to use. Refer the website for more information on the software.

4.5.2 DFMEA
Risk assessment was made in a software called CEDOC. Different failure modes were identified, analysed and incorporated in the design.

CEDOC:
CEDOC is a program that deals with machine safety and has been developed in order to facilitate the introduction of proper CE marking routines. This software allows the user to perform the assessment based on the type of risk assessment as chosen by the user. For example, risk assessment for design and construction, lifting equipment, machine mobility, wood working machinery. Etc.

Some of the important areas that were dealt during the risk assessment were,

- Safety requirements
- Working positions
- Information’s and warnings

The entire document on the risk analysis is confidential and is available only with Scania CV AB.
4.5.3 Manufacturing and Assembly Considerations in design

In order to ease the manufacturing and assembly of the station, it is always good to have fewer number of parts within the station. This will have substantial impact on the cost and development time. This has been kept in mind throughout the development stage. Most of the parts used in the station are made common to reduce the need to create new part numbers and has at most 4 unique sub-assemblies. This construction also ensures the cost to manufacture the parts and assemblies is less.

- Only 3 unique tube parts has been used in the entire base construction assembly.
- Pillar assemblies in the front and back of the station share all the common parts except the difference in length of the tube in front and rear.
- Most of the parts used in the station are standard parts available in the market. For instance, the bolts, nuts and rectangular tubes which constitutes the major part of the entire station assembly.
- The station is simple in design with standard components and simple parts to develop.
- Lift table in the only complicated assembly in the entire station. It is a custom made and supplied by an external supplier which reduces the burden on Scania CV AB be able to manufacture the lift table by themselves.
- The assembly of this station is the same as the assembly of another similar station and suppliers identified to manufacture this station are the same who developed an already existing station in Scania CV AB.

4.5.4 Cost Considerations in design

One of the important criteria that was considered during the concept selection was the cost of development. The main goal in later stages in design was to minimize the cost as much as possible. Following points have be considered into the detail design to reduce the cost.

- Cost of around 50,000 SEK has been minimized by eliminating an electrical actuator for tilting purpose which was the original idea during the concept development phase. It has been designed such that, a simple rectangular beam can serve the same purpose at much lower cost.
- Lift table serves multi-purpose solutions. It assists the driver to position the cabin on the station, protects weighing scales and performs tilting operation.
- Most of the parts used in the station are standard parts which eliminates the need to manufacture new parts.

Final cost estimation is provided in Appendix 9.
4.5.5 Ergonomics during operation

One of the main customer need was to achieve the best possible design solution while an operator is operating on the station. The assessment on the ergonomic factor is made throughout the development process.

Some of the important ergonomic factors that were considered during the development were,

- Operating height
- Component weight
- Handling grip
- Push-pull retardation forces
- Component surface

For each of these factors, Ergonomic standard values are maintained in accordance with the Scania’s Ergonomic standard. The exact values are not presented as these values are confidential.
Accuracy estimation

At this point, we know that the two necessary steps involved in measuring CG is by obtaining the load readings in horizontal and tilted conditions. Knowing these values, one can obtain CG values as described in the theory section. But the question is, how accurate are these results from the constructed station? This section will provide a detailed answer to this question.

One of the important requirement of Scania CV AB is that the measured values from the measuring station should be of high accuracy. In the beginning of the development process, it was difficult to estimate the accuracy of the station since, the geometry and form of the station were unknown. During the detailed construction phase, selection of the components and tolerances are set carefully to attain good accuracy from the station.

Error estimation

One of the simplest way to estimate the worst-case error is by considering the 2 extremes of the parameter that affects the values of the CG i.e., for minimum and maximum case. The meaning of this statement is that, for example, load readings 3 & 4 (w3 and w4), the length of the skid (l) and the total weight (W_{tot}) are the affecting parameters for CG\textsubscript{x} as defined by the formulas. Each of these parameters are considered as variables in the equation. The minimum value of CG\textsubscript{x} is obtained when numerator in the equation is minimum & the denominator is maximum and wise verse for the maximum value of CG\textsubscript{x}. The same is applicable for CG\textsubscript{z} also.

The sources of errors were first identified, and the error analysis is done by considering the results from one of the experiments which was already done by Scania CV AB. The readings are presented in the below Table 2. The formulas and calculations pertaining to the error analysis is presented in Appendix 10. It is to be noted that, this analysis is done assuming the load readings that are given are actual (even though it is not). This analysis is beneficial to understand how the deviations in the constructed station will affect the overall result from the designed station.

<table>
<thead>
<tr>
<th>Description</th>
<th>Designation</th>
<th>Values (kgs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load readings in horizontal condition</td>
<td>W1</td>
<td>368.018</td>
</tr>
<tr>
<td></td>
<td>W2</td>
<td>368.018</td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>311.4818</td>
</tr>
<tr>
<td></td>
<td>W4</td>
<td>311.4818</td>
</tr>
<tr>
<td>Load readings in tilted condition (16 deg.)</td>
<td>W1'</td>
<td>454.358</td>
</tr>
<tr>
<td></td>
<td>W2'</td>
<td>454.358</td>
</tr>
</tbody>
</table>

Table 2: Measurement from R cab

Based on the above input values, the error in CG\textsubscript{x} is less and deviates only by around 4mm from the actual. Whereas, the error in CG\textsubscript{z} is around 70mm which is high. In order to investigate this further, Sensitivity analysis is carried out.
4.6.2 Sensitivity analysis

Sensitivity analysis is performed in Mode Frontier software. The main purpose of this sensitivity analysis is to find out the most sensitive variable that influences the values of CG\(_X\) and CG\(_Z\) the most. CG\(_Y\) is not considered in this analysis simply because it is affected in a similar way as CG\(_X\). This is due to the nature of its theoretical formula which is similar to the formula used to estimate CG\(_X\).

From the same values presented in previous section, the optimization is carried out for 150 design input points. The results from the sensitivity analysis are shown in Figure 26: Sensitivity Analysis. The meaning of these decimals that correspond to every parameter in the blocks is that, higher this value (Positively or negatively and close to +1 or -1), greater is its effect on the output result for a small change in the input parameter. For example, referring to the same figure, CG\(_X\) value is most affected by the length of the skid positively. This also means that, a small change in the value of skid length results in large change in the output i.e., CG\(_X\).

Similarly, CG\(_Z\) value is most affected by the tilt angle negatively. It should be noted that other parameters in CG\(_X\) and CG\(_Z\) also affect the result to a certain degree. But, all these other parameters are less affected than the once mentioned above. Moreover, these parameters are mainly the load readings from weighing scales. This has already been controlled by selecting an accurate weighing platform (0.03 % Full Scale). There are weighing scales which reads accuracy in % of Reading rather than % of Full Scale are much more accurate than the selected one. Due to some cost constraints during the later stages in the project, this was limited to the selection of a reasonably accurate weighing platform. This was also one of the reason why Concept 1 was selected over the other concepts during the concept selection stage.

\[
W_{tot} = (w1 + w2 + w3 + w4)
\]

\[
CGx = \left(\frac{(w3 + w4) * l}{W_{tot}}\right)
\]

\[
CGz = \left(\frac{(w1' + w2') * l}{W_{tot}}\right) - (l - CGx) \left[\frac{1}{\tan \alpha}\right]
\]
The length of the skid cannot be controlled as it is an already existing part and cannot be regulated in this station design. This deviation in CGX is however acceptable since the variation is very little from the actual (Refer section 4.6.1 and Appendix 10). However, this is not in the case of tilt angle which affects CGZ value. This parameter can be controlled as it is a part of our design. Geometric dimensions and tolerances in the station are defined by considering this effect. Tight tolerances are given in the drawings and use of high resolution (5” or 5/60°) universal protractor has been suggested to measure the tilt angle which can reduce this variation significantly. Upon contacting the supplier of the weighing platforms, the internal tolerances at the supplier end for this weighing platform are maintained at 0.017 % Full Scale instead of 0.03% Full scale. This will yield more accurate results! The error analysis is performed again with these new values and is presented in Appendix 11. The difference in CG value is dramatically reduced by more than 50% and needless to say, sufficient to perform any design calculations using these values.
5 Results

This chapter presents the major results that were achieved from the previous chapter. i.e., chapter 4.

5.1 Multi-purpose lift table

- Cabins are handled by the fork lift trucks through skids. Generally, in production plants, workload on the forklift truck drivers is high and the operating conditions are harsh. During such conditions leaving a weight of 2000Kgs (cab & skid) directly on the weighing scales is risky and it might damage the weighing scales and reduces the warranty period of these scales. In this case, the lifting table is used to eliminate this problem.
- Apart from the above function, lifting table also helps to position the skid with the cab with the help of the guides mounted on top of it.
- In our selected method, to calculate CGZ, one needs to rotate the object around an axis as explained in the theory section. To achieve this, selection of the lifting equipment under a certain cost constraint is another challenging task in this project. Lift table can also perform this function by just connecting a simple standard rectangular beam link from the lift table to the skid in our station. This will be clearly explained in the section 5.3(STEP 3).

Thus, by incorporating the lifting board into the station, it can perform 3 different functions which are essential to perform the experiment in the station.

5.2 Mobile station

Another striking feature of this station is that it allows user-friendly transportability from one place to another. Whole station is very rigidly built and supported by means of rectangular beams which are welded together. As explained in the section 4.5.1.1, the entire station is firmly bolted at 10 positions to the ground. By releasing these bolts, one can simply move the whole station from one place to another by means of forklift.

During transportation of the whole station, lifting table is always at its lowest position. This reduces the vertical CGZ value of the station with increased stability. Moreover, the entire station is built almost symmetrically to improve the stability and ease the lifting during transportation operations by means of forklifts. It has also been suggested to remove the lift link assembly during the transportation as it is a moving part in the station.
5.3 Station operating procedure

This section elaborates on how an operator should operate on the station. This is explained in a step by step procedure to be able to understand and visualize all the operations in the station.

**STEP 1:**

Initially, when the forklift carries the skid with the cab, the lifting table is at its maximum height (1500mm from the base construction). In this condition, the plane where all the four weighing scales are mounted is approximately 300mm below this lifting table’s maximum height. When the skid enters the station, it makes its first contact with the back guides. After doing so, side guides and the front guides assist the driver of the fork lift to be able to position the skid with cab on the lift table. Now, the lift table is operated at low speed to bring down the skid with cab on the weighing platforms. All these 4 weight readings are transferred and stored automatically in the computer. Refer section 4.5.1.4 for circuit connection for the weighing scales. Figure 27 visually explains STEP 1 (Note that, only the forks of the forklift is shown and not the entire fork lift truck).

*Figure 27: Positioning of cab on the weighing scales (Step1)*
STEP 2:

Once the table leaves the skid on the weighing platform, it now operates at high speed and lowers itself to its lowest position (350mm from the base construction). The operator now releases the index pin on the support pillar and moves the lift link assembly forward with the help of the handle provided in the clamp of the lift link assembly. The clamp is designed such that, it positions itself in the skid without the need to adjust from externally. The clamp is now positioned and the index pin on the clamp is now released to be able to rotate the cover on the clamp and lock the skid. Refer Figure 28 for pictorial understanding of the working process.

Figure 28: Clamping the skid
STEP 3:

When the clamp is locked, the lift table is operated at low speed in the upper direction. Also, Jacob Safety sensors are installed in the station that allows the lift table to operate only at low speeds when the lift link is in contact with the skid. The lift link assembly will tilt the skid with cab towards the front. When the table reaches 1260mm from the base construction, the skid will be tilted to a maximum angle with respect to the maximum height of the lift table (1260 mm). Now the readings in the front 2 scales are recorded again in the computer and the angle is measured from the flat surface on the pillar to the surface of the skid. The skid is tilted back to the weighing platform and table is raised to its original position to unload the skid with cab from the station. See Figure 29 for operating process of this step.

![Figure 29: Tilting to a certain Angle](image)

5.4 Calculation module

One of the main goal in this thesis is to establish a simple user-friendly calculation module to calculate the weight and centre of gravity values of the cabin after performing the experiment on the station. The weight values which has been read has to be converted into CG values. The calculation module has been designed in such a way that the user inputs minimal number of data to have the simplest user interface and obtain the necessary output in a fraction of a second. Such a module is shown in the Figure 30.
Calculation for Centre of Gravity of the truck cabin

Input values when skid is horizontally placed

<table>
<thead>
<tr>
<th>CAB type</th>
<th>P/G 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>368,018 kgs Front Left Platform</td>
</tr>
<tr>
<td>W2</td>
<td>368,018 kgs Front Right Platform</td>
</tr>
<tr>
<td>W3</td>
<td>311,481 kgs Back Left Platform</td>
</tr>
<tr>
<td>W4</td>
<td>311,481 kgs Back Right Platform</td>
</tr>
</tbody>
</table>

Input values when the skid is tilted

<table>
<thead>
<tr>
<th>Skid tilt angle</th>
<th>16,000 deg</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1'</td>
<td>454,358 kgs Front Left Platform</td>
</tr>
<tr>
<td>W2'</td>
<td>454,358 kgs Front Right Platform</td>
</tr>
</tbody>
</table>

Output Values

<table>
<thead>
<tr>
<th>CG_x of Cab</th>
<th>1663,629 mm From Cab Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG_y of Cab</td>
<td>0,000 mm From Cab Reference</td>
</tr>
<tr>
<td>CG_z of Cab</td>
<td>226,876 mm From Cab Reference</td>
</tr>
<tr>
<td>Weight of Cab</td>
<td>1108,998 kgs</td>
</tr>
</tbody>
</table>

NOTE! The estimated CG value is for the cabin alone in vertical condition and from the cab zero reference!
After the experiment has been conducted on the station, the user will now copy the load data’s which has already been stored in the computer and paste it in this calculation module. After entering the load data’s in both horizontal and tilted condition, the type of cab on which the experiments are being performed can be selected in the dropdown list. As soon as all these inputs are entered, the values of the weight and centre of gravity are directly displayed.
6 Discussion

A detailed discussion about the method used in this project and the results obtained is made in this section. To what extent the mentioned theory is relevant for the chosen method, challenges faced by the authors at different stages of this project and how the authors arrived with their final design is explained in a chronological order in this section.

6.1 Method

A classic product development work flow process with steps like understanding customer needs, then converting them into targets, developing concepts which satisfy the needs, evaluation and selection of concepts based on the customer needs and finally realization of the chosen concept was followed in the methodology of this project. Books like David Ullman and Steven D. Eppinger were referred a lot for this methodology implementation since the processes described in these books are relevant to the subject of the thesis.

As the time progressed, knowledge about the construction of station increased but simultaneously, design freedom is curtailed with design constraints like cost, safety, time etc. As per the aforementioned design method, team had developed five different concepts to measure that is capable of measuring CG values and each concept has its own uniqueness. For example, Concept 4 uses load cells which measure loads in 3 different directions instead of normal weighing platforms and one can achieve most accurate results with this concept in relative to other concepts. But, during final concept selection phase, the cost became an important criteria in this project. All the other team members of MPCT department were involved in the selection of the concept and concluded to proceed with concept 1. Also, since Scania CV AB has already conducted tests on CG in similar way to the idea behind concept 1 and are familiar with this principle, all the design engineers were comfortable to select concept 1 to proceed further with the detailed design phase. In this detailed design phase, good characteristics of all the neglected concepts were taken into consideration in developing the final design.

6.2 Theoretical Frame of Reference

For determining CG values of the cabin, tilting and Instability techniques were extensively considered for this project. Relevant literature is gathered, and previous experiments based on these two techniques were studied thoroughly. Because of certain constraints like not tilting the cab to complete 90°, having large A surface areas like wind shield, Cab outside surfaces etc. tilting technique is adopted to determine CG values for cab. Appropriate mathematical formulas for calculating CG values with the tilting technique were derived and incorporated these formulas into a simple user-friendly calculation interface in Excel. These formulas were tested for different cabs by using Scania’s previously measured CG data’s. Some of the values like CG values of skid which is a made up of just one material: Steel, distances from skid reference point to cab-0 reference point were measured directly from the CATIA V5 since these measurements are exact. Obtained results show that the CG values measured from theoretical formulas agreed well with the Scania’s experimental data.

6.3 Results

Proposed model has some notable attributes like multi-purpose lift table and provisions for moving the entire station from one place to another. Thorough discussions have been made with HYMO (Lifting board supplier), to take full responsibility to construct the lift table along with the required operating speeds, installing sensors and safety stops at times of emergency. All these are more precisely explained in this user guide.
Apart from this, details like warning signs, providing a chain to lock the lifting link, rubber pads to avoid metal to metal contacts, buffers to take some impact loads, notes and stickers for the physical station were provided in the drawings and instruction manual. During development process, necessary standards and machine directives were followed during the detail design phase and mostly standardised parts were used for all the machine element components.

Since, the station is a ‘measuring station’, Provision’s for calibration has also been provided by means of the floor mounting screws. Flatness in the top skid mounting surface can be easily achieved just by adjusting these floor mounting screws.

Proper mathematical error estimation of the method is performed to analyse what worst case error that this station can produce while estimating CG values. But this is only in adverse conditions. However, the Station can perform much better than these estimated error values as the weighing platform appears to be more accurate than the specifications provided in its data sheet and more accurate angle measuring device will be used for every measurement in the experiment instead of relying on the known angle from the height of lift table. The accuracy of the station could have been improved if load cells with high accuracy were installed instead of the simple weighing platform. However, this was not possible due to cost considerations at the later stages of design. Also, since cabin is a highly expensive assembly, the accuracy from the readings have to be compromised by not tilting the assembly by complete 90° during the vertical CG height measurement. But, the values obtained from the station are sufficient to perform design calculations.

Detailed 2-D production drawings were produced according to Scania CV AB drawing standard and the Bill of material was prepared. These drawings were later sent to a supplier for an approximate estimation of manufacturing costs to this project. However, drawings will again be checked thoroughly by Scania CV AB and will be sent to different suppliers. Based on the quote provided by the suppliers, one will be chosen to manufacture the prototype.
7 Conclusions

In this master thesis, a complete construction of the CG measuring station is described and proper theoretical proof with evidence have been provided to proceed forward with the development. The initially set target specification along with all the needs were quite able to achieve in the result. The metric corresponding to the tolerances, form of the station and accuracy of the measuring devices are well within the set targets. Some of these are maintained in the detailed internal drawings and the others concerning to the measuring devices are realized during the selection of devices.

This station is designed such that the work to be performed on the actual station will be intuitive and relative theories have been followed to provide a solid theoretical proof. With Just 6 load readings along with the tilted angle one can calculate the centre of gravity of the cabin with ease. Also, these readings are recorded and stored directly in the computer reducing the burden on the operator for the need to manually note these values. To ease the working process, a complete technical user guide which contains detailed instructions for the operators is also provided together with the design of the station. The calculation module is made extremely simple for any user to perform the calculation without even the need to refer the instruction manual. Involving the project manager and supervisor in all the crucial phases of this project and taking their insights helps the team to focus more on the project purpose. Design engineers at MPCT department are contended with the outcome of this project.

In the outcome of the project all the needs of Scania CV AB which were defined earlier in the project and all the criteria’s set were achieved. These are presented below.

- Good quality of measurement sufficient to perform design calculations
- Versatile to perform the experiment on any cabin with its transport skid
- Safety has been given at most priority in every part of the design by incorporating buffers, dampers and warning signs with much details provided in detailed drawings
- Station has been designed in accordance with Scania’s ergonomic standard
- Design of the station is made extremely simple with use of most of the standard parts
- Cost well within the limits
- Robust design of the station has been achieved

Though all criteria’s were achieved, there are some drawbacks with the station.

- Since the station is heavy, it might lead to some difficulties during installation
- The maximum tilt angle that can be achieved during tilting in this station is ~ 20°. Higher angles cannot be tested which yields more accurate results.

Even though a prototype is not built in this project, Scania did receive all the necessary supporting documents, drawings, user-interface, and manuals for the future production of a prototype.

To finally conclude, the outcome of this project is a complete 3D model and 2D drawings of the station in CAD, user instruction manual with operating instructions and a calculation module in Excel. By this, all the project goals were achieved successfully by answering all the research questions in our project within the given timeframe and met the expectations of what the project has to deliver.
7.1 Scope

Designing a product which matches to the rapid evolving customer needs and dynamic changes in industries is a substantial challenge in itself. However, this current thesis work focusses mainly on the project goal i.e. calculating weight and all the CG values of the cab. One can expand the horizon of this in future in some of the following ways.

- Weighing modules used in this station are accurate. However, there are weighing modules available in the market with much more accuracy. These can be replaced for high accuracy load measurements.
- Some of the operations like connecting the clamp to the skid, removing the clamp, lift link mounting and resting operations can be automated by incorporating more advanced technology into this project.
- Apart from measuring weight and CG values one can use this station to calculate moments of inertia by making some modifications.
- To achieve maximum rigidity heavier beams were used for supporting structures. By performing structural optimization on load carrying components, one can reduce the total weight of this station without compromising the rigidness of the station.
8 References


Appendix 1

Types of Truck Cabins

The truck cabins can be categorized as Low (L), Normal (N) and Highline (H) depending on the type of truck segment (see Figure 31). The basic difference between these cabins is the roof top height from the ground level. Scania’s old generation trucks are also currently in the market, hence, the production unit at Oskarshamn produce cabins for both old and new generation trucks. (Scania, 2016)

![Figure 31: Low, Normal and Highline Cab (Scania Official home page)](image1)

Scania, Oskarshamn mainly produce cabins for P, G and R-series trucks. These series are available in either one, two or all the above three categories (Low, Normal and Highline). P-series trucks are ideal for urban & regional operations, constructions and other demanding conditions. G-series trucks are designed for customer’s specific needs such as Poor road conditions, distribution and construction. The persistent and versatile R-series trucks are designed for long haulage. (see Figure 32)

![Figure 32: P, G and R-series truck (Scania Official home page)](image2)
Appendix 2
Interview 1

Face to face interview with the supervisor, Martin Kjellman at Scania CV AB was conducted on 16th of January’18. The interview started with the supervisor presenting the overview of the entire project such as the purpose to establish a station, thesis goals and deliverables. After presenting a summary of the project, discussions were made from a broad perspective with some of the key discussion points and feedback was received.

This appendix presents all the minutes of the meeting.

When: 16th January’18

Time: 8.20 to 9.30

Where: Technical centre, Scania CV AB, Oskarshamn

Participants:

Martin Kjellman  Martin.Kjellman@scania.com
Shiva Kumar P    shipa037@student.liu.se
Srinivas Bendapudi sribe799@student.liu.se

Minutes:

An intuitive method to determine CG is not known by Scania CV AB.

CAD models of the cab does not contain the right material.

Many components in CAD are modelled using surfaces.

Location of the wires is not defined in CAD.

Do not consider cost as a factor at this stage.

CGy location is not much of an interest to us. It is almost close to the centre position of the cab. However, it will still be interesting to know.

The CG of the cab should be measured with the transport skid.

Cabin should be safe during measurement.
Another interview with a colleague at Scania CV AB, Erik Idberg who is a designer at MPCT department was conducted on 16th of January’18. The purpose of this meeting was to understand the various types of skids used for the cabs and to have a physical demonstration of the working of skids in the workshop. The discussion points were recorded and are presented below.

This appendix presents all the minutes of the meeting.

When: 16th January’18

Time: 13.00 to 14.00

Where: Technical centre, Scania CV AB, Oskarshamn

Participants :
Erik Idberg  
erik.idberg@scania.com
Shiva Kumar P  
shipa037@student.liu.se
Srinivas Bendapudi  
sribe799@student.liu.se

Minutes:

There are two basic types of skids. Assembly skid and Transport skid.

Skids are manufactured in Poland and in outskirts of Oskarshamn.

Transport skid for P/G/R are adjustable to accommodate in 1 skid. They are usually painted in green or grey.

Separate transport skid for S cabs and are not adjustable.

Reference points on the skid to measure CG.

Mechanisms involved in skid to adjust to different positions.

The maximum angle to which the cabin can be tilted on skid is 38° to the front and 54° sideways. These are extreme values and not a good idea to tilt so much.
Appendix 3
Questionnaire

1. What is the purpose of the station?
   Measure CG and weight for all new generation truck cabin

2. How many stations are planned to implement?
   One

3. What is the need to measure CG of the cabin?
   Design of new equipment
   Changes in the current equipment
   Change in the assembly process of the cabin

4. Is this measured CG any interest/importance for SCANIA R&D in Södertälje? Why?
   Quite interesting as they do not have an equipment/station to measure CG

5. How is CG currently measured? What are the problems faced?
   Not in a rational way. We don’t know if the values are correct.

6. Should it be measured for all the 3 co-ordinates? why (if only one or two co-ordinates)?
   X and Z coordinates only. There is not a big difference in CG Y and is almost in the centre of the cabin.

7. What is the accuracy expected of the measurement?
   Highly accurate

8. How frequent are these measurements taken?
   Only for the prototypes and when there is a design of new product.
9. Where is the station planned to be located?
   Not decided. But has to be mobile.

10. Who operates on the station? (Users)
    Anyone should be able to operate on the station.

11. What are the types of truck cabins produced by SCANIA?

12. Should the station be able to measure CG for any truck cabin?
    yes!

13. Should we focus on ergonomic aspects while operating on the station?
    Yes! Follow Scania’s Ergonomic system.

14. Is Aesthetics any important characteristic of the station?
    Not necessary.

15. What are the expectations from this thesis project?
    Specifications of the components, BOM and detailed design. It will also be nice if you suggest us the suppliers.

16. How do we prove the concept?
    Provide concert suggestions and provide theoretical evidence.

17. Should we build prototype?
    No!

18. When will the station be manufactured?
    Not planned yet.
19. What is the investment for this project?
   Should be cost effective but do not take cost into consideration at this stage.

20. Are there any constraints in the project? (Ex. Cost limit, Max. weight, time limit)
   Time limit. Has to be completed within the time.

21. Do you have any previous collected CG and weight data for various cabins?
   We will provide you once you show us your concepts.

22. Finally, would you like to add any comments or questions?
   It should be easy to measure.
   Safety is at most important.
   Measurements should be made with the transport skid.
   Should be intuitive and rational.
   Maximum weight of the cab is 2000 kg.
Appendix 4
Concept 1

Morphological combination: Aa-Bb-Cd-Da-Ea-Fa-Ga-Ha

![Diagram showing lifting with weighing platform]

**Design and function**

This is a simple and straightforward concept which measures CG values in total of two steps. In the first step, skid together with the cab will be placed on the four platforms with the help of forklift. Platforms should be mounted rigidly under the four corners of the skid so that one can take the reaction load readings directly from these platforms, see Figure 33. With these load readings and expressions derived in lifting method one can calculate the CG\(_X\) and CG\(_Y\) values. To obtain CG\(_Z\), skid along with cabin should be lifted around the extreme edge of the skid to a desired angle with the help of a cylinder. During lifting, to restrict the movement of skid in longitudinal direction, skid should be mounted on an axle which is supported by means of guide rail mechanism so one can completely hinder the motion in longitudinal direction. With the help of a clamp as shown in the figure one can rigidly fixed the skid position on the front axle while lifting.

**Advantages and dis advantages**

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost effective and economic method</td>
<td>For high accuracy one needs to tilt higher tilt angles</td>
</tr>
<tr>
<td>Concept can be realized with available equipment in Scania’s workshops.</td>
<td></td>
</tr>
<tr>
<td>Lifting can be done directly by the skid itself and reduce the number of parts.</td>
<td></td>
</tr>
</tbody>
</table>
Concept 2

Morphological combination: Aa-Ba-Da-Ed-Fd-Hc

![Concept 2: Instability with wall](Image)

**Design and function**

This concept works on the principle of instability method explained in literature review. An L shaped square platform supported by two \(3/4\)th circled plates mounted rigidly on four guide rails as shown in the figure. In the middle sprocket and gear mechanism is provided for tilting assistance. In the first step skid together with is placed on the four weighing platforms to determine longitudinal and transverse CG values. With the help of electric motor and gear mechanism one can tilt the platform in anticlockwise direction till the instability position of cabin is reached. Padded cushion support is provided on the side wall to avoid damage to the cabin, see Figure 34. To measure angle exactly at this state a protractor is attached to the base plate and with this value one can measure the vertical height CG\(_Z\) as per the method description.

**Advantages and dis advantages**

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durability of the station is very high.</td>
<td>Extra care is to be taken to avoid damage to the cab during instability state.</td>
</tr>
<tr>
<td>Station is economical.</td>
<td>Tilting must be very slow to attain the instability point.</td>
</tr>
<tr>
<td></td>
<td>Consumes lot of time.</td>
</tr>
<tr>
<td></td>
<td>Might have to repeat the process to check the repeatability of the angle.</td>
</tr>
<tr>
<td></td>
<td>Noisy because of Sprocket and Chain mechanisms.</td>
</tr>
</tbody>
</table>
Concept 3

Morphological combination: Ac-Ba-Ca-Da-Ea-Fa-Ha

Design and function

This concept is similar to the concept 2 except that the instability point is captured when the position of the slot changes. The centre of gravity in this concept is also calculated in two steps. This design consist of an inner symmetrical plate above which 4 weighing platforms are placed and an outer frame which is attached to an actuator. The inner plate is assembled with 4 pins in 4 ends of the plate and is free to rotate about the centre axis within the length of the slot provided in the outer frame.

The working of this concept is briefly explained below with reference to Figure 35.

Initially, the pins are locked with the help of a clamp (Not shown in figure, refer Morphology for the type of clamp). By doing so, the movement of the inner plate within the slot is prevented and the inner plate remains horizontal. Now, by placing the skid along with the cab on the weighing platform, the reaction forces in this horizontal position yields CGx and CGy. Now the clamps are released in order to determine the CGz Value. Assuming the CG lies in the left from the centre as shown, as soon as the clamps are released, the centre plate tilts and takes a new position in the slot there by shifting the CG position to the same angle as covered by the slot β. The actuator is actuated very slowly till the position of the new CG is in line with the central rotating axis. At this point the position of the pin in the slot changes and the angle is recorded by immediately stopping the motion of the actuator further.

This design gives slight advantage over concept 2 in terms of safety of the cab. By incorporating this design, since the skid along with the cabin is rigidly clamped in the inner plate the cabin will be safe unlike in the concept 2.
Advantages and dis advantages

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precise measurement of instability (angle)</td>
<td>Tilting must be very slow</td>
</tr>
<tr>
<td>Simple in design</td>
<td>Consumes lot of time.</td>
</tr>
<tr>
<td>Cheap</td>
<td>May have to repeat the experiment to check for the repeatability for instability.</td>
</tr>
<tr>
<td></td>
<td>May have to measure on both the sides</td>
</tr>
<tr>
<td></td>
<td>Time consuming, and lot of patience is required</td>
</tr>
<tr>
<td></td>
<td>Effect of frictional force might lead to error in angle reading.</td>
</tr>
</tbody>
</table>
Concept 4
Morphological combination: Ac-Ba-Ca-Db-Ea-Fa-Gb-Ha

![Diagram of Tilt with Load Cell Design]

**Figure 37: Tilt with Load Cell Design**

**Design and function**

The design of this concept is similar to the design presented in the concept 3 except that this concept has a single mounting platform rotated about the central axis with the assist of an actuator. Above the platform are the load cells clamped to the platform using bolts and the arrangement is shown in the two-dimensional figure above.

The platform is first stabilized to the horizontal condition and the skid along with the cab is placed and clamped above the load cells. The guide to the placement over this load cells are not shown (Refer Morphology for the guides). The reaction forces are measured to calculate $CG_X$ and $CG_Y$ values in this condition. The platform is then tilted to a certain prescribed angle to note down the reactions again from the load cells to estimate $CG_Z$ value, see Figure 37.

**Advantages and dis advantages**

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate measurement for less tilt angles</td>
<td>Clamps must be extremely strong for the cab to be safe</td>
</tr>
<tr>
<td>Dynamic measurements possible in future</td>
<td>Since the pivot is in the centre, it is extremely important to balance to obtain accurate measurement.</td>
</tr>
<tr>
<td>Quick measurements</td>
<td>Expensive design</td>
</tr>
</tbody>
</table>
Concept 5
Morphological combination: Ad-Ba-Cb-Db-Ee-Fc-Gb-Hd

Design and function

This concept consists of a swing platform in which 4 load cells with clamp are incorporated as described in concept 4. Under the platform are the sliding blocks in the 4 corners of the platform. These blocks keep the swing in the horizontal condition, see Figure 38.

During the horizontal condition, the skid along with the cab are clamped on the load cells. The reaction forces are measured to calculate CG\textsubscript{X} and CG\textsubscript{Y} values in this condition. In order to measure the vertical height CG value, the blocks are made to slide away from the platform. There will be a tilt in the platform as soon as the blocks are slide away depending on the position of CG. The platform is then further tilted to the same side by a known mass to note down the tile angle and reactions again from the load cells to estimate CG\textsubscript{Z} value.

Advantages and disadvantages

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple in design</td>
<td>A known mass can tilt only one angle</td>
</tr>
<tr>
<td>Dynamic measurements possible in future</td>
<td>Several masses might be required if readings are to be compared for different angles</td>
</tr>
<tr>
<td>Eliminates the need of actuator</td>
<td>Expensive due to load cells</td>
</tr>
<tr>
<td>Quick measurements</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 5

Preliminary cost estimation

A preliminary cost estimation was made based on the quotes received from the suppliers of the individual parts.

<table>
<thead>
<tr>
<th>Concept 1</th>
<th>Concept 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts list</td>
<td>Quantity</td>
</tr>
<tr>
<td>Weighing platforms</td>
<td>4</td>
</tr>
<tr>
<td>Indicator</td>
<td>1</td>
</tr>
<tr>
<td>Rail Guide</td>
<td>4</td>
</tr>
<tr>
<td>Cylinder</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concept 3</th>
<th>Concept 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts list</td>
<td>Quantity</td>
</tr>
<tr>
<td>Weighing platforms</td>
<td>4</td>
</tr>
<tr>
<td>Indicator</td>
<td>1</td>
</tr>
<tr>
<td>Cylinder</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concept 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts list</td>
</tr>
<tr>
<td>Load cells + amplifying devices</td>
</tr>
<tr>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>
Appendix 6
Concept Scoring Meeting Details

This appendix presents all the minutes of the meeting.

**When:** 6th March’18

**Time:** 9.30am to 11.30am

**Where:** Technical centre, Scania CV AB, Oskarshamn

**Participants:**

- Conny Elmbro  
  conny.elmbro@scania.com
- Martin Kjellman  
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- Erik Idberg  
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**Minutes:**

- Recapitulated together all the five developed concepts one by one.
- Selected “Concept 2” as datum concept for reference.
- Analysed and compared all the other concepts with respect to the reference concept.
- Comparison is based on selection criteria based on needs list.
- Concept 1 is the chosen one as this concept is similar to the sample experiments conducted at Scania CV AB and all the participants decided to go forward with it.
- Advantages of all the other four concepts will be taken into consideration during final detail design phase.
**Appendix 7**

Buffer selection

\[ F = \mu R \]

where,

- \( F \): Force on the back guides
- \( \mu \): Co-efficient of friction between skid and forks of the forklift
- \( R \): Mass of skid and cabin

\[ R = 2000 \text{ kgs} \]
\[ \mu = 0.12 \]

Therefore, \( F = 240 \text{ kgs} \)

![Figure 39: Final Back Guide Design](image)

Taking moments about the pivot point,

\[ (240 \times 500) + (M \times 150) = 0 \]

Therefore, \( M = -800 \text{ kgs} \)
Selected Damper:

TRELLEBORG INDUSTRIAL AVS

Compactor Shear Mounting

Technical Drawing

2" & 3"  

BR 3.00

Product Data

<table>
<thead>
<tr>
<th>DRAWING No.</th>
<th>PART No.</th>
<th>TYPE</th>
<th>Dimensions (mm)</th>
<th>Max Load (kg)</th>
<th>Max Deflection (mm)</th>
<th>Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A   B   C   D   E</td>
<td>COMPRESSION</td>
<td>SHEAR</td>
<td>COMPRESSION</td>
</tr>
<tr>
<td>17-448F-01</td>
<td>10-01618</td>
<td>2&quot; COMP 60 IRH</td>
<td>100 85 120 110 60 11 5</td>
<td>840 90</td>
<td>0 7.5</td>
<td>1.1</td>
</tr>
<tr>
<td>17-448E-01</td>
<td>10-01619</td>
<td>2&quot; COMP 65 IRH</td>
<td>100 85 120 110 60 11 5</td>
<td>1000 100</td>
<td>0 7.5</td>
<td>1.1</td>
</tr>
<tr>
<td>17-434F-02</td>
<td>10-00067</td>
<td>3&quot; COMP 55 IRH</td>
<td>146 146 182 182 76 13 7.5</td>
<td>2000 220</td>
<td>11 13</td>
<td>3.6</td>
</tr>
<tr>
<td>17-434E-00</td>
<td>10-00065</td>
<td>3&quot; COMP 60 IRH</td>
<td>146 146 182 182 76 13 7.5</td>
<td>2500 280</td>
<td>11 13</td>
<td>3.6</td>
</tr>
<tr>
<td>17-434E-01</td>
<td>10-00066</td>
<td>3&quot; COMP 65 IRH</td>
<td>146 146 182 182 76 13 7.5</td>
<td>3000 340</td>
<td>11 13</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Figure 40: Damper

Source: (Trelleborg, 2017)
### Appendix 8

**FEM Analysis**

#### Material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material type</td>
<td>Isotropic</td>
</tr>
<tr>
<td>Yield stress</td>
<td>250 MPa</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>200 MPa</td>
</tr>
<tr>
<td>Poisson ratio</td>
<td>0.266</td>
</tr>
<tr>
<td>Density</td>
<td>7860 kg/m³</td>
</tr>
</tbody>
</table>

For all the analysis which is performed in CATIA V5, parabolic mesh with reasonable mesh density is set until convergence is achieved.

**Base construction**

- Evaluated for a load of 20000 N on surface of each pillar assembly
- 34000 N distributed load on rails in the centre.
- Clamped at holes mounting on the floor

![Figure 41: FEM analysis Base Construction](image)

---

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Pillar assembly

- Evaluated for a load of 20000 N on top surface of pillar assembly
- Clamped at holes in the bottom

Figure 42: FEM Analysis Pillar Assembly
**Support pillar**

- Evaluated for a load of 450 N on top surface of pillar assembly
- Clamped at holes in the bottom

*Figure 43: Fem analysis lift link support pillar*
Support Component

- Evaluated for a line load of 20000 N
- Clamped at holes in the bottom

Figure 44: FEM Analysis Supporting Plate
Lift beam

- Evaluated for a load of 20000 N at top holes
- Clamped at holes in the bottom

Figure 45: Fem Analysis Lifting Beam
Clevis bracket

- Evaluated for a load of 20000 N at top holes
- Clamped at holes in the bottom

*Figure 46: Fem Analysis Clevis Joint for Lift Link*
**Clamp assembly**

- Evaluated for a load of 20000 N at surface
- Clamped at holes in the bottom

*Figure 47: FEM Analysis for Clamp Assembly*
Appendix 9

Final Cost Estimation

A final cost estimation was made based on the quotes received from various suppliers.

<table>
<thead>
<tr>
<th>Description</th>
<th>Supplier</th>
<th>Cost (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighing module</td>
<td>VETEK</td>
<td>39950</td>
</tr>
<tr>
<td>(Weighing platforms + indicator + software + cables)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lift table</td>
<td>HYMO</td>
<td>107000</td>
</tr>
<tr>
<td>(Associated Sensors included)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing and assembly of station</td>
<td>To be identified</td>
<td>~ 150000</td>
</tr>
<tr>
<td>Other Accessories</td>
<td>Trelleborg, SKF, Wiberger</td>
<td>&lt; 5000</td>
</tr>
<tr>
<td>(Dampers, buffers, bronze bushes, shafts, handles .ect)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>~ 300000</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 10
Error Estimation

Below formulas explain the different conditions under which one can attain minimum and maximum values.

Minimum values:

\[
W_{tot\_min} = \min(w1 + w2 + w3 + w4)
\]

\[
CG_{x\_min} = \frac{\min((w3 + w4) * l)}{\max[W_{tot}]} - \max(l - CGx)
\]

\[
CG_{z\_min} = \frac{\min[(w1' + w2') * l]}{W_{tot}} - \max(l - CGx)
\]

Maximum values:

\[
W_{tot\_max} = \max(w1 + w2 + w3 + w4)
\]

\[
CG_{x\_max} = \frac{\max((w3 + w4) * l)}{\min[W_{tot}]} - \max(l - CGx)
\]

\[
CG_{z\_max} = \frac{\max[(w1' + w2') * l]}{W_{tot}} - \min(l - CGx)
\]

Weighing scale error estimation:

Capacity of each weighing platform = 1500 kgs (Full Scale)

Full scale error = 0.03 % Full Scale

Error = 1500 \times 0.03/ 100 = 0.45 kgs

- Resolution on angle is set from its marginal value in product specification.
- Skid tolerances are taken from internal drawings.
<table>
<thead>
<tr>
<th>Sources of errors</th>
<th>Accuracy of weighing platform</th>
<th>0.45 kgs</th>
<th>0.45 at 0.03% FS</th>
<th>0.225 at 0.017% FS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Skid tolerance in length</td>
<td>2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Skid tolerance in width</td>
<td>2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resolution on angle</td>
<td>0.5 deg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Assuming the values are actual

|                   | W1 actual | 368.018 kgs | W2 actual | 368.018 kgs | W3 actual | 311.4818 kgs | W4 actual | 311.4818 kgs |
|                   | W tot actual | 1358.9996 kgs |
| Actual skid length | 2390 mm | Actual skid width | 1630 mm |
| Actual tilt angle  | 16 deg |
| W1' actual | 454.358 kgs | W2' actual | 454.358 kgs |

### Sources of errors

#### Minimum values

|                   | W1 min | 367.57 kgs | W2 min | 367.568 kgs | W3 min | 311.0318 kgs | W4 min | 311.0318 kgs | W tot min | 1357.20 kgs |
|                   | W tot min | 1358.9996 kgs |
| Skid length min   | 2388 mm | Skid length max | 2392 mm |
| Skid width min    | 1628 mm | Skid width max | 1632 mm |
| Tilt angle min    | 15.5 deg | Tilt angle max | 16.5 deg |
| W1' min | 453.908 kgs | W1' max | 454.808 kgs |
| W2' min | 453.908 kgs | W2' max | 454.808 kgs |

### CG x and CG z of assembly

| Actual | 1095.572905 mm | Actual | 1059.0688 mm |
| Min    | 1091.628684 mm | Min    | 988.1728723 mm |
| Max    | 1099.530941 mm | Max    | 1134.717989 mm |
| Difference for min | 3.944120978 mm | Difference for min | 70.8952768 mm |
| Difference for max | 3.957235361 mm | Difference for max | 75.6491894 mm |
## Appendix 11

### Weighing scale error estimation

**Capacity of each weighing platform = 1500 kgs (Full Scale)**

**Full scale error = 0.017 % Full Scale**

Error = 1500 * 0.017/ 100 = 0.225 kgs

<table>
<thead>
<tr>
<th>Sources of error</th>
<th>Accuracy of weighing platform</th>
<th>Full scale error = 0.017 % Full Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.225 kgs</td>
<td>0.45 at 0.03% FS</td>
</tr>
<tr>
<td></td>
<td>0.225 kgs</td>
<td>0.225 at 0.017% FS</td>
</tr>
<tr>
<td>Skid tolerance in length</td>
<td>2 mm</td>
<td></td>
</tr>
<tr>
<td>Skid tolerance in width</td>
<td>2 mm</td>
<td></td>
</tr>
<tr>
<td>Resolution on angle</td>
<td>0.0833333333 deg</td>
<td></td>
</tr>
</tbody>
</table>

### Assuming the values are actual

| W1 actual                              | 368.018 kgs                   |
| W2 actual                              | 368.018 kgs                   |
| W3 actual                              | 311.4818 kgs                  |
| W4 actual                              | 311.4818 kgs                  |
| W tot actual                           | 1358.9996 kgs                 |
| Actual skid length                     | 2390 mm                       |
| Actual skid width                      | 1630 mm                       |
| Actual tilt angle                      | 16 deg                        |
| W1' actual                             | 454.358 kgs                   |
| W2' actual                             | 454.358 kgs                   |

### Minimum values vs Maximum values

| W1 min                                 | 367.79 kgs                    | W1 max                                 | 368.24 kgs                           |
| W2 min                                 | 367.793 kgs                   | W2 max                                 | 368.243 kgs                          |
| W3 min                                 | 311.2568 kgs                  | W3 max                                 | 311.7068 kgs                         |
| W4 min                                 | 311.2568 kgs                  | W4 max                                 | 311.7068 kgs                         |
| W tot min                              | 1358.10 kgs                   | W tot max                              | 1359.90 kgs                          |
| Skid length min                        | 2388 mm                       | Skid length max                        | 2392 mm                               |
| Skid width min                         | 1628 mm                       | Skid width max                         | 1632 mm                               |
| Tilt angle min                         | 15.91666667 deg              | Tilt angle max                         | 16.08333333 deg                     |
| W1' min                                | 454.133 kgs                   | W1' max                                | 454.583 kgs                          |
| W2' min                                | 454.133 kgs                   | W2' max                                | 454.583 kgs                          |

### CG_x of assembly vs CG_z of assembly

| Actual                                   | 1095.572805 mm               | Actual                                   | 1059.0688 mm                         |
| Min                                      | 1093.141344 mm               | Min                                      | 1026.87033 mm                        |
| Max                                      | 1098.008814 mm               | Max                                      | 1091.653234 mm                       |

| Difference for min                        | 2.431460914 mm               | Difference for min                        | 32.19847009 mm                       |
| Difference for max                        | 2.436008909 mm               | Difference for max                        | 32.58443396 mm                       |