Degree project

Development of plumb elevator shaft

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Summary

This degree project is the final part of the bachelor in mechanical engineering at Linnaeus University in Växjö. The thesis has been accomplished at ALT Hiss AB in Alvesta. The company manufactures hydraulic elevators, less traction elevators and escalators. Several visits to ALT Hiss AB have been made and on these occasions the designing group has been able to ask questions and collect answers.

The aim of this degree project has been to design a tool that plumbs the elevator shaft. The requirements from the company has been to design a tool that is placed on the top of the elevator shaft and to be able to determine were the elevator cage could be placed. Currently, the company uses an old method and experience to plumb the elevator shaft.

The thesis has been performed with literature studies, interviews and data collections. The Linnaeus University database, OneSearch, has also been a useful source for searching articles, books and journals.

Using the product development process as an application to the problem has created some concepts. The designing methods have been a substrate to the literature studies. Different product development process has been approved to be successful in the application.

The result is presented as a final concept sketch and idea drawing. Weighting and ranking different concepts have selected the final concept. The tool is clearly set with dimensions and the result is illustrated in the appendixes.
Abstract

This degree project is the final part of the bachelor in mechanical engineering at Linnaeus University in Växjö. The project has been accomplished at ALT Hiss AB in Alvesta. The company manufactures hydraulic elevators, less traction elevators and escalators. The purpose of this thesis has been to design a tool that plumbs the elevator shaft. The thesis has been completed with literature studies, interviews and data collections.

The final concept sketch and idea drawing is presenting the result.

Keywords:

- Product development
- Plumb the elevator shaft
- Elevator guide bar bracket
- Plumb line
Preface

This thesis has been done during the spring 2014 in collaboration with ALT Hiss AB. Thus thanks to the company ALT Hiss AB for being able to provide us this opportunity.

We would like to thank our supervisors Lars Ericsson and Valentina Haralanova for the feedback and support during the project.

Specially thanks to Anders Stenkilsson and Christer Lennartsson for all the necessary information that we have collected from them.

We would also like to thank our examiner Samir Khoshaba for guiding and giving us information of a successful degree project.

Elvedin Mešinović

Ermin Cerić

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1. Introduction

The report describes how to achieve the best conceptual design and to extract a final concept. ALT Hiss AB will use this for an improvement of plumb the elevator shaft. This degree project has been completed in the spring 2014 and is the final part of the bachelor study in mechanical engineering at Linnaeus University.

1.1 Background

ALT Hiss AB was registered 1994 because of the dismantling of DEVE elevators, which was a leading elevator company in the residential and industrial lifts. In the current situation the company is located in Alvesta and three co-owners manage it.

![Elevator guide rails placed on the guide bar brackets.](image)

The current method that plumbs the elevator shaft is used without any tool. The guide bar brackets are instead mounted on top of the elevator shaft to be able to set the plumb lines on the brackets. The installer mounts the guide bar brackets, below the first mounted bracket, using the plumb line as an indication.
This method is time consuming and needs a precise alignment. Figure 1.1.1 illustrates the guide rails and guide bar brackets mounted to each other.

The task is to develop a concept to the tool and the base to manufacture. The tool shall first be mounted on the top of the shaft. The tool is used to verify the elevator shaft by positioning the plumb line and to determine where the elevator cage shall be placed. The tool shall target the elevator’s guide bar brackets. Finally to verify the elevator’s guide bar brackets in respect of the vertical line.

ALT will produce or hire a company to manufacture the tool. Thereafter an instruction will be developed in how it should be used and if it would be possible to test it in the reality.

1.2 Purpose and goal

The purpose of this project is to fulfil the company’s requirements, which is to develop a concept. The goal is not only to achieve the requirements it’s also to facilitate the installers. It is important that the elevator cage is lifting smoothly and not bumping into the elevator’s rail track.
1.3 Limitations

The following limitations have been made so the project doesn’t get too extensive.

- The project is limited to 10 weeks.
- The dimensions for the elevator shaft are required from ALT Hiss AB.
- The project does not include testing a prototype.

1.4 Timeframe

Figure 1.4.1 illustrates a timeframe created by how the report is planned.
2. Theory

2.1 Activity planning

A description of the flow of work is based on the essentials of the systematic approach. The goal is to adjust the general statements and to integrate the working and the making steps for the area of use.

The planning and the design are useful to be processed into four main stages.

Before starting a product development it is required to treat the given task in details. The requirements and the existing constraints have been defined by collecting information into task clarification, which is the first stage.

Selecting the problems, creating a function structure, searching for the right principles and then relating those into working structure is achieving a conceptual design. Which is the second stage.

In the third stage, the project group are starting from a concept. To get different variants of information it’s required to produce preliminary layouts. These layouts are important to obtain an embodiment design.

The fourth and the last stage is for instance a design process for preparation, dimensions, and drawings.⁴
2.2 Defining the problem

In order to make a successful design three steps must be considered.
A problem that needs to be solved or a solution to a problem comes from an idea.
This means the designing of the project starts with an idea.
In the beginning of the project it is important to define the problem. By starting to name a
problem it gets easier to make a sketch of the concept.
The quality of the sketch is not as important as the time and the cost.

To define the context it is important to define documents, studies, collections and
summarizations in the right approach.
It’s important to state and constantly clarify what the system boundary is to minimize the
miscommunication for everyone involved. A mission statement is made when goals for the
design are created. Make context diagram or context matrix to have a clear view of the
different parts that have a connection with the design.
Only three roles are enough to describe by trying to find out who is involved in the design and
their point of view. The owner of the system is the individual who sets design goals and
authorizes major design decisions. The customer is the individual who approves purchase of
the system and transfers it into use. The user is the individual who actually uses the system for
an approved purpose.
The customers and workplaces is a good source for information. It’s recommended to
interview the customer and visit the workplace to gather information. Collected information
shall be organized in group system and make it possible to decide the importance of the
design.

Developing the behavioural descriptions is created with a template of five sections. The first
step is to name the use case. The second step is to describe the state of the system, called
initial conditions. The third step is describing the behaviour for the events and activities that
have been made. The fourth section is, ending conditions. It describes the state of the system
and is placed at the end of the behaviour. If the ending conditions are not positioned in the
end of the behaviour, then it’s measured as a failure. The fifth section is the notes. Here is
written the ideas that occur during the behaviour description.
The end of defining the problem, a product diagram, context matrix, mission statement, table
of product objectives and a list of functional requirements will be created.5
2.3 Measuring the need and setting the targets

The designer has to find out as much as possible about the customer needs and the customer product objectives to make it specific for the engineer.

Extracting and gathering related data collections to a metric with consideration of the design goal is called the Goal Question Metric (GQM) and consists of four steps.

The voice of the customer identifies the goals of the measurements. Only the high-levelled product objectives are taken into consideration. The formulation of the question is often missing in the data collection.

If the second step, generating questions that define the goals in a quantitative way, isn’t accomplished it wouldn’t gather any answers on the questions.

It’s important to ask the questions before collecting the data. It is the best guarantee that the data will generate meaningful answers.

In the third step of specifying the measures needed to answer the questions, the metrics are possible to design and collected data will answer the questions.

If the product design is, for example, fastest to put away than other products, then a quantitative basis is achieved.

In the fourth and last step the GQM method is developing data collection to calculate the metrics.5

Benchmarking is gathering of information on the market of similar product that’s already in stores for sales and is on the market. This is a good way to compare others product with the product that’s being developed.6
2.4 Design Core: The product design specification

In the design core of product design specification (PDS), the creation and development is taken to a greater detail. In this stage it is important to measure the PDS as a dynamic sense and not static because the changes that is done during the design core are not failing, instead it’s building a good basic of PDS.

Market research, competition analysis, literature searching, patent extracting, etc., is a starting point. When starting with a blank paper it is improbable to complete the task/project. Thus to be effective the solution is to be organized and systematic. The success comes by paying attention to the detail.

The contents of product design specifications are for instance performance, environment and target product cost.

The performance needs to be fully defined. The more complex the product is, the more possibility there is for failures.

Groups that pay attention to establishing objective shows the evidence of research for a more successful design.

To be successful the product’s environment should consider and investigate all possible aspects. Some of the aspects can for instance be, temperature range, pressure range, humidity, gravity forces, dirt or dust. These aspects are affecting the product in different areas, for example, during manufacture, storage or assembly.

The aspects of all kind need to be taken in consideration before being experienced of it.

All type of products that are considered to be movable should be designed for transport and storage. The cost that comes with packing should be added to the product cost and volume.

The size of the products is not only important for the ergonomic. There is a number of facts that will be considered, like the cost, safety or production.

The size is mostly taken into consideration if the product is going to fit or which size it needs to be. The difficulty and shapes of the product are two properties that need to be taken into consideration no matter what.
The weight, as “the size”, is significant for many properties of the product. Handling the product during installation or other workshops is taken important.

Selecting materials for the product are left to the group. All special material needs should be specified by the standard.

It’s important to achieve all the necessary information on customer likes or dislikes. There are different inputs like, eyeball-to-eyeball discussion, question and answer or specifications. The inputs would be able to give necessary data as, if the product is already on the market or a new product.

Usually the product, which left the manufacture, needs to be tested. Data collection and the history of the product are required for the important information that is needed. The testing involves planning and performance for the cost and to confirm the compliance.

The safety properties of the future design and its place need to be measured. Standards are used for covering the safety properties. Safety is one of the factors that are being taken into consideration when installing a product.
2.5 House Of Quality (HOQ)

House of quality is fundamentally a diagram that looks like a house. HOQ is used to communicate with design and engineering. The most important characteristic targets for the product would be gained if the voice of the customers and product objectives were making it more specific for the engineers, for example, answering in units like km/h or meters.\(^2\)

According to article, *a rough set based data mining approach for house of quality analysis*, by Jing Rong Li and Qing Hui Wang, the ultimate goal with house of quality is to find out the interrelationship between customer needs and product characteristics.

![Figure 2.5.1. Simple example of the house of quality\(^2\)](image)
2.6 Exploring the design space

Through working in a group sooner or later “downsides” will appear. The most common is having tunnel vision with only one idea. This means continuing working on the same idea without making any analyses, gathering information and with no discussion internally in the group about different solutions or ideas. But still it could be best idea or the worst idea. Often a great idea appears on the table, but can seem quiet radical and different. This leads to that the group decides a much “safer” approach and more common solution to avoid different thinking.

Discovering concepts that are appropriate to the design problems are the first stage of the exploration process. Approaching the process systematically makes it possible by following four steps.

It’s impossible to create a solution without observing a problem first. The details that matters the most needs to be valued after detailed function view of the problem has been developed. This clarifies the problem and decomposes the functions.\textsuperscript{5}

The second step is to brainstorm and research. Brainstorming is a good method for finding creative solutions but that doesn’t mean it’s always realistic. To make a brainstorm session successful there are some rules to follow. There should be at least one person participate. Let everyone contribute with their ideas and never say others ideas are impossible to complicated or bad.\textsuperscript{1}

According to article, \textit{Seven Ways to Innovate Your Brainstorms for Better Results}, by Rigie Mitchell, the goals of the session should be very clear in the beginning of the brainstorming. Prepare a compelling of the statement of the challenges and obstacles. The members shall contribute with their knowledge. Share out some background information about the task to gain a greater understanding. Correct idea generation techniques will make the creative problem solving more affective and defining the accepted objective criteria as standard to validating the result of ideas. Finlay all the ideas should be written down and sorted by its importance for the design.
The third step in the process is to organize the list of concept fragments into a tree. The tree is called, a concept classification tree, and is a group of concept fragments put into a tree-structure.

If the tree is being studied it could be seen that some branches should be expanded. The words can also be pruned from further consideration.

To explore the multitude of ways, ideas can be combined to form that the solutions are needed in a systematic way.

Matrix of concept fragments organized by function is called, a concept combination table or morphology box. The concept fragments are being combined with each other but all fragments doesn’t need to follow all possible combinations.

Every combination of ideas from the concept combination table should demonstrate a different design path.

With a morphological chart the designer can have a clear point of view, of the whole design and all the different functions and concepts. This is very useful for the visualization and helping of finding the most suitable design. From the focus the development effort table is what the design or function shall perform. Extract it in the left table and name in functions. And the potential solutions are extracted from brainstorming, research and sometimes costumers and in places on top of the table. Drawing a line through all of the rows creates the concept and it is acceptable to have more than one solution on each row. The outcome will result in at least one concept.

The second step is to take the combined fragments and design a concept. It could be a sketch of how the product might work together or it may be a fully design product.

The last step of progressing the process is to identify the subsystems.

The summarization step, which is taken into consideration before moving on with the concept selection, is to identify the subsystems of the product. A subsystem is gathered elements of a system that has a detectable function.\(^5\)
2.7 Optimizing design choices

The main task in this step is to take previous sketches and concepts and select the most potential design concept and often it is quite difficult to make that decision. A good way to select and approach this step if by using an established method called the Pugh analyse. There are seven steps to take in consideration and carryout.

The first step is to select one concept, which is the most promising. With help of the customer project objectives the data can be translate into attributes for the design choice. When the objective has been overlooked, for example, if the objective is being discovered and it differs from the concept, then the set of product goals and tests should be reconsidered. This step identifies the relevant attributes.

The third step is to make a screening of the concepts. It is used to eliminate and find concepts that are not worth to continuing working on. A simple way is to make rating and scoring system for elimination.

The fourth step requires more advanced rating system. It’s being repeated from the previous step and the rating is more detailed as the detailed attribute-weighting scheme.

In the fifth step, weighting the attributes, it is being extracted in the different product objective from previous chapter. It’s an important step because some of the product characteristics will start to show up. All the previous ratings and weight are combined into a matrix at the stage, scoring and ranking the alternatives. This will give us the designs “finishing” matrix.

In the last step the best concept is being selected.
2.8 Developing the architecture

In the fifth step of product development, it is important to transfer the data from the fourth previous chapters. The reason for that is, to take the general data from the design problems and “translate” them into a problem of designing subsystems. When it comes to subsystems, they have to work with others subsystems. If a subsystem fails it shall not affect the overall design. Descriptions are required for every subsystem because of risk of misunderstanding and miscommunication assuming that this is a larger group project.

The operational description template shall contain behaviour of use cases, which are mapped to the affected subsystem. This means explaining the behaviour detail in every step. Following with locating and identifying functions that works, as the system shall perform. To add extra information into the operational description template, a simple way is just by adding an extra column.

Throughout working in a group, things can get quiet hard to organize all the behavioural description. There is two ways to approach this problematic. The first way is to identify functional relationships. For instance before creating a matrix one could clarify the functional view. The second way is called summarize state changes and is useful to describe the system in different phases.

When approaching the constructions of the physical architecture of the system begin with summarizing the systems interface and adding an interface matrix. The interface matrix shall contain data about internal and external entities of the system in question. Link all subsystems and document techniques for a superior organizing. That will benefit the following phase of the design. From a design and safety point of view it’s strongly recommended to reason in the group about issues when something fails or working improperly. This is called identifying emergent interactions and can easily be discovered in interaction matrix. The final part is to generate a concept sketch. This will give a clearer view and a greater understanding of the design.\(^5\)
2.9 Failure Mode and Effects and Critical Analyse (FMECA)

Every design has some weak points and building a product in certain way, has also some risk of failures. To save money and time for the company one must be more accurate about getting the design right before the product is built. The risk of failure in a design is impossible to remove but the option to eliminate or reduce the fails is achievable. There is a method called failure mode effects and critical analyse, also known as FMECA. The designers have to make a systematic review of the system or product.

According to article, failure analysis of machinery component by considering external factors and multiple failure modes – A case study in the processing industry, by R. Ahmad FMECA is best applied to identifying and classify characteristics. This includes analysing its functions. In which mode the failure accurate and what the causes of the failure are. And the failure consequences are important to reflect on, how the process or product will be affected. Like mentions before this will give a clearer view on how to reduce the consequences and prevent failures.

According to article, Reliability Analysis of Aircraft Equipment Based on FMECA Method, by Jun Li and Huibin Xu there is also one more part to take in consideration, which is to basically measure the degree of the seriousness of the failure and to classify them into four different types. Starting off with the highest Type one disastrous, Type two fatal, Type three critical and Type four slightly. The final segment is to weight and rank all failures, how often and measure the frequency they occur. This can be calculated and ranked with risk priority number, RSN.
3. Method

The degree project has been performed with literature studies, interviews and data collections. Using the product development process as an application to the problem has created some concepts.

3.1 Literature study

The most gathered literature information is from Linnaeus University library together with the course 2MT002, Product development through system engineering. Systems engineering is basically a process for design. It’s has proven to be a good method for design and product development.

Product development methods are described and explained in the literature books. The Linnaeus University database, OneSearch, has been used for searching articles, books and journals. Internet has been used for searching information online.

3.2 Interview

Several visits to ALT Hiss AB have been made and at these occasions the group has been able to ask questions and collect answers of the technical manager. This has led to necessary information for the group to be able to continue in the right direction of getting the design right. The visits have given the group a deeper understanding of the company.

3.3 Data collection

With the help of the contact person of the company, the group has received several important documents, such as measure of the elevator cage, guide bar bracket and 3D-CAD models. This has been an important part of the work because the design is based on the information from these.
4. Application

4.1 Activity planning

Figure 4.1.1. Activity plan

Figure 4.1.1 shows the activity plan of the application. The activity plan is processed through planning, task clarification and conceptual design. The figure 4.1.1 also illustrates that a conceptual design is gained if following steps are taken; the task of the project through, the plan, clarifying the task, developing the principle solution and developing the construction structure.
4.2 Defining the problem

The companies’ request is to develop a concept for plumb of elevator shaft. To plumb the elevator shaft by the current method takes a lot of time when placing the elevator cage accurately. As correctly the installer mounts the cage the more comfort is for the users of the elevator.

The current assembly methods for plumb the elevator shafts are time-consuming and it complicates the installer’s way of working.

Name of the problem: The mounting is time consuming.

Figure 4.2.1 illustrates one of the companies’ models of the guide bar brackets mounted on the guide rails.

Finding a way to make the assembly less complicated makes it easier for the elevator installers. To approach this problem is by making the process design. The time is limited to 13-06-2014 and the budget is unlimited.

Designing an assembly tool for plumb the elevator shaft due to the fact that it needs to be safe, precisely and easy to assembly could be advanced. It has to also have a simple construction to save time.
The process is divided into three roles; owner, customer and user. The owner is the group of designers. The customer is the company, ALT Hiss AB, and the user will be the installer from the company.

Our mission is to design a concept sketch for plumb of elevator shaft.

![Diagram](image)

*Figure 4.2. Context diagram for the tool*

A context diagram for the tool is illustrated in figure 4.2. It’s a relationship between the internal and external entities. The internal entity is the tool and the external entities are the company, elevator shaft, installer and the storage.

A relationship is illustrated in figure 4.2 between the tool and the elevator shaft, “Tool placed in elevator shaft”.

In current situation the installer mount the guide bar brackets parallel to each other on the top of the elevator. Then the installer places the wire in four different holes on the guide bar brackets. In order to avoid getting the guide rails on the wire the installer places a pin in between the guide bar bracket and the wire.

In the mounting process a weight is mounted at the end of the wire, which is hanging through the elevator shaft. The installer then places the weight into a bucket of oil, which makes it harder to move because of its viscosity. This is called “plumb line”.
Figure 4.2.3 illustrates a guide bar bracket with the function that plumbs the lines and holds the elevator guide rails.

All the guide bar brackets get mounted in the elevator shaft by following the plumb line and then the elevator guide rails get placed on the guide bar brackets. A tool is also used to get the guide rails parallel to each other.

When the mounting process is done correctly the elevator cage should not have any vibrations or swings while moving.

The customer comments are collected in table 4.2.2 where they explain the problems of the current method of mounting the tools.

<table>
<thead>
<tr>
<th>Table 4.2.2. Customer comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takes time to mount guide bar bracket</td>
</tr>
<tr>
<td>Complicated to plumb elevator shaft</td>
</tr>
<tr>
<td>The current guide rail tool could be more user friendly</td>
</tr>
<tr>
<td>The wire rope is unstable</td>
</tr>
<tr>
<td>It will simplify if the guide bar brackets doesn’t need to be mounted before plumb the elevator shaft</td>
</tr>
<tr>
<td>The guide rails are difficult to adjust</td>
</tr>
<tr>
<td>It would simplify if the plumb of elevator shaft could be measured</td>
</tr>
<tr>
<td>Limited dimensions in the elevator shaft</td>
</tr>
</tbody>
</table>
The customer comments from table 4.2.2 are divided in groups and organized in similarity in table 4.2.3.

*Table 4.2.3. The affinity groups*

<table>
<thead>
<tr>
<th>Mounting</th>
<th>Facilitation</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complicated to plumb elevator shaft</td>
<td>It will simplify if the guide bar brackets doesn’t need to be mounted before plumb the elevator shaft</td>
<td>The wire rope is unstable</td>
</tr>
<tr>
<td>Takes time to mount guide bar bracket</td>
<td>It would simplify if the plumb of elevator shaft could be measured</td>
<td>Limited dimensions in the elevator shaft</td>
</tr>
</tbody>
</table>

The left and the right columns are what the customer said respectively the translation from the voice of the customer into how the owners understood it. These comments are illustrated in table 4.2.4.

*Table 4.2.4. The voice of the customer*

<table>
<thead>
<tr>
<th>Make the tool easy to mount</th>
<th>Make a tool that is easy to attach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make the tool user friendly</td>
<td>Do not make the tool too complex</td>
</tr>
<tr>
<td>Make the tool easy to put away</td>
<td>Make a tool that is easy to fold</td>
</tr>
<tr>
<td>Make the tool safe</td>
<td>Don’t make the tool too heavy</td>
</tr>
<tr>
<td>Make the tool safe</td>
<td>Don’t make the tool too large</td>
</tr>
<tr>
<td>Make the tool safe</td>
<td>Do not let the tool injure the installer</td>
</tr>
</tbody>
</table>

Table 4.2.5 “Primary use cases for the tool” are taken with respect of table 4.2.1 with the name “Context matrix for the tool”. The use cases are prioritised in table 4.2.6 with the High (H), Medium (M) and Low (L).

For example “Installer attach guide bar bracket” is high prioritised because it’s important that the installer makes it carefully. Another example is “Installer take tool from storage” which is low prioritised since transporting is not taken into consideration as much as the high prioritised use cases.

*Table 4.2.5 Primary use cases for the tool*

<table>
<thead>
<tr>
<th>Use Case</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
</tr>
<tr>
<td>Installer take tool from storage</td>
</tr>
<tr>
<td>Installer mount tool into elevator shaft</td>
</tr>
<tr>
<td>Installer attach guide bar bracket</td>
</tr>
<tr>
<td>Installer attach guide rails</td>
</tr>
<tr>
<td>Installer demount tool from elevator shaft</td>
</tr>
<tr>
<td>Installer place tool in storage</td>
</tr>
</tbody>
</table>
Table 4.2.6. Prioritized use cases for tool

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installer take tool from storage</td>
<td>L</td>
</tr>
<tr>
<td>Installer mount tool into elevator shaft</td>
<td>M</td>
</tr>
<tr>
<td>Installer attach guide bar bracket</td>
<td>H</td>
</tr>
<tr>
<td>Installer attach guide rails</td>
<td>H</td>
</tr>
<tr>
<td>Installer demount tool from elevator shaft</td>
<td>L</td>
</tr>
<tr>
<td>Installer place tool in storage</td>
<td>L</td>
</tr>
</tbody>
</table>

Table 4.2.7 and table 4.2.8 illustrates the behavioural description of the high-prioritized use cases. The use cases are “Installer attach guide bar bracket” and “Installer attach guide rails”. The behaviour threads, which are described below the Installer, System (tool) and Guide bar bracket, are the activities and events. For example “The installer attach the guide rails vertical” as illustrated in table 4.2.8.

Table 4.2.7. Behavioural description of “Installer attach guide bar bracket” use case

<table>
<thead>
<tr>
<th>Installer attach guide bar bracket</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial condition:</strong></td>
</tr>
<tr>
<td>System is in the unloaded state</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Installer</th>
<th>System (tool)</th>
<th>Guide bar bracket</th>
</tr>
</thead>
<tbody>
<tr>
<td>The installer mount the tool into the elevator shaft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer secure the tool is set</td>
<td>The system shall hold its position</td>
<td></td>
</tr>
<tr>
<td>The installer set the plumb line into position</td>
<td>The system shall hold the plumb line</td>
<td></td>
</tr>
<tr>
<td>The installer mount the guide bar bracket</td>
<td>Guide bar brackets are mounted on the wall</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The system shall indicate the guide bar brackets position</td>
<td></td>
</tr>
</tbody>
</table>

| Ending conditions:                          |
| The guide bar brackets are in the armed state |
**Table 4.2.8. Behavioural description of “Installer attach guide rails” use case**

_Installer attach guide rails_

<table>
<thead>
<tr>
<th>Initial condition:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System is in the loaded state</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Installer</th>
<th>System (tool)</th>
<th>Guide rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>The installer attach the guide rails vertical</td>
<td>The system shall indicate the guide rails position</td>
<td></td>
</tr>
<tr>
<td>The installer attach the tool to the guide rails</td>
<td>The system shall place the guide rails in proper position</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ending conditions:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The guide rails are in the armed state</td>
<td></td>
</tr>
<tr>
<td>2. The system is in the loaded state</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2.10 indicates primary and secondary use cases. These use cases are prioritized with big letters as described in table 4.2.6. The secondary use case is a list of failure possibilities. For example “Installer drops tool”, which is given a high priority.

**Table 4.2.10. Primary and secondary use cases with priorities**

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
<td></td>
</tr>
<tr>
<td>Installer take tool from storage</td>
<td>L</td>
</tr>
<tr>
<td>Installer mount tool into elevator shaft</td>
<td>H</td>
</tr>
<tr>
<td>Installer attach guide bar bracket</td>
<td>H</td>
</tr>
<tr>
<td>Installer attach guide rails</td>
<td>H</td>
</tr>
<tr>
<td>Installer demount tool from elevator shaft</td>
<td>M</td>
</tr>
<tr>
<td>Installer place tool in storage</td>
<td>L</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td></td>
</tr>
<tr>
<td>Installer drops tool</td>
<td>H</td>
</tr>
<tr>
<td>Installer mount tool incorrectly</td>
<td>M</td>
</tr>
<tr>
<td>Tool falls on installer during mounting</td>
<td>H</td>
</tr>
<tr>
<td>Tool gets dirty and unusable</td>
<td>M</td>
</tr>
</tbody>
</table>
A summarization of the context matrix for the tool is illustrated in table 4.2.11. It is focused on the tool and its external entities. For example “Installer injures him/her-self or another installer”.

**Table 4.2.11. Summary context matrix for the tool**

<table>
<thead>
<tr>
<th>Is related to</th>
<th>Installer</th>
<th>Tool</th>
<th>Guide bar bracket</th>
<th>Guide rail</th>
<th>Store surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installer</td>
<td>Injures him/her-self or another</td>
<td>Using</td>
<td>Attach or mount</td>
<td>Attach or mount</td>
<td>Drops tool against</td>
</tr>
<tr>
<td>Tool</td>
<td>Mounted by but does not harm</td>
<td>Indicate proper position of</td>
<td>Place in proper position of</td>
<td>Survives impact with</td>
<td></td>
</tr>
<tr>
<td>Guide bar bracket</td>
<td>Mounted by but does not harm</td>
<td>Detected by</td>
<td></td>
<td>Hold</td>
<td></td>
</tr>
<tr>
<td>Guide rail</td>
<td>Attached vertical by but doesn’t harm</td>
<td>Detected by</td>
<td>Attached on</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Store surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: The tool boundary is in bold.*

Table 4.2.12 contains index numbers, originating requirements and abstract function names. The originating requirements are followed by the actions under abstract function names. An example is, “The system shall survive a collision with a hard surface in working order” which is followed by the action, “Survive collision”.

**Table 4.2.12. Draft of originating requirements**

<table>
<thead>
<tr>
<th>Index</th>
<th>Originating Requirements</th>
<th>Abstract Function Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR.1</td>
<td>The system shall be set in elevator shaft in its proper position</td>
<td>Set</td>
</tr>
<tr>
<td>OR.2</td>
<td>The system shall hold the plumb line</td>
<td>Hold</td>
</tr>
<tr>
<td>OR.3</td>
<td>The system shall indicate the guide bar bracket in its position</td>
<td>Indicate</td>
</tr>
<tr>
<td>OR.4</td>
<td>The system shall indicate the guide rails position</td>
<td>Indicate</td>
</tr>
<tr>
<td>OR.5</td>
<td>The system shall place the guide rails in proper position</td>
<td>Place</td>
</tr>
<tr>
<td>OR.6</td>
<td>Guide bar bracket is mounted on the wall</td>
<td>Mounted</td>
</tr>
<tr>
<td>OR.7</td>
<td>The guide rails are mounted on the guide bar bracket</td>
<td>Mounted</td>
</tr>
<tr>
<td>OR.8</td>
<td>The system shall inform the installer that the tool is safe</td>
<td>Inform</td>
</tr>
<tr>
<td>OR.9</td>
<td>The system shall survive a collision with a hard surface in working order</td>
<td>Survive collision</td>
</tr>
<tr>
<td>OR.10</td>
<td>The system shall successfully complete each cycle of use for many cycles</td>
<td>Repeat</td>
</tr>
</tbody>
</table>
4.3 Measuring the need and setting the targets

Table 4.3.1 illustrates the high-level product objectives from the voice of the customer that can be find in table 4.2.4.

Table 4.3.1. Product objectives

<table>
<thead>
<tr>
<th>Tool easy to mount</th>
<th>Tool user friendly</th>
<th>Tool easy to put away</th>
<th>Tool safe</th>
</tr>
</thead>
</table>

A analyse of the product objectives are illustrated in table 4.3.2. The table shows the difference between the product objectives and analyse/for the purpose of/with respect to/from the perspective of/in the context of. It presents names of the different quality attributes. For example, the tool is easy to put away is with respect to a name of, storability.

Table 4.3.2. Analysing product objectives

<table>
<thead>
<tr>
<th>Analyse (The object or process under measure)</th>
<th>For the purpose of (Understanding, designing, controlling, or improving the object)</th>
<th>With respect to (The quality focus the object that measurement focuses on)</th>
<th>From the perspective of (The people that measure the object or who value the attribute)</th>
<th>In the context of (The environment in which the measurement takes place)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool easy to mount</td>
<td>Tool</td>
<td>Usability</td>
<td>User</td>
<td>Elevator shaft</td>
</tr>
<tr>
<td>Tool user friendly</td>
<td>Tool</td>
<td>Usability</td>
<td>User</td>
<td>Elevator shaft</td>
</tr>
<tr>
<td>Tool easy to put away</td>
<td>Tool</td>
<td>Storability</td>
<td>User</td>
<td>Storage</td>
</tr>
<tr>
<td>Tool safe</td>
<td>Tool</td>
<td>Safety</td>
<td>Company, user</td>
<td>Elevator shaft, outdoor</td>
</tr>
</tbody>
</table>
Table 4.3.3 is a list of goals, questions, and ideal -and approximate metrics. The questions are more quantitatively oriented than the goals. Ideal metric is a measurement that directly answers a question. The difficulty of collecting data is ignored at ideal metric column. At approximate metric column the difficulty and expense is not being ignored, instead it’s being collected and proposed. An example of a goal is, for making the tool easy to mount there is set a question of how many parts the tool makes. An ideal metric for the question is an answer of yes or no, which follows by an approximate metric of numbers of pieces.

Table 4.3.3. Defining metrics to answer questions

<table>
<thead>
<tr>
<th>Goal</th>
<th>Questions</th>
<th>Ideal Metric</th>
<th>Approximate Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool easy to mount</td>
<td>Is the tool made of many parts?</td>
<td>Answer: Yes/No</td>
<td>Number of pieces</td>
</tr>
<tr>
<td>Tool user friendly</td>
<td>Does the tool have any instruction?</td>
<td>Answer: Yes</td>
<td>(No substitute)</td>
</tr>
<tr>
<td></td>
<td>How long time does it take to learn how to use the tool?</td>
<td>Hour(s)</td>
<td>(No substitute)</td>
</tr>
<tr>
<td>Tool easy to put away</td>
<td>Where will it be stored?</td>
<td>In the storage, service-vehicle</td>
<td>(No substitute)</td>
</tr>
<tr>
<td></td>
<td>How much space will it take?</td>
<td>Usable storage space</td>
<td>(No substitute)</td>
</tr>
<tr>
<td></td>
<td>What is the total maximum weight of the tool?</td>
<td>30 kg</td>
<td>(No substitute)</td>
</tr>
<tr>
<td>Tool safe</td>
<td>How long does the tool last until it breaks?</td>
<td>Forever</td>
<td>Ages from first time of use</td>
</tr>
<tr>
<td></td>
<td>Does the tool have any sharp edges?</td>
<td>Answer: No</td>
<td>(No substitute)</td>
</tr>
</tbody>
</table>

Table 4.3.4 illustrates the calculations for the remaining product objectives. It’s important to make the tool easy to mount as noticed on the high-levelled number rating in the table 4.3.4. All product objective results are summed to one. Product objectives are prioritised and ranked in table 4.3.5.
### Table 4.3.4. Computing relative priorities of product objectives

<table>
<thead>
<tr>
<th></th>
<th>Tool easy to mount</th>
<th>Tool user friendly</th>
<th>Tool safe</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.35</td>
<td>0.25</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>Tool easy to put away</td>
<td>Tool inexpensive</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Tool easy to mount for the installer</td>
<td>Tool user friendly for the installer</td>
<td>Tool safe for the installer</td>
<td>Tool safe during mounting</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>Formula</td>
<td></td>
<td>=0.3*1</td>
<td>=0.2*1</td>
</tr>
<tr>
<td></td>
<td>Rounded Result</td>
<td></td>
<td>0.35</td>
<td>0.25</td>
</tr>
</tbody>
</table>

### Table 4.3.5. Relative priorities and ranking of product objectives

<table>
<thead>
<tr>
<th>Product Objectives</th>
<th>Relative Priority</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool easy to mount for the installer</td>
<td>0.35</td>
<td>1</td>
</tr>
<tr>
<td>Tool user friendly for the installer</td>
<td>0.25</td>
<td>2</td>
</tr>
<tr>
<td>Tool safe for the installer</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>Tool safe during mounting</td>
<td>0.15</td>
<td>4</td>
</tr>
<tr>
<td>Tool light weight</td>
<td>0.048</td>
<td>5</td>
</tr>
<tr>
<td>Tool easy to put away for the installer</td>
<td>0.032</td>
<td>6</td>
</tr>
<tr>
<td>Tool inexpensive for the company</td>
<td>0.02</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Benchmark data for competitive products of the tool cannot be compared because there is not same or similar tool of this kind. The tool is specially designed for the method of plumb the elevator shaft.

House of quality can be viewed in appendix 1. It contains the customer comments, customer perceptions, engineering characteristics, impact of engineering characteristics on customer objectives, interrelationships and targets.
Customer objectives are being ranked with engineering characteristics. The ranking is being placed in the so called, “main floor”.

The current way of plumb the elevator shaft is being compared with the new one, as shown in the customer perceptions.

The specific targets has been set at the end of the quality house and the “roof” has been set from the different combinations of the impact of engineering characteristics on customer objectives. From the customer requirements the data have been collected to translate units to a more specific value. The tool shall weight less than 30 kg and the material shall be aluminium or sheet metal. The fillet radius shall be less than 5 millimetres to avoid scratching the user of the tool.

Table 4.3.6 illustrates all the combined and collected requirements for the measures. These requirements are taken from the previous chapter, table 4.2.12, and from the house of quality, appendix 1.

Table 4.3.6. Collected system-level requirements: Functional and technical performance measures

<table>
<thead>
<tr>
<th>Index</th>
<th>Originating Requirements</th>
<th>Abstract Function Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR.1</td>
<td>The system shall be set in elevator shaft in its proper position</td>
<td>Set</td>
</tr>
<tr>
<td>OR.2</td>
<td>The system shall hold the plumb line</td>
<td>Hold</td>
</tr>
<tr>
<td>OR.3</td>
<td>The system shall indicate the guide bar bracket in its position</td>
<td>Indicate</td>
</tr>
<tr>
<td>OR.4</td>
<td>The system shall indicate the guide rails position</td>
<td>Indicate</td>
</tr>
<tr>
<td>OR.5</td>
<td>The system shall place the guide rails in proper position</td>
<td>Place</td>
</tr>
<tr>
<td>OR.6</td>
<td>Guide bar bracket is mounted on the wall</td>
<td>Mounted</td>
</tr>
<tr>
<td>OR.7</td>
<td>The guide rails are mounted on the guide bar bracket</td>
<td>Mounted</td>
</tr>
<tr>
<td>OR.8</td>
<td>The system shall inform the installer that the tool is safe</td>
<td>Inform</td>
</tr>
<tr>
<td>OR.9</td>
<td>The system shall survive a collision with a hard surface in working order</td>
<td>Survive collation</td>
</tr>
<tr>
<td>OR.10</td>
<td>The system shall successfully complete each cycle of use for many cycles</td>
<td>Repeat</td>
</tr>
<tr>
<td>OR.11</td>
<td>The system shall weight less than 30kg</td>
<td>Weight</td>
</tr>
<tr>
<td>OR.12</td>
<td>The system shall be made by suitable material such as aluminium or sheet metal</td>
<td>Material</td>
</tr>
<tr>
<td>OR.13</td>
<td>The system shall not have any sharp edges, fillet radius under 50mm</td>
<td>Sharp</td>
</tr>
</tbody>
</table>
4.4 Design Core: The product design specification

The four red dots that can be viewed in appendix 2 are in current method being plumbed by mounting the first guide bar bracket and then positioning the plumb lines.

The environmental aspects for the designed tool are the temperature range, gravity forces, dirt and dust.

The temperature range is changed during its life length. The tool is being stored, transferred and used in a shaft with a room temperature.

The gravity forces are loaded when the tool is being mounted or when the tool is being used.

Dirt and dust are a problem for everyone that considers getting into an elevator shaft.

Loading the tool in the storage, transporting the tool, unloading the tool from the storage and mounting the tool into elevator shaft are several movable steps that needs to be taken into consideration. Therefore it is important to make the tool simple to move for the installer.

The size and the weight of the tool are a considering factor for the safety.

The tool has to fit the companies’ requirements, 1600-2000mm, for making the tool adjustable in the elevator shaft. From the engineers perspective it is also important to make the tool without edges and as simple as possible because safety and simplicity is one of the most important properties.

One of several companies’ requests is that the tool should be in sheet metal if possible. The choice of material stands between aluminium and sheet metal.

All gathered customer comments are illustrated in table 4.2.3 and table 4.2.4 under defining the problem.

When the tool is manufactured, it’s going to be tested by the company. The information of how the tool is acting and all data collection needs to be done because of the importance of the tools further development.

Using standard products for the tool gives a view of the tools costs. The costs will be taken into consideration.
4.5 Exploring the design space

The system flow is illustrated in figure 4.5.1. When the plumb line gets mounted it has to go through the system of plumb the elevator shaft until the plumb line can be dismounted.

Figure 4.5.2 illustrates a more detailed system flow diagram. It shows detailed steps of how it’s changed and what is applied.

For example, the guide bar brackets mounted in the elevator shaft is applied with human power.

When brainstorming all the free expressions and ideas from the group are shown. All from ordinary words to sentences. For example, “Tube connector” can be set on pipes. “Screw” can be fixed on aluminium profiles, pipes.
Brainstorming

- 3D model in solid works of the elevator shaft
- Vacuum cleaner to blow of the dust
- Plumb line
- Pipes
- Screw
- Bolt
- Tube connector
- Aluminium profiles
- Locking sleeve
- Adjustable leg
- Clamping ring
- GPS-System
- Measurement on the tool
- Clear marked line
- Tool for holding the plumb line
- Click system when setting plumb line
- Put/Place on the top/bottom
- Hanging system
- Laser
- Click rail track
- Click rail system
- Frame profile
- C-Profile
- I-Beam
- Plumb Bob
- Adjustable tool

A description of focusing the development effort can be viewed in appendix 3. It illustrates two connected behaviour descriptions, “Decompose functions using abstract language” with “Focus the development effort”.

Decompose functions using abstract language is a restatement of behaviour descriptions with finer detail. The behaviour descriptions can be found in table 4.3.7 and table 4.3.8.

Focus the development effort is a more oriented table, which is divided in bold italics. Functions that are highlighted (bold italics) have the potential of leading, for example, “The system shall hold its position”. The functions that are not highlighted (not in bold italics) can be left.
Table 4.5.2 illustrates the generate concept fragments. The fragments are certain taken from the brainstorming. The functions, which are italic, are taken from table 4.5.1.

Table 4.5.2. Generate concept fragments for each function

<table>
<thead>
<tr>
<th>The system shall hold its position</th>
<th>The system shall hold the plumb line</th>
<th>The system shall indicate the guide bar brackets position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>Clamping ring</td>
<td>Plumb line</td>
</tr>
<tr>
<td>Frame profile</td>
<td>Engraved indication</td>
<td>Wire</td>
</tr>
<tr>
<td>C-Profile</td>
<td>Pipe</td>
<td>Sensor</td>
</tr>
<tr>
<td>I-Beam</td>
<td>Pin</td>
<td>Human vision</td>
</tr>
<tr>
<td>Aluminium profiles</td>
<td>Laser</td>
<td></td>
</tr>
<tr>
<td>Tube connector</td>
<td>C-Profile</td>
<td></td>
</tr>
<tr>
<td>Adjustable leg</td>
<td>Robot</td>
<td></td>
</tr>
<tr>
<td>Locking sleeve</td>
<td>Human power</td>
<td></td>
</tr>
<tr>
<td>Bolts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screw</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical motor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pneumatic</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5.3, table 4.5.4 and table 4.5.5 have the same signification but other content. The headlines and the words are identified and selected from table 4.5.2.

The tables are first compound as a concept classification tree. Thereafter the words that are not considered suitable are strikethrough. The tables are then called, prune or expand concept fragments.

Table 4.5.3. Prune or expand concept fragments

<table>
<thead>
<tr>
<th>The system shall hold its position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
</tr>
<tr>
<td>Electrical</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Pipe</td>
</tr>
<tr>
<td>Frame profile</td>
</tr>
<tr>
<td>C-Profile</td>
</tr>
<tr>
<td>Aluminium profiles</td>
</tr>
<tr>
<td>Screw</td>
</tr>
<tr>
<td>Bolt</td>
</tr>
<tr>
<td>Tube connector</td>
</tr>
<tr>
<td>Adjustable leg</td>
</tr>
<tr>
<td>Locking sleeve</td>
</tr>
</tbody>
</table>
Table 4.5.4. Prune or expand concept fragments

<table>
<thead>
<tr>
<th>The system shall indicate the guide bar brackets position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
</tr>
<tr>
<td>Plumb line</td>
</tr>
<tr>
<td>Wire</td>
</tr>
</tbody>
</table>

Table 4.5.5. Prune or expand concept fragments

<table>
<thead>
<tr>
<th>The system shall hold the plumb line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
</tr>
<tr>
<td>Human power</td>
</tr>
<tr>
<td>Engraved indication</td>
</tr>
<tr>
<td>Pipe</td>
</tr>
<tr>
<td>Pipe</td>
</tr>
<tr>
<td>C-Profile</td>
</tr>
</tbody>
</table>

Table 4.5.6 and table 4.5.7 illustrates two different concept combination tables.
The words from table 4.5.6 are recognised in table 4.5.3 and table 4.5.5.
In table 4.5.7 the words are combined with each other. For example, pipe and clamping ring is a combination.

Table 4.5.6. Create concept combination table

<table>
<thead>
<tr>
<th>The system shall hold its position</th>
<th>The system shall hold the plumb line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe</td>
<td>Pipe</td>
</tr>
<tr>
<td>Adjustable leg</td>
<td>Clamping ring</td>
</tr>
<tr>
<td>Aluminium profiles</td>
<td>Engraved indication</td>
</tr>
</tbody>
</table>

Table 4.5.7. Create concept combination table

<table>
<thead>
<tr>
<th>The system shall hold its position</th>
<th>The system shall hold the plumb line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe and pipe (Tube connector)</td>
<td></td>
</tr>
<tr>
<td>Pipe and clamping ring</td>
<td></td>
</tr>
<tr>
<td>Pipe and engraved indication</td>
<td></td>
</tr>
<tr>
<td>Adjustable leg and pipe</td>
<td></td>
</tr>
<tr>
<td>Aluminium profiles and engraved indication</td>
<td></td>
</tr>
</tbody>
</table>

Note: All combinations of the table on the left with the table on the right are feasible
Figure 4.5.3. Pipe and pipe (Tube connector)

Figure 4.5.3 illustrates two pipes, which are connected with a tube connector. The combination is identified in concept combination table 4.5.7. The pipes are orthogonal to each other due to the tube connector. The pipes can be adjusted by unscrewing the tube connector.

Figure 4.5.4. Pipe and clamping ring

A pipe with clamping rings and a piece of steel in between is illustrated in figure 4.5.4. The pipe and clamping ring connection is known from the table 4.5.7. This method gives the installer more flexibility to easily regulate where the plumb line is going to be placed.
Figure 4.5.5. Pipe and engraved indication

Figure 4.5.5 illustrates a pipe with engraved indication. The link between the pipe and engraved indication is selected from table 4.5.7.

The indication is for plumb the lines. This makes the installer less concerned about where the plumb line is going to be set.

Figure 4.5.6. Adjustable leg and pipe

Figure 4.5.6 illustrates the adjustable leg combined with the pipe and a screw nut. The combination is recognised in concept combination table 4.5.7.

The leg is placed against the wall while the screw nut cannot be in contact with the pipe, otherwise it will not be adjustable.
Figure 4.5.7 illustrates aluminium profiles combined with engraved indication. The combination is identified in concept combination table 4.5.7.

The engraved indication clearly shows that the plumb line has its position. The aluminium profiles have tracks to make the connector stable and secured. It is also known that the profiles are adjustable to give the exactly length.
Figure 4.5.8 is a morphological chart. The chart is divided into functions and solutions. The functions are recognised in table 4.5.1 and the solutions are designed by constructing the products.

Pipes, tube connector, adjustable leg, clamping rings, engraved indication and plumb line is the first solution. This solution is marked with a blue line.

The second solution is marked with an orange line and contains aluminium profiles with screw, engraved indication and plumb line.

The third solution is a combination of screw, pipes and laser. This solution is marked with a green line.
Figure 4.5.9 illustrates a concept combination of pipes (a), tube connectors (b), adjustable legs (c), engraved indications on clamping rings (d) and plumb line (e). The solutions are designed in the morphological chart, figure 4.5.8.

By using the tool in parts makes it simpler to mount it on the top of the elevator shaft. The tube connector links the pipes as described in figure 4.5.3. The adjustable legs are placed against the wall and can be adjusted in suitable lengths. The clamping rings are static on the pipes and they are indicated with an engraving. The tool illustrates plumb lines and where the elevator is going to be set.
Concept 2, which is illustrating in figure 4.5.10, is combined with aluminium profiles (a), screws (b), engraved indications (c) and plumb line (d).

Aluminium profiles are adjustable to offer the length it needs. The screws are drilled in the wall, which makes the tool safer. The engraved indications on the profiles give the installer a simpler alignment and the plumb line shows were the elevator cage should be placed.

The products that have been exhibited and made in a solution are from figure 4.5.8.
Figure 4.5.11 illustrates a concept with laser (a), pipes (b) and screws (c). The products are design and selected to a solution in table 4.5.8.

The laser gives a clear and exact understanding of what the installer should do. With horizontal and vertical marks from the laser gives the installer a perfect place were the elevator cage is proper. The pipes are easily mounted with screws that give less flexibility but more safety.
Table 4.5.8 illustrates the functions and components into subsystems. There are identified three subsystems of the tool, plumb elevator shaft system, locking system and mounting system.

**Table 4.5.8. Organize functions and components into subsystems**

<table>
<thead>
<tr>
<th><strong>Plumb elevator shaft system</strong></th>
<th><strong>Locking system</strong></th>
<th><strong>Mounting system</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>The system shall hold the plumb line</td>
<td>The system shall hold its position</td>
<td>The system shall indicate the guide bar brackets position</td>
</tr>
<tr>
<td>Weight</td>
<td>Pipe</td>
<td>Plumb line</td>
</tr>
<tr>
<td>Clamping ring</td>
<td>Frame profile</td>
<td>Wire</td>
</tr>
<tr>
<td>Engraved indication</td>
<td>C-Profile</td>
<td>The system shall indicate the guide rails position</td>
</tr>
<tr>
<td>Pipe</td>
<td>I-Beam</td>
<td></td>
</tr>
<tr>
<td>Pin</td>
<td>Aluminium profiles</td>
<td></td>
</tr>
<tr>
<td>Laser</td>
<td>Tube connector</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adjustable leg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Locking sleeve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bolts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Screw</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electrical motor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pneumatic</td>
<td></td>
</tr>
</tbody>
</table>
4.6 Optimizing design choices

One of the three concepts from figure 4.5.9, figure 4.5.10 or figure 4.5.11 will be the promising design concept.

Table 4.6.1 is the system attributes divided in goals and attribute names. It illustrates the customer product objectivise.

<table>
<thead>
<tr>
<th>Goals</th>
<th>Attribute name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make the tool easy to mount for installer</td>
<td>Mounting</td>
</tr>
<tr>
<td>Make the tool user friendly for installer</td>
<td>Ergonomic</td>
</tr>
<tr>
<td>Make the tool safe</td>
<td>Safety</td>
</tr>
<tr>
<td>Make the tool easy to put away</td>
<td>Storing</td>
</tr>
<tr>
<td>Make the tool light weight</td>
<td>Light</td>
</tr>
<tr>
<td>Make the tool inexpensive</td>
<td>Affordability</td>
</tr>
</tbody>
</table>

Table 4.6.2 illustrates the attribute names from table 4.6.1 combined with the selected concepts.

The concepts are rated with plus (+), minus (-) or equal (0) grades. This is resulting in that the concept 3 is better than the reference concept.

Since there are only three concepts presented, none of them will be skipped and they will be performed in the next step of scoring the alternatives.

<table>
<thead>
<tr>
<th>Attribute name</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mounting</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Ergonomic</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Safety</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Storing</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lightly</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Affordability</td>
<td>+</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 4.6.3 illustrates a more detailed rating scale from table 4.6.2. Plus-zero-minus rating system has been replaced with a more detailed graded scale.

Concept 1 has the highest total score unlike the table 4.6.2 were the concept 3 was highest.

Table 4.6.3. Rating the alternatives in each attribute

<table>
<thead>
<tr>
<th>Attribute name</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mounting</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Ergonomic</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Storing</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Lightly</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Affordability</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>18</td>
<td>19</td>
</tr>
</tbody>
</table>

Giving a weight for attribute names, as illustrated in table 4.6.4, will make it simpler to select the most suitable concept.

Table 4.6.4. Attribute weights

<table>
<thead>
<tr>
<th>Attribute name</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mounting</td>
<td>18%</td>
</tr>
<tr>
<td>Ergonomic</td>
<td>10%</td>
</tr>
<tr>
<td>Safety</td>
<td>18%</td>
</tr>
<tr>
<td>Storing</td>
<td>7%</td>
</tr>
<tr>
<td>Lightly</td>
<td>5%</td>
</tr>
<tr>
<td>Affordability</td>
<td>9%</td>
</tr>
</tbody>
</table>

The rating is regarded to 1-5 as illustrated in table 4.6.5. An example is that the mounting is rated at five while the storing is lower rated, with a number of three. The weighted score is calculated by multiplying the weights with the rating. Concept 1 has the highest total score and will be developed.

Table 4.6.5. Design concept scoring and ranking

<table>
<thead>
<tr>
<th>Attribute name</th>
<th>Weights</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rating</td>
<td>Weighted score</td>
<td>Rating</td>
<td>Weighted score</td>
</tr>
<tr>
<td>Mounting</td>
<td>18%</td>
<td>5</td>
<td>0.9</td>
<td>3</td>
</tr>
<tr>
<td>Ergonomic</td>
<td>10%</td>
<td>3</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>Safety</td>
<td>18%</td>
<td>4</td>
<td>0.72</td>
<td>3</td>
</tr>
<tr>
<td>Storing</td>
<td>7%</td>
<td>3</td>
<td>0.21</td>
<td>3</td>
</tr>
<tr>
<td>Lightly</td>
<td>5%</td>
<td>4</td>
<td>0.20</td>
<td>3</td>
</tr>
<tr>
<td>Affordability</td>
<td>9%</td>
<td>5</td>
<td>0.45</td>
<td>3</td>
</tr>
<tr>
<td>Total score</td>
<td>2.79</td>
<td>2.01</td>
<td>2.12</td>
<td></td>
</tr>
<tr>
<td>Rank</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Continue?</td>
<td>Develop</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Elvedin Mešinović & Ermin Cerić
4.7 Developing the architecture

Appendix 4 is a view of an operational description template with system states and targets. The analysis is showing within the operational for instance are stable, unstable, locked. The subsystems are linked with the state and timing and provides important information to the designer. For example, when the operator is unpacking the tool from the storage it is providing information of energy transfer and the system state is unloaded, unstable and unarmed.

Table 4.7.1 is an object-oriented view. Functional requirements and the subsystems are containing in the table of view. It illustrates the collected functional requirements for each subsystem.

Table 4.7.1. Object-Oriented view: Functional requirements by subsystems

<table>
<thead>
<tr>
<th>Plumb elevator shaft system</th>
<th>Locking system</th>
<th>Mounting system</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system shall hold the plumb line</td>
<td>The system shall hold its position</td>
<td>The system shall enter the state</td>
</tr>
<tr>
<td>The system shall secure its proper position</td>
<td>The system shall be mounted correctly</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The system shall indicate the right position</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The system shall be placed to storage</td>
<td></td>
</tr>
</tbody>
</table>

The requirements trace matrix can be viewed in appendix 5. It illustrates the information from the collected system-level requirements with functional and technical performance measures, table 4.4.6, and the functional requirements that are derived from the operational description template.

Table 4.7.4 is a summary of state changes. It illustrates the combined state changes from appendix 3. The relationship between the state changes has given the information event. For example, the loaded, stable and armed state changes in a relationship with each other gives an information event that the tool is in position.
Table 4.7.4. Summary of state changes

<table>
<thead>
<tr>
<th>State Changes</th>
<th>Unloaded, unstable, unarmed</th>
<th>Unloaded, unstable, unarmed</th>
<th>Loaded, stable, armed</th>
<th>Loaded, unlocked, armed</th>
<th>Loaded, locked, armed</th>
<th>Loaded, stable, armed</th>
<th>Unloaded, Unstable, unarmed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unloaded, unstable, unarmed</td>
<td>“energy in”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unloaded, unstable, unarmed</td>
<td></td>
<td>“tool in position”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loaded, stable, armed</td>
<td></td>
<td></td>
<td>“tool secured”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loaded, unlocked, armed</td>
<td></td>
<td></td>
<td>“load”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loaded, locked, armed</td>
<td></td>
<td>“tool in position”</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loaded, stable, armed</td>
<td></td>
<td></td>
<td>“tool in storage”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unloaded, Unstable, unarmed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.7.5 is listing the system objects, internal and external.

The interface matrix for the tool illustrates the internal and external subsystems. The relationship between the subsystems names the event as the message. An example is that, operator load the plumb shaft system.

Table 4.7.5. Interface matrix for tool

<table>
<thead>
<tr>
<th>Tool</th>
<th>Operator (installer)</th>
<th>Plumb elevator shaft system</th>
<th>Locking system</th>
<th>Mounting system</th>
<th>Mounting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator (installer)</td>
<td>“load”</td>
<td>“tool in position”</td>
<td></td>
<td>“tool in position”</td>
<td></td>
</tr>
<tr>
<td>Plumb elevator shaft system</td>
<td></td>
<td>“tool in position”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locking system</td>
<td></td>
<td></td>
<td>“tool in position”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting system</td>
<td>“tool in position”</td>
<td>“tool secured”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td>“load”</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.7.6 illustrates the reordering and regrouping subsystems from the design structure matrix that results in deleting the rows and columns of table 4.7.5. The bolded areas are divided in, “locking -and mounting system” and “plumb elevator shaft system” with “mounting”.

Table 4.7.6. Reorder and regroup subsystems

<table>
<thead>
<tr>
<th></th>
<th>Plumb elevator shaft system</th>
<th>Mounting</th>
<th>Locking system</th>
<th>Mounting system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plumb elevator shaft system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locking -and mounting system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Locking system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting system</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.7.1. Tube connector

Figure 4.7.1 illustrates a tube connector with the function of placing the pipes perpendicular to each other. It’s simple to attach the pipes into the tube connector and lock them. The screws on the tube connector have to be tightened to lock the pipes.
Figure 4.7.2 illustrates a clamping ring with a circular engraved track. The function of the track is to set and tie the plumb line. The ring is placed and locked on the pipe with a screw.

Figure 4.7.3 illustrates an adjustable leg with slip protection. The threaded shaft is placed into the pipe and locked with a tightened bolt. The adjustable leg is placed toward a wall.
4.8 Failure Mode Effects and Critical Analyses (FMECA)

Different kind of risks may require different severity scales. Table 4.8.1 illustrates a severity scale that is used frequently in applying the approach. A rating scale is used from 1-10.

Table 4.8.1. Severity of failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Severity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The effect is not noticed by the customer</td>
</tr>
<tr>
<td>2</td>
<td>Very slight effect noticed by customer</td>
</tr>
<tr>
<td>3</td>
<td>Slight effect that causes customers annoyance, but not seek service</td>
</tr>
<tr>
<td>4</td>
<td>Slight effect, customer seeks service</td>
</tr>
<tr>
<td>5</td>
<td>Moderate effect, customer require immediate service</td>
</tr>
<tr>
<td>6</td>
<td>Significant effects, causes customer dissatisfaction</td>
</tr>
<tr>
<td>7</td>
<td>Major effect, system may not be operable; elicits customer complaint</td>
</tr>
<tr>
<td>8</td>
<td>Extreme effect, system is inoperable</td>
</tr>
<tr>
<td>9</td>
<td>Critical effect, complete system shutdown; safety risk</td>
</tr>
<tr>
<td>10</td>
<td>Hazardous; failure occurs without warning; life-threatening</td>
</tr>
</tbody>
</table>

Table 4.8.2 illustrates ratings from 1-10, approximate probability of failure and described occurrence. For example, rating number ten has an approximate probability of bigger than a half and describes as an extremely high occurrence.

Table 4.8.2. Probability of occurrence of failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Approx. Probability of failure</th>
<th>Description of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;1 x 10^-6</td>
<td>Extremely remote</td>
</tr>
<tr>
<td>2</td>
<td>1 x 10^-3</td>
<td>Remote, very unlikely</td>
</tr>
<tr>
<td>3</td>
<td>1 x 10^-5</td>
<td>Very slight chance of occurrence</td>
</tr>
<tr>
<td>4</td>
<td>4 x 10^-4</td>
<td>Slight chance of occurrence</td>
</tr>
<tr>
<td>5</td>
<td>2 x 10^-3</td>
<td>Occasional occurrence</td>
</tr>
<tr>
<td>6</td>
<td>1 x 10^-2</td>
<td>Moderate occurrence</td>
</tr>
<tr>
<td>7</td>
<td>4 x 10^-2</td>
<td>Frequent occurrence</td>
</tr>
<tr>
<td>8</td>
<td>0,20</td>
<td>High occurrence</td>
</tr>
<tr>
<td>9</td>
<td>0,33</td>
<td>Very high occurrence</td>
</tr>
<tr>
<td>10</td>
<td>&gt;0,50</td>
<td>Extremely high occurrence</td>
</tr>
</tbody>
</table>
Table 4.8.3 illustrates the possibility of detecting the failure. The rating scale is listed with numbers of 1-10, where rating number one is almost always detected and rating number ten is with no chance of detection.

### 4.8.3. Likelihood of detecting the failure

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description of detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Almost certain to detect</td>
</tr>
<tr>
<td>2</td>
<td>Very high chance of detection</td>
</tr>
<tr>
<td>3</td>
<td>High chance of detection</td>
</tr>
<tr>
<td>4</td>
<td>Moderate high chance of detection</td>
</tr>
<tr>
<td>5</td>
<td>Medium chance of detection</td>
</tr>
<tr>
<td>6</td>
<td>Low chance of detection</td>
</tr>
<tr>
<td>7</td>
<td>Slight chance of detection</td>
</tr>
<tr>
<td>8</td>
<td>Remote chance of detection</td>
</tr>
<tr>
<td>9</td>
<td>Very remote chance of detection</td>
</tr>
<tr>
<td>10</td>
<td>No chance of detection</td>
</tr>
</tbody>
</table>

Failure mode effects and critical analyses, FMECA, can be viewed in appendix 6 and is illustrating the weaknesses in the design.

The first step is to find the critical components on the tool. The second phase is to describe the function, failure mode, failure cause and assessment of failure effect of the components and the third step is to calculate the risk priority number, RPN. This is done by multiplying the remarks, which is rated from table 4.8.1, table 4.8.2 and table 4.8.3.

The most critical component on the tool is the tube connector with an RPN of 60. The tube connector is related with other components. If the tube connector fails there will be subsequent errors on the tool.
5. Result and analyse

Results of this degree project are going to be presented with the final concept sketches and idea drawings. The idea drawings can be viewed in appendix 7. The sharp edges have been taken into consideration and eliminated form the tool. It is an important factor when the installer mounts the tool into the elevator shaft.

Having a dialog with our contact persons from the company and the results from table 4.6.5 the best solution to develop further more is concept 1.

Figure 5.1 Final sketch concepts

Figure 5.1 illustrates the final concept. The adjustable legs are used to mount onto the wall and hold the whole tool steady. Walls of the elevator shaft are often not straight and can be in different lengths; 1600-2000 mm. Design of this tool is very flexible and can be adjustable to the elevator shaft length. There is a threaded hole in the steel bar with the function to hold the adjustable legs shaft in place. It can be locked and tightened with a bolt when the right length is found.

The pipe and the steel bar are attached to the adjustable legs, which is threatened with M20 and the pitch is 1.25. They are used to hold and support the weight of the components. The tube connector main function is the ability to connect different pipes and steel bars together and to
make sure they are perpendicular. This will make it simple for the installer to measure out where the elevator cage shall be placed and that there actually is space for it.

The screws on the tube connector have to be tightened to lock the pipes and steel bars. The pipe is weaker than the steel bar because its function is to hold the engraved clamping ring, the weight and stress is smaller.
The function of the track is to set and tie the plumb line on the engraved clamping ring. The ring is placed and locked on the pipe with a screw.

The weight has been big at the primary concept sketch. Thus on the way of this project the weight has been a big factor. Changes have been done and the final concept illustrates an improvement of a less weighted tool.
6. Discussion

The planning has been a very important factor in the degree project. Thus the planning could have been done in a better way.

Following the product development process from the theory has resulted in a conceptual sketch. This has been very helpful to organize all ours ideas and explore different solutions. Sketching down ideas on paper with a pen and discussing the idea is a fast way and effective way off getting closer to the solution. Drawing an idea directly on the 3D-CAD program can be sometimes very time consuming and a waste off time and energy. The contact persons on the company has been very supporting by explaining the problem many times and answering our questions.

There are some questions to take into consideration before even considering of making a construction. For instance by doing advanced calculations with a program is to find out the deflection and what max forces it can withstand, even if the loads on the current situation are very low. The adjustable leg is maybe the best solution right now but with more time and experience different solutions could have been made. This could possible be answered by doing a prototype of the sketch.

The contact persons from the company have been very positive about the new concept and might test it in the reality.
7. Conclusion

This degree project has involved product development of a tool for plumb the elevator shaft and measuring were the elevator cage could be placed. The designing group are convinced that the conceptual design fulfils the customers’ requirements and expectations. The idea drawings are done as an encouragement to constructing a prototype. All necessary measurements are included such as scale, part list and size.

A few questions are remaining about that the conceptual design will operate as intended. Probably the easiest way would be to manufacture a prototype and verify whether the conceptual design works or not.
8. Reference list


Articles:


Internet sources:

- ALT Hiss AB, Om oss.  
  http://www.althiss.se/om_alt.asp?altsite=!  
  (Accessed 27 April 2014)

- Wiberger, Produkter och prislista.  
  http://www.wiberger.se/templates/_prislista.htm  
  (Accessed 24 April 2014)

Contact persons:

- Stenkilsson, Anders. Technical manager. ALT Hiss AB.

- Lennartsson, Christer. Employee. ALT Hiss AB.
9. Content list (Appendix)

Appendix 1: House Of Quality (HOQ)

Appendix 2: Elevator cage dimensions

Appendix 3: Focus the development effort

Appendix 4: Operational description template with system states and targets

Appendix 5: The requirements trace matrix

Appendix 6: Failure Mode Effects and Critical Analyses (FMECA)

Appendix 7: Idea drawings
Appendix 2: Elevator cage dimensions
# Appendix 3: Focus the development effort

**Installer plumbs of elevator shaft**

### Initial condition:

System is in the unloaded state

<table>
<thead>
<tr>
<th>Installer</th>
<th>System (tool)</th>
<th>Guide bar bracket</th>
<th>Guide rails</th>
</tr>
</thead>
<tbody>
<tr>
<td>The installer position the tool into the elevator shaft</td>
<td>The system shall hold its position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer secure the tool is set</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer set the plumb line into position</td>
<td>The system shall hold the plumb line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer mount the guide bar brackets</td>
<td>The system shall indicate the guide bar brackets position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The Installer connect the guide rails</td>
<td></td>
<td>The guide bar brackets are mounted on the wall</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The guide bar brackets shall convert energy to translational energy</td>
<td>The guide rails shall be applied with translational energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The system shall indicate the guide rails position</td>
<td>The guide rails are mounted on the brackets</td>
</tr>
</tbody>
</table>

### Ending conditions:

1. The system is in the loaded state
2. The guide bar brackets and guide rails are in the armed state

*Note: Italics indicate functions that have the potential of leading to fundamentally different design approaches.*
## Appendix 4: Operational description template with system states and targets

<table>
<thead>
<tr>
<th>Operator (Installer)</th>
<th>Tool</th>
<th>Locking system</th>
<th>Mounting system</th>
<th>Mounting</th>
<th>System state</th>
<th>Timing</th>
</tr>
</thead>
<tbody>
<tr>
<td>The installer unpack tool from storage</td>
<td><em>Plumb elevator shaft system</em></td>
<td></td>
<td></td>
<td></td>
<td>Unloaded, unstable, unarmed</td>
<td></td>
</tr>
<tr>
<td>Energy transfer (“energy in”)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer place the tool in elevator shaft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unloaded, unstable, unarmed</td>
<td></td>
</tr>
<tr>
<td>Information event (“tool in position”)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The system shall enter the state</td>
<td>1 second</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The system shall hold its position</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The system shall secure its proper position</td>
<td>Loaded, stable, armed</td>
</tr>
<tr>
<td>Step</td>
<td>Action</td>
<td>State</td>
<td>Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer plumbs the elevator shaft</td>
<td>The system shall hold the plumb line</td>
<td>Loaded, unlocked, armed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer define the tool in the exact position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material transfer</td>
<td>The system shall be mounted correctly</td>
<td>Loaded, locked, armed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(“load”)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information event (“tool in right position”)</td>
<td></td>
<td>1 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer mounts the guide bar brackets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer mounts the guide rails</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action</td>
<td>Specification</td>
<td>Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>--------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall indicate the right position</td>
<td>Information event (&quot;guide bar brackets and guide rails in position&quot;)</td>
<td>1 second</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The installer dismount the tool</td>
<td>The system shall be placed to storage</td>
<td>900 seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Information event (&quot;tool in storage&quot;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>The mounting parts displaced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix 5: The requirements trace matrix

<table>
<thead>
<tr>
<th>(Row) is derived from (column)</th>
<th>OR.1</th>
<th>OR.2</th>
<th>OR.3</th>
<th>OR.4</th>
<th>OR.5</th>
<th>OR.6</th>
<th>OR.7</th>
<th>OR.8</th>
<th>OR.9</th>
<th>OR.10</th>
<th>OR.11</th>
<th>OR.12</th>
<th>OR.13</th>
</tr>
</thead>
<tbody>
<tr>
<td>The system shall hold the plumb line</td>
<td>DR.1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall hold its position</td>
<td>DR.2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall secure its proper position</td>
<td>DR.3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall enter the state</td>
<td>DR.4</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall be mounted correctly</td>
<td>DR.5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall indicate the right position</td>
<td>DR.6</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall be placed to storage</td>
<td>DR.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The system shall survive a collision</td>
<td>DR.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

The system shall be set in elevator shaft in its proper position
The system shall hold the plumb line
The system shall indicate the guide bar bracket in its position
The system shall indicate the guide rails position
The system shall place the guide rails in proper position
Guide bar bracket is mounted on the wall
The guide rails are mounted on the guide bar bracket
The system shall inform the installer that the tool is safe
The system shall survive a collision with a hard surface in working order
The system shall successfully complete each cycle of use for many cycles
The system shall weight less than 30kg
The system shall be made by suitable material such as aluminium or sheet metal
The system shall not have any sharp edges, fillet radius under 50mm
### Appendix 6: Failure Mode Effects and Critical Analyses (FMECA)

<table>
<thead>
<tr>
<th>Critical component</th>
<th>Function</th>
<th>Failure mode</th>
<th>Failure cause</th>
<th>Assessment of failure effect</th>
<th>Remarks</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustable leg</td>
<td>Extend the range of tool</td>
<td>Does not extend</td>
<td>Dirt</td>
<td>Tool cant be mounted</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Hold position on the wall</td>
<td>Cant hold the tool</td>
<td>Slip protection is not enough</td>
<td>Tool falls down</td>
<td>1</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Steel bar</td>
<td>Hold device in place</td>
<td>Crack in the steel bar</td>
<td>Weakened properties</td>
<td>Steel bar gets bended of the load</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Tube connector</td>
<td>Hold steel bar and pipe perpendicular to each other</td>
<td>Not mounted corrected</td>
<td>Incorrect mounting and locking</td>
<td>Subsequent errors</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Clamping ring</td>
<td>Adjustable and can be fixed into position</td>
<td>Vibrations</td>
<td>Incorrect locking</td>
<td>Moves to incorrect position</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Pipe</td>
<td>Hold parts into position</td>
<td>Gets compressed by involved parts</td>
<td>To strong fixed mounting</td>
<td>Pipes get bended</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------------</td>
<td>----------------------------------</td>
<td>--------------------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plumb line</td>
<td>Straight vertical line</td>
<td>Not straight</td>
<td>Low weight wire</td>
<td>Windy and dusty environment in the elevator shaft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engraved clamping ring</td>
<td>Holding a firmly tied wire</td>
<td>Wire falls down</td>
<td>Weak tying of the wire</td>
<td>Can’t adjust the wire position</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix 7: Idea drawings

Number of page(s): 6

<table>
<thead>
<tr>
<th>Balloon nr.</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steel bar</td>
</tr>
<tr>
<td>2</td>
<td>Tube connector</td>
</tr>
<tr>
<td>3</td>
<td>Pipe</td>
</tr>
<tr>
<td>4</td>
<td>Adjustable leg</td>
</tr>
<tr>
<td>5</td>
<td>Clamping ring</td>
</tr>
</tbody>
</table>

Tool

Scale: 1:50

Name: Elvedin & Ermin

Date: 2014-05-27

Sheet 1 of 1
Adjustable leg

Elvedin & Ermin

SCALE: 1:5

Date: 2014-05-27

A4
Tubeconnector

Name: Elvedin & Ermin

Date: 2014-05-27

SCALE: 1:2

Sheet 1 of 1
Clamping ring

Scale: 1:2

Date: 2014-05-27

Elvedin & Ermin
Steel bar

Name: Elvedin & Ermin

SCALE: 1:20

Date: 2014-05-27

Sheet 1 of 1
Pipe

NAME: Elvedin & Ermin

SCALE: 1:1

DATE: 2014-05-27