Redesigning fire suppression system for safety
Abstract

This degree project is divided into two subprojects. Both of the projects are executed for Fogmaker, a company that specialises in designing and installing fire suppression systems in engine compartments. These projects are executed according to product development methods.

The first subproject described in this report is about designing a handle for the transportation of a 35kg weighing fire extinguisher. The handle functions as a safety seal and as a grip that makes it easier and safer to lift the fire extinguisher. A casted zinc T-handle is the best solution based on cost and AHP (Analytic Hierarchy Process) analysis. An FMECA (Failure Mode Effect and Criticality Analysis) and a FEM (Finite Element Method) study have been performed to verify the design.

A zinc prototype of the safety handle has been manufactured and is ready for testing. It is expected that 10,000 handles will be produced every year once this prototype is approved by Fogmaker.

The second subproject concerns a connection hub placed on a pressurized bottle. In order to make the fire suppression system more reliable this component needs to be redesigned. An external company with the required expertise in hydraulic systems will develop the connection hub in cooperation with Fogmaker, based on the conceptual designs described in this report. An FMECA of the new connection hub concept proves this redesign increases the safety of the system.

The overlying subject of both of these projects is the safety of the fire suppression system. Thanks to the accomplishment of both project, the system has become safer and more reliable.
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A. Preface

This report presents the project “redesigning Fogmaker fire suppression system for safety”, the projects client is Fogmaker International AB who manufactures fire suppression systems with water mist for engine compartments (Fogmaker International AB, 2014). Fogmaker is continuously developing their products to increase safety and reliability, and to decrease costs. Marie Ingemansson supervises the project on behalf of Fogmaker.

The project is executed by Roeland Bisschop and Fêdde Zijlstra as their degree project. Both the project members are in the final year of their Bachelor of Mechanical Engineering. They are studying at Linnaeus University through an exchange program with Windesheim University of Applied Science in the Netherlands.

The third stakeholder for this project is Linnaeus University, who holds responsibility for the educational quality and the competences of students that will receive their degree. Therefore Valentina Haralanova and Samir Khoshaba will supervise the project on behalf of Linnaeus University.

The authors would like to express their thanks to all the people involved in the completion of the project. First of all the colleagues working at Fogmaker A.B.

Fogmaker AB:

- Andreas: for giving us the opportunity to work for Fogmaker, and supporting us in the project by all means.
- Marie for supervising our project, providing fast responses and organizing relevant meetings.
- Matthias for being such a great help in calculating and minimizing the costs. Making quick decisions to place an order for the safety handle
- Gustav for providing technical product support and feedback. Whilst stimulating us to be creative.
- Jonny for creating 3D printed prototypes

KH Metallgjuteri has been of great help in the development of the safety handle, we really appreciate their fast responses and expertise on the field of zinc casting.

Stig Wahlström’s expertise has helped us greatly in redesigning the connection hub.

Great thanks to our teachers at both Linnaeus University and Windesheim University of Applied Science. Their lectures have equipped us with substantial Mechanical Engineering knowledge that has proven to be of vital importance.

Thanks to Valentina and Samir for their coaching and feedback on our reports.
B. Backgrounds and task formulation

Fogmaker international AB develops, manufactures, and markets fire suppression systems for engine compartments, and is continuously striving to improve the reliability and safety of their products whilst decreasing production costs. A schematic overview of the system is displayed in Figure 1. A fire in the engine compartment will melt the orange detector tube, triggering the Piston Accumulator to eject high pressure water mist through the sprinkler nozzles.

One of the developments that is soon to be marketed is a larger piston accumulator to increase fire extinguishing capacity, resulting in a weight of maximum 35 kg. This increase in weight has caused the need for an ergonomic lifting solution as the current lifting method is not ergonomic or safe. Therefore the main aim of the “safety handle” subproject is to develop an ergonomic lifting grip for the piston accumulator of the fire extinguisher system.

Figure 1 Fire suppression system schematic

In addition a redesign of the connection hub of the detection cylinder is required. As the current system disables the operator’s alarm signals if the shut off valve is closed. Hence, to increase the systems reliability the connection hub will be redesigned in the subproject “detection cylinder connection hub”.

The first section of the report presents a theoretically based method that is applied to both sub projects. In succession, Section B and C present the sub projects that focus on the design of the safety handle, and the detection cylinder connection hub. In section D the projects and the method are evaluated, discussed, and concluded.
C. Methods

This section elaborates on the methods used during the projects, starting with the methods used during the projects start-up. Thereafter, four product development methods are compared.

1. Project start

When starting a project the first step that needs to be taken is to define and plan the project tasks, this is often executed poorly causing projects to run overtime and over budget. Resulting in high project failure rates, within high tech projects only 9% is delivered on time and under budget, and only 16% deliver what was promised (Carr, 2000). Since this project is executed as part of a degree project it is of utmost importance that the project is finished on time and with satisfying quality.

To minimize the risk of project failure the first week of the project has been aimed at writing a plan of approach using the structure defined by R. Grit (2008), where the following steps are subsequently clarified:

- Background
- Project Description
- Activities (work breakdown structure)
- Scope
- Products (deliverables)
- Quality control
- Organization
- Planning
- Risk management

This approach is in harmony with the book Project Management by S. Antvik and H Sjöhom (2012), which has been used as supplement. To ensure that all necessary parts of the project have been explained in the plan of approach.

To structure this report Rien Elling’s book Rapportagetechniek has been consulted, as it clearly describes the desired content of each report section (Elling, et al., 2005).
2. Development Method

There are a lot of different development methods available, every expert within the field of product development gradually formulates a method that is applicable in his or her own area of application (Marinova & Phillimore, 2003) (Monö, 1997). Four different approaches have been compared to derive a product development method applicable for Fogmaker’s projects. To ensure that a suitable method will be used it is necessary to compare four methods used by companies whose business is related to Fogmakers. The methods have been put side to side in Table 1.

The first methodology is quite practical and has been described by H.H. Kroonenberg (2004), the method is well known and widely used in engineering projects in the Netherlands. The second method originates from IDEO, America’s leading design firm (Kelley, 2001). This approach has a bigger focus on analysing the user and visualizing the context. The third method is described in Jönsson’s book “product development, work for premium values”, based on studies at Volvo (Jönsson, 2004). As development processes in the automobile industry require large investments there is a big focus at pre-studies and testing. The last method, Jackson, is distinctive because of its systems approach to fully define the product (Jackson, 2010).

All the methods described in Table 1 emphasize on a specific part of the project development process. When starting the project there was no Fogmaker specific project development method defined. Therefore the method used during this project has been derived from the previously described methods, and adjusted to Fogmaker’s wishes.
### Table 1 Product development methods overview

<table>
<thead>
<tr>
<th></th>
<th>Kroonenberg</th>
<th>Kelley</th>
<th>Jönsson</th>
<th>Jackson</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem Definition</strong></td>
<td>Pre study</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyse problem, context, users, and project scope</td>
<td>Understand</td>
<td>Define the problem</td>
<td>Define the problem</td>
<td>Define the problem</td>
</tr>
<tr>
<td>Create a package of demands separated in functional demands and fabrication demands</td>
<td>Observe and analyse the users in real life situations</td>
<td>Measure the needs</td>
<td>Translate them to technical requirements using QFD</td>
<td></td>
</tr>
<tr>
<td><strong>Determine Methods</strong></td>
<td>Visualize</td>
<td>Product and process development</td>
<td>Explore the design space</td>
<td></td>
</tr>
<tr>
<td>Find solutions for the functions by brainstorming</td>
<td>Visualize concepts, and how they will be used, for instance by renderings or prototypes.</td>
<td>Brainstorming and creating concepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compile morphologic overview</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Select concepts from morphologic overview</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Assign weights to the demands</td>
<td></td>
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<tr>
<td>Weight concepts</td>
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<td></td>
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</tr>
<tr>
<td>Present findings in Kesselring graph</td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Determine Design</strong></td>
<td>Evaluate and refine in a series of short iteration cycles, the first idea is never the best.</td>
<td>Validate the design</td>
<td>Verify the requirements (testing) and manage the risks (FMEA)</td>
<td></td>
</tr>
<tr>
<td>Iterate</td>
<td>Tool manufacture</td>
<td>Execute the design</td>
<td>Schedule the project tasks and execute the design</td>
<td></td>
</tr>
<tr>
<td>design on shape, material, and fabrication, to provide the most cost effective solution.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Implement</strong></td>
<td>Prepare design for commercialization.</td>
<td>Pre-try-out series</td>
<td>Try-out series</td>
<td>Start of production</td>
</tr>
<tr>
<td><strong>Verification of test series</strong></td>
<td>Pre-try-out series</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Iterate the design process</strong></td>
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<td></td>
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</tr>
</tbody>
</table>
3. Project definition

At the start of the project an extensive project description has been described in the Plan of Approach (Grit, 2008). This description has been created in close cooperation with Fogmaker, and has been approved by all stakeholders.

The product requirements consist of functional requirements, production requirements, and requirements derived from the customer needs. To define the customer's needs a combination of Kelly and Jacksons methods has been used. Jackson uses a use case template to define how users interact with the product in different situations (Jackson, 2010). Because of its industrial design background the method described by Kelley emphasizes on visualizing the use cases and observing the customer (Kelley, 2001). A combination of these two methods enriches the quality of the user analysis, therefore the use cases have been analysed according to Kelley's method and documented in a template structured like Jacksons.

4. Concept phase

The concept phase it is about generating concepts for the application and to select the best solution for the client. A detailed description of the steps taken during the concept phase are shown in the next paragraphs.

4.1. Brainstorming

Brainstorming is a very popular and commonly used technique for the creation of ideas (Stutton & Hargadon, 1996). Several rules can be used to improve the efficiency of a brainstorm session, like the ones formulated by Osborn (1957). Whose rules instruct: to continue building upon previous ideas, to stimulate contributing crazy ideas, to generate a large quantity of ideas, and not to criticize any idea during the brainstorm. In the decades after Osborn’s publication a lot of additional studies have been aimed at increasing brainstorm efficiency (Putman & Paulus, 2009). In Kelley’s book (2001), seven tips are listed to increase efficiency and stimulate creativity. One of these tips is to incorporate physical products in the brainstorm.

In this project we used Osborn's standard rules for brainstorming and Kelley's tip to have physical products during the brainstorming, by having several products and systems components available at the brainstorm sessions.

4.2. Creating concepts

To derive concepts from a brainstorm chart a morphologic overview is a very useful tool. Oxford Dictionaries defines morphology as the study of the forms of things (2014). The technical product development approaches of Kroonenberg and Jackson use a morphologic chart to list the sub-solutions from the brainstorm per product function. From this overview concepts are selected by combining the best or most interesting sub-solutions per function. This step should be in close corporation with the customer, so that the best concepts are compared.
4.3. Selecting concepts

Multiple criteria effect the ranking of the concepts, these criteria are established in corporation with the customer and often involve production costs, weight, reliability, sustainability, aesthetics, and ergonomics. One of the most common decision making methodologies in engineering, business, and science fields is known as Multi-Criteria Decision Analysis (MCDA) (Triantaphyllou & Baig, 2005). Where different alternatives are ranked according to a number of criteria, to reach the following goals:

- Rank the alternatives and designate the most beneficial alternative
- Provide an indication on the alternatives performance with respect to the criteria

There are different MCDA techniques, the most common method is the Analytic Hierarchy Process (AHP) as developed by Thomas L. Saaty in the 1970s (Saaty, 2006). The mathematical system behind AHP makes it possible to subsequently compare two alternatives, and compile a ranking from this information. Different variations of AHP (Zhû, 2014), are aimed at improving the reliability of the results. As the outcome of the ranking strongly depends on the judgment of the participants. In this process an Excel template is used, while verifying the reliability of the outcome by consulting Fogmaker experts (Goepel, 2013).

The AHP method is used to assign weight factors to the different criteria, and rank the concepts according to every one of these criteria. The data created by these weightings have been compiled and presented in a table to graphically show the ranking of the concepts.

5. Evaluate and refine the design

In this step of the development process the selected concept is improved and evaluated to optimize the design. In agreement with Fogmaker four aspects of evaluation are selected: product strength, costs, reliability, and ergonomics. The results of these evaluations are used to refine the concept.
5.1. Product Strength

The introduction of computers have triggered significant changes in the Mechanical Engineering work and tools (Samuelsson & Wiberg, 1998). Increasing powerful Computer Aided Design (CAD) programs – like SolidWorks, Pro E, CATIA, and Solid Edge - strongly increase an engineer's productivity as 3D products can quickly be created, reviewed, and documented in 2D drawings. Whilst the products dynamic response and fatigue strength can be computed by Computer Aided Engineering (CAE) software tools as ANSYS, ADAMS, LMS, and MSc (Jia, et al., 2013). CAD programs advance the CAE integration in CAD software has significantly improved. As shown by SolidWorks, the simulation package provides a toolbox that is complete enough to perform the required analysis (SolidWorks Corp., 2014). The possibilities include: sustainability analysis, structure analysis, fatigue analysis, and fluid flow analysis. (SolidWorks Corp., 2014)

The predominant mathematic model used by the previously mentioned CAD and CAE programs is known as the Finite Element Method (FEM). This method divides a product in a finite number of elements, this division is called a mesh and shown in Figure 2 (Qiukai, et al., 2014).

Creating a mesh of a product makes it possible to calculate the products stresses by approximation. The number of elements in a mesh determine the accuracy of the results, a mesh with more elements is more accurate than a similar mesh with less elements. However, when the number of elements in a mesh increase the calculation time increases as well. More information about FEM can be found in (Zienkiewicz & Taylor, 1989) and (Samuelsson & Wiberg, 1998).
5.2. Cost analysis
A product should always be as cost effective as possible, therefore a thorough economic analysis is important. According to (Sullivan, et al., 2012) and (Antvik & Sjöholm, 2012) the biggest cost savings when developing a product, can be reached at the beginning of the project (Figure 1). A method that can be used to analyse the total cost of a product is a Life Cycle Cost Analysis (LCCA), as explained by (Blanchard, 2004) and (Sullivan, et al., 2012).

![Figure 3 - Importance of the start of a project (Antvik & Sjöholm, 2012, p. 94)](image)

This method is commonly used in the field of Operation Management, it gives a good overview of the total costs as it considers both the acquisition (production) costs and the operation costs. The total costs are disposed in a cost breakdown structure, and compiled taking into consideration the time value of money (effect of interest on monetary value).

The production costs will be determined in close cooperation with Fogmaker's purchase department and Fogmaker's suppliers.

5.3. Reliability
Reliability is a very important product characteristic, since a product failure can often have far reaching implications. Fogmaker’s customers are located all over the globe, and the systems are often used in harsh environments like mines. For instance, the costs caused by a malfunctioning fire suppression system in a mining machine are substantial. Since Murphy’s Law states that everything that can go wrong eventually will, an analysis to investigate the possible failure modes of a product is very useful. Jackson (2010) suggests to use a Failure Mode and Effects Analysis (FMEA) which was developed by NASA (Military, United States, 1980). This method defines the risks and effects of every component within the product, from this analysis a risk assessment can be completed (Carlson, 2012).

In situations where a more detailed risk assessment is preferred, criticality can be added to the analysis creating a Failure Mode Effects and Criticality Analysis (FMECA). FMECA is most commonly required by customers in automotive and military applications (Carlson, 2012), as Fogmaker’s products developed for customers in these fields the FMECA method is preferred.
There are different tools available to support an FMECA, these tools include several templates and computer programs like Isographs Reliability Workbench (Isograph, 2014). This software will be used in cooperation with Windesheim University of Applied Sciences.

5.4. Ergonomics

It is very important that the final products are ergonomic to use, and comply with Europeans CE standards. The concepts have been designed according to CE standards (NEN-EN, 1993) where guidelines are listed for manual lifting of products. The human measurements listed in (Dreyfuss, 2002) have been used for dimensioning the sizes of the products handles. However, to verify the concepts ergonomics it is useful to test 3D models printed by Fogmaker’s Replicator 2 desktop printer (Makerbot, 2014).

Besides the ergonomics of handles and grips the visual interface of the products should also be ergonomic. “Visual ergonomics is an example of human specific sub-category of ergonomics which draws on physical ergonomics (e.g. lighting, visual displays, workstation design, visual disabilities) and cognitive ergonomics (e.g. information design) and requires an underlying knowledge of the function of the visual system and of visual perception” (Long & Long, 2012). To verify the visual ergonomics of the products American and European standards will be consulted.

5.5. SWOT analysis

A SWOT analysis is a commonly used analysis tool to describe a systems strong and weak points, both external and internal (Al-Araki, 2013). A SWOT analysis uses four characteristics to describe a system, the first of which is **Strengths** where all strong points of the product itself are listed and described. The second characteristic is the products **Weaknesses**, in this section the weaknesses or worries of the product are described with a small risk indication. Thirdly the **Opportunities** that the product creates are described, these opportunities are outside of the product or system. Finally **Threats** are mentioned, these are external factors that could potentially influence the products success.
D. A safety handle for transport

The subject of the second section of this report is the product development of a safety handle that is used to transport a fire extinguisher.

6. Project definition

As mentioned in Section A Chapter 3, the first step in a project is to clearly define the project. In order to create a good project definition it is important to have a clear structure. The project definition is divided into three paragraphs. The first one will elaborate on the background. Further on the second paragraph presents the use case analysis. Finally, the last paragraph compiles all the given information into a table of requirements.

6.1. Backgrounds

The Fogmaker fire suppression system contains two bottles. The piston accumulator and the detection cylinder. The safety handle for transport is designed for the piston accumulator.

Attaching the handle should be done by twisting it into the extinguisher fluid outlet, as shown in Figure 1. This connection has thread in it which is closed by a plug when the piston is not in use or when it is transported.

However, there are some requirements for the design of this safety handle for transport. It has multiple functions. It needs to seal the outlet for extinguisher fluid. Furthermore it needs to protect the other components located on the cap against impact loads, which for example can occur when the bottle is dropped. However, the main goal of the handle is to provide an ergonomic grip at a low cost.

The most fragile component on the top cap is the manometer. The top cap can be equipped with different types of manometers depending on the regulations and standards of the country where the product is sold. Especially the manometer according to the American standard is very vulnerable to any type of load. If the manometer would break, when the bottle falls on the floor for example, it could be possible that the sealing breaks as well. This means the pressure can escape and therefore create a safety hazard.

For the reasons stated above the handle should function as a protective barrier. However, the main function of the handle remains to provide an ergonomic grip for lifting the piston accumulator. Currently it occurs that the bottle is lifted by gripping the manometer and pulling it upwards. As mentioned before, these can be rather fragile and are not designed for carrying the bottle.

Figure 1 Overview of the situation

Figure 2 Top cap of the piston accumulator
In short, incorporating this handle in the design will make sure that the bottle will not be lifted by the manometer and it will make installation and transportation safer more comfortable and therefore increasing the customer value of the product.

6.2. Use case analysis

According to (Jackson, 2010) a use case analysis is performed. The analysis shows in which context the safety handle is used. By dividing the situations and placing them in a matrix, an easy to understand overview is created. A correct use case analysis should consist of all the situations in which the subject is involved, with its respective users and products.

6.2.1. The context of the system

Packaging the system is the first situation. It involves the following users and products:

- Mechanic, the person that is responsible for assembling and packaging the system.
- Piston accumulator, the system is capable of suppressing fire in engine compartments once it is mounted.
- Safety handle, the subject of this project. A handle that makes it easy to lift the piston accumulator.
- Overhead crane, a crane that is used to place the cylinder inside a cardboard box.
- Cardboard box, used for transporting the detection cylinder.

After packaging the system is put on transport. This is the second situation:

- Cardboard box
- Piston accumulator
- Safety handle

Finally, once the system reaches the client it has to be unloaded. It involves the following users and products:

- Mechanic, the person that will mount the system in an engine compartment.
- Piston accumulator
- Safety handle
- Cardboard box
- Engine compartment, the Fogmaker fire suppression system is installed in engine compartments.
### Table 2 Behavioural description of the packaging use case

#### Piston Accumulator is Packaged

**Initial conditions**

Piston Accumulator is assembled, the valve and components are mounted on the top cap. A sealing is connected to the safety handle.

<table>
<thead>
<tr>
<th>Mechanic</th>
<th>Piston Accumulator</th>
<th>Safety Handle</th>
<th>Overhead Crane</th>
<th>Cardboard Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjoins Piston Accumulator and Safety Handle</td>
<td>Is adjoined with</td>
<td>Is adjoined with</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Safety Handle</td>
<td>Piston Accumulator</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unfolds cardboard box</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Is unfolded and ready for piston accumulator</td>
</tr>
<tr>
<td>Connects safety handle to overhead crane</td>
<td>Is connected to</td>
<td>Is connected to</td>
<td>Is connected to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>overhead crane</td>
<td>overhead crane</td>
<td>safety handle</td>
<td></td>
</tr>
<tr>
<td>Loads piston accumulator in the cardboard box with overhead crane</td>
<td></td>
<td></td>
<td></td>
<td>Moves the piston accumulator</td>
</tr>
<tr>
<td></td>
<td>Is positioned in</td>
<td>Is positioned in</td>
<td></td>
<td>Is loaded with piston accumulator</td>
</tr>
<tr>
<td></td>
<td>cardboard box</td>
<td>cardboard box</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disconnects overhead crane from safety handle</td>
<td>Is disconnected from</td>
<td>Is disconnected from</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>overhead crane</td>
<td>overhead crane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Places protective cardboard strip, and closes box</td>
<td></td>
<td></td>
<td></td>
<td>Box is closed and ready for transport</td>
</tr>
<tr>
<td></td>
<td>Is packed in</td>
<td>Is ready for</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>cardboard box and</td>
<td>transport</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ready for transport</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 3: Behavioural description of the transport use case

**Piston Accumulator is Transported**

**Initial conditions**
Piston Accumulator is packaged inside a cardboard box. It is about to be transported to the customers either by: air, road transport, or shipment.

<table>
<thead>
<tr>
<th>Cardboard box</th>
<th>Piston Accumulator</th>
<th>Safety Handle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encloses the Piston Accumulator</td>
<td></td>
<td>Protects fragile components on top of the piston accumulator</td>
</tr>
<tr>
<td>Is protected by Cardboard box and Safety Handle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mechanic**

Recieves Piston Accumulator in cardboard box

Opens cardboard box

Grabs safety handle

Lifts piston accumulator out of cardboard box

Carries piston accumulator to engine compartment

Mounts piston accumulator in designated area

Removes safety handle from piston accumulator

Ready for use

Mechanic disposes cardboard box and safety handle for recycling

<table>
<thead>
<tr>
<th>Piston Accumulator</th>
<th>Safety Handle</th>
<th>Cardboard Box</th>
<th>Engine compartment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is lifted</td>
<td>Provides ergonomic grip for mechanic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is carried</td>
<td>Provides ergonomic grip for mechanic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is mounted</td>
<td>Provides ergonomic grip for mechanic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is removed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protected by fire suppression system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is recycled</td>
<td>Is recycled</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: Behavioural description of the unloading use case

**Piston Accumulator is Unloading**

**Initial conditions**
Piston Accumulator is packaged inside a cardboard box, and about to be mounted in an engine compartment.
6.2.2. Lifting the piston accumulator

The method that the operator uses to lift the piston accumulator is very interesting, because the safety handle needs to be optimized for the operator. In order to understand the needs of the operators they must be analysed. Especially the way they are lifting the piston accumulator without a safety handle.

Figure 3 illustrates how the operator lifts the piston accumulator out of the cardboard box. They grab the manometer and lift the piston accumulator out of the box. Lifting the piston accumulator in this manner can cause major damage to the manometer. If the manometer would break and come out of the valve it could cause a leak. And since there is about 100 bars of pressure in the piston accumulator this will be very dangerous. Once there is a small leak it can expand and lead to the whole piston bursting.

Another way of lifting the piston accumulator is by putting hands around the top cap. In Figure 4, the hands would be placed near the black band closest to the top cap. It is uncomfortable to lift the piston like this and the chance of dropping the piston is therefore increased. When the piston is dropped there is a chance that the impact causes the cylinder to burst or that components are destroyed.

The risks for incidents during this process can be decreased by adding a handle to the piston accumulator. With a handle the operator can comfortably grip and lift it. A handle makes the product look professional as well. It shows that the company that builds and installs these systems pay attention to detail and that they care about making quality products.
6.2.3. Regulations and standards

There is a standard regarding the amount of weight a person is allowed to lift. It changes depending on the manner of lifting. If a person is allowed to lift with two hands they are allowed to lift heavier for example.

Physical strain is the subject of the standard used, officially called NEN-EN 1005-3 February 1999. According to this norm a risk assessment has to be performed for extraordinary conditions.

An overview of the lifting method is illustrated in Figure 5. With these dimensions it is possible to sketch how the product is lifted from the ground by the operator. These dimensions are used in the risk assessment for the lifting process.

According to the standard, ideally persons that are specialised and trained will lift weights above 30 kilograms. Furthermore, the process should only be done for professional use.

According to the risk assessment method (NEN-EN, 1999), the process of finding the correct lifting position is done by following several steps. In total there are 3 methods. Each method has different checkpoints and calculations that need to be completed. For example, the result from the steps taken in the first method can be either that the system is good enough as it currently is or that the risk assessment must advance to the second method. Until finally the third method is reached.

The third method results in a specific conclusion. It requires the values for the letters shown in Figure 5. These are then put in a table and are used to calculate if it is preferable to lift the piston accumulator with one or two hands. Which influences the design of the handle, because it is important to make the handle as comfortable as possible.

A overview of the whole calculation process is attached in appendix IV of this report. It gives detailed information on how the lifting process is sketched. The conclusion of these calculations is that it is preferable to lift the piston accumulator with two hands. Which is understandable as the piston weighs 35kg. However, it might not be possible to design a handle that is suitable for two hands as the handle does need to fit inside a cardboard box. It would be the most comfortable solution for the operator non the less.
### 6.3. List of requirements

The product requirements consist of functional requirements, production requirements, and requirements derived from the customer’s needs or the customer’s wishes. The customer’s needs are derived from the use case analysis. To define the customer’s needs a combination of Kelley (Kelley, 2001) and Jacksons (Jackson, 2010) methods have been used in paragraph 1.2.

In this case the functional and production requirements are called the absolute requirements. All of the absolute requirements need to be satisfied in order to complete the project successfully. On the other hand there are secondary requirements or the customer’s wishes. Fulfilling a customer’s wish is not a necessity. The project group should try to fulfil these wishes as much as possible though. It is important to complete the project as well as possible.

#### 6.3.1. List of absolute requirements

As explained earlier, these requirements must be fulfilled.

**Table 5 Absolute requirements for the safety handle**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td>Must fit in the same place as the one where the current pressure seal is fixed in. ¼ inch BSP thread. Must fit inside the cardboard box. Maximum height of 50mm and a maximum width of 100mm. May not collide with other components that are connected to the piston accumulator.</td>
</tr>
<tr>
<td><strong>Strength</strong></td>
<td>The safety handle must be strong enough to be able to lift the heaviest piston accumulator of 35kg. Once mounted on the piston accumulator it must be strong enough to resist impact force when it is tipped over.</td>
</tr>
<tr>
<td><strong>Protection</strong></td>
<td>The pressure switch and the manometer must be protected so that they will not be destroyed when the piston accumulator falls on the ground.</td>
</tr>
<tr>
<td><strong>Ergonomics</strong></td>
<td>The website url and recycling symbol must be displayed. It must look trustworthy, strong and resilient according to Fogmaker’s corporate identity. The handle must be red, orange or a metallic colour. It must provide an ergonomic and obvious grip for the user. The user must be able to lift the system while wearing gloves. Must function in dusty and dirty environment as Fogmaker’s customers are forestry, mining, automotive, and military industries.</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>The handle must seal the piston accumulator making leakage impossible. Even when other safety mechanisms fail.</td>
</tr>
<tr>
<td><strong>Industry demands</strong></td>
<td>Approved materials according to automotive industry. Zinc, stainless steel, brass or polymers.</td>
</tr>
<tr>
<td><strong>Batch size</strong></td>
<td>10.000 handles will be produced in the first year of production. After the initial year and increased turnover is expected. Which might lead to an increased batch size over time.</td>
</tr>
</tbody>
</table>
6.3.2. List of desired requirements
The requirements desired to be fulfilled.

Table 6 Desired requirements for the safety handle

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycling</td>
<td>Polymers are not preferable due to recycling costs for customers in Germany for example. Using one material for the handle is preferred. This will make it easier to recycle the product.</td>
</tr>
<tr>
<td>Production costs</td>
<td>As low as possible. The current pressure seal is 0.29 euro.</td>
</tr>
<tr>
<td>Protection</td>
<td>The pressure switch and the manometer must be protected so that they will not be destroyed when the piston accumulator falls on the ground.</td>
</tr>
<tr>
<td>Weight</td>
<td>As low as possible, in order to keep implementing a return system viable.</td>
</tr>
</tbody>
</table>
7. Concept phase
This chapter explains important methods that have been used applied in this section, including brainstorming and multi criteria decision making. A morphologic overview has not been included as the functions of the T-handle are limited. Therefore the brainstorming has not been separated per product function but aimed at full handle shapes. Paragraph 1 presents the concepts created during brainstorming, which are ranked and evaluated in paragraph 2 and 3. Paragraph 4 describes an initial cost inquiry.

7.1. Generating concepts
There are many different shapes and types of handles that can be chosen for the client. Finding the best type of handle for this situation is important. Therefore it is good to take different types of handle shapes/types and to compare them to each other. One handle might be perfect for situations where space is not an issue. But for other situations it might prove to be not possible to use this handle. In the following paragraphs different types of handles are introduced.

7.1.1. Hand wheel
This type of lifting handle looks very promising. It is possible to hold and lift it with two hands and it is a standard component that can be bought from numerous suppliers. These handles can be found in polymer but also steel. It is possible to manufacture these in polymers and metals.

Figure 6 Example valve hand wheel
Based on the internet research these lifting wheels can vary in price between 3,33 SEK and 199,94 SEK. Since the piston accumulator does not require a big handle, especially because of limited space, the price will be around the lower price segments.

However, it might be a problem to connect the safety seal to the lifting handle. It can be possible to make thread on both sides of the safety seal and to make thread inside of the safety handle. The handle can be twisted onto the safety seal in this case. Another solution is to weld the hand wheel on to the safety seal.
7.1.2. “Spade handle”
This handle design can be found on a lot of spades and therefore earned this name. It is possible to dimension the part in such a way that it can be gripped with both hands. This product could be made from a lot of different materials. The best manufacturing method would be with injection moulding. The handle could be made from any type of plastic or from zinc or other metals.

This handle are not common with outgoing thread on it. So finding it as a purchase part will be very difficult. It is possible to make it by building a mould.

![Spade handle](image)

Figure 7 A spade handle

7.1.3. Cowbell handle
The cowbell handle looks similar to the spade handle. This handle is better optimized for lifting with two hands since it has a rounded handle. The handle could be connected by welding onto the safety seal. For this type of handle it is hard to find a purchase part. This makes this option considerably more expensive and therefore less attractive to use as alternative.

The part can be custom made by building a mould. But building a mould costs a lot of money and in order to return the investment the handle price will have to increase.

![Cowbell being lifted](image)

Figure 8 A cowbell being lifted
7.1.4. T handle
The T handle is also an interesting alternative for a lifting handle in this situation. This handle is a standard component and is widely available with thread, which makes it quite cheap since a mould does not have to be made. Fogmaker’s suppliers can supply these type of standardised T-handles.

This handle is better for one handed lifting. It is possible to use it with two hands as long as the size is large enough.

![Figure 9 A T handle with thread](image)

7.1.5. Knob
The knob idea is actually not so great, the ergonomics and strength make it not suitable for a system that is 35 kg. However, the costs will be rather low and the shape is quite similar to the currently used pressure gauge.

These knobs are widely available and are purchase parts. These knobs can be bought for a low price from Fogmaker’s suppliers.

![Figure 10 A knob](image)
7.2. Selecting the concepts

The concept validation process is used to find the best concepts for the customer. With the help of the Analytical Hierarchy Process the concepts are compared to each other. Each concept receives a score for each criterion. The concept that has the highest scores for the most important criteria is the best one.

7.2.1. Initial ranking

The first concept validation is performed by the project group in order to find the best concepts. Several criteria have been formed based on the customer’s requirements and wishes.

The criteria are:

- Ergonomics: Provide an ergonomic grip
- Costs: Have low production costs
- Aesthetics: Be a customizable product
- Recycling: Easy to recycle or transport

The criteria have been ranked using the Analytic Hierarchy Process. This process uses a matrix that shows the relations between each attribute, as shown in Figure 11 Matrix with relations between criteria. By calculating the Eigenvector of this matrix the derived weight factors are determined resulting in the following percentages:

Percentages:

- Ergonomics: 31.2%
- Costs: 44.3%
- Protection: 20.4%
- Recycling: 4.2%

This process is repeated to determine the rankings of the concepts with respect to each criteria. All the rankings are gathered in table 7. The rankings per criteria are multiplied by the weight factors to determine the contribution to the final concept ranking.
From these weight factors and the ranking of each concept for each criterion, the best concepts are:

Graph 1 Preliminary concept validation

The best concepts according to this selection are the hand wheel and the plastic knob. The first concept validation results will be presented to Fogmaker. The opinion of the customer is very important. Fogmaker has given some insight on the importance of the criteria. More about this can be found in the next paragraph.

7.2.2. Concluding ranking
Discussing these weight factors with the client has changed the ranking. The client believes that ergonomics and protection are not that important. Instead they think that the aesthetics and recycling are more important. Therefore the concept validation process has been done again with the corrected data.

The new concept validation has a new criterion, Aesthetics. This criterion focuses on how easy it is to customize the component and make it unique. Customizing can be done with paint, stickers, logos and such. After weighing the criteria again according to the Analytical Hierarchy Process:

- Ergonomics: 10,3%
- Costs: 46,6%
- Protection: 5,6%
- Recycling: 23,2%
- Aesthetics: 14,4%
This gives the following table:

**Graph 2 Final concept validation**

<table>
<thead>
<tr>
<th>Design</th>
<th>Provide ergonomic grip</th>
<th>Low production costs</th>
<th>Protection of components</th>
<th>Recycling</th>
<th>Aesthetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spade handle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic knob</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-handle zinc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-handle plastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand Wheel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The T-handle in zinc comes out as the best concept with the plastic T-handle and knob coming in second and third. The good customizability plays a big part in the success of the zinc T-handle. These new results are presented to the client to see if they agree with the current findings.

From the meeting with the client it becomes clear that even though the hand wheel offers good protection and ergonomics that it is too heavy and expensive. From now on the project will focus on the T-handles in zinc and plastic. The other alternatives are not good enough to be invested further. The next steps will be to contact suppliers and to find the correct purchase parts.

The plastic knob will not be considered as the best option any longer. Printing the logo and brand name on a knob is not ideal. A knob is not good at showing the aesthetics that Fogmaker wishes to show. Therefore the T-handles are the design that Fogmaker wants to continue with.
7.3. Evaluating the concepts

In this chapter the concepts that came out as the best ones in the ranking are evaluated and refined. In the first paragraph a new design is introduced. This design is suggested by Fogmaker as they believe it is a very cheap solution. In the second paragraph the T-handle is evaluated. Results from an inquiry that is performed under supplier concludes this chapter. Since costs play the biggest part in the design. Contacting the suppliers for their price offers provides valuable information which helps with choosing the final concept.

7.3.1. Bolted handle

These handles came up as ideas created by Fogmaker. These ideas were unfortunately made after the ranking process had been fulfilled as they desired that the costs of these handles were checked.

However, these bolted handles are discussed in the next chapter.

**Round handle**

Since price is one of the most important factors for the handle the cheapest possible or the simplest of concepts had to be considered as well. That’s when a new design was created, a simple tube or a profile with a bolt through it. The safety seal is fixed to the end of the bolt with glue.

This system is cheap because of its simplicity, it is just a combination a standard sized tube or profile and a bolt. See the specifications of the round handle assembly in Figure 12. The tube has two different sized holes which allows the bolt to be hidden inside the tube. By designing the handle like this the lifting becomes more ergonomic as the bolt head is not in the way.

**Square handle**

In Figure 13 the assembly with a rectangular profile is shown. Because of the rounded corners it should still be reasonably comfortable to lift the cylinder. In this design the bolt head is not hidden inside the profile. It is like this because it is not that much of a bother on a flat surface as it would be on a rounded surface.

The question now is which one of the profiles would be cheaper to manufacture. The tube shaped profile might be a cheaper part than the rectangular one but the rectangular should have cheaper production costs.

The drawings have been sent to the suppliers to find out what the costs would be of producing these when the batch size would be 10,000 pieces per year.
7.3.2. T-Handle design

The T-Handle is custom made since it will be produced with a mould. The goal is to keep the handle as light as possible while still keeping enough strength to resist the various impacts the handle could endure. The handle is thick on the outer sides and very thin in the middle. It is thick on the outside to give the user as much grip as possible and to provide a comfortable lifting experience. The handle does not have to be thick everywhere so it is thin in the middle. This saves a lot of material and weight.

To find out if the handle can still resist the forces that it might come in contact an FEM analysis is been performed. The model is put in several scenarios to simulate real life situations. It is calculated on impact forces in case the piston accumulator would be dropped or if it falls. In the worst case scenario the handle will deform and show some cracks. But the chance that this happens. Even if the handle deforms, the most important components remain intact. More detailed information about this FEM analysis is found further on in this section.

Technical drawings are made of the SolidWorks models for the suppliers. The models contain the information and measurements required to build the mould. These drawings have been sent to several suppliers of Fogmaker AB and to a plastic expert. The plastic expert’s role is to provide a plastic that has similar characteristics to zinc. All the suppliers have been asked to provide information about the costs of producing the mould and eventually the products. It is required to build about 10.000 handles per year.

Figure 14 Preliminary T-Handle design
7.3.3. Material selection

There are two materials that can be selected for the T-handle. It is either made from plastic with a metal insert or completely casted out of zinc. Both of the materials have their strengths and weaknesses. For this scenario the best material has to be selected. This part focuses on explaining the strengths and weaknesses of the materials in this scenario.

**Plastic**

Plastics can be threaded in many different ways; casting, cast inserts, press inserts cut, pressed or rolled in a casted product. Cutting plastic thread is not a good idea because material on the thread becomes sensitive to tear. Rolling the thread is not recommended because of the elasticity of the material. Having the thread casted will increase the costs for a mould since the division becomes more complicated. Mould separation marking can affect the quality of the thread negatively. For threads with high demands an insert is the preferred option. The inserts - made from steel, copper or aluminium – are placed in the mould before the casting process starts. In the mould the cast will form around the insert and be shrunk on the insert as the material cools off. When the material shrinks tensions will form that might lead to tear. That is why an insert may not have sharp edges and such. (Kooijman & Pallada, 2009).

The use of plastic material for screw manufacturing is very uncommon. Machine components experts advise against the use of plastic. A solution is using an insert in combination with the plastic component (Muhs, et al., 2007).

From this information it is safe to say that a plastic thread is not a good option as it has too much risks. Using an insert will make the handle much more reliable. It will also make the handle look much stronger which is something that plays a role as well. The operators should have the feeling that the handle is actually able to lift the heaviest fire extinguisher.

However, there is a downside to using inserts as well. It becomes harder and therefore more expensive to recycle the handle. Since the handle is made of two different materials they will need to be separated first. If the handle would be made from just plastic then the handle can be shredded and the granulate can be reused.

**Zinc**

Zinc is excellent for casting products and thanks to alloy elements like aluminium, it has a far higher strength than any polymer. The combination of injection moldability, strength, stiffness, and corrosion resistance makes it perfect to be used for similar applications for which polymers are generally used. However, zinc is heavier, is unsuitable for electrical isolation and can’t be coloured (Kooijman & Pallada, 2009).

Zinc 5 is the most commonly used alloy since it has the most all round characteristics (Internation Zinc Association , 2014). Therefore this is the preferred zinc alloy for most zinc applications.

The main problem with subjecting plastic injection mouldings to higher stresses is that even glass fibre filled plastic injection have a much lower elastic modulus than metal die castings. When components need even moderate rigidity the plastic mouldings will have to be very thick whereas the zinc wall section can be thin. This dramatically increases the cycle time of the plastic casting process as it takes longer to fill up the mould and it more time before the
product has cooled down. Concluding, plastic mouldings become increasingly uncompetitive when more strength and toughness is required for the product.

Underneath is a short overview zinc is compared to plastic injection mouldings (International Zinc Association, 2014).

- Vastly superior stiffness
- More consistent properties
- Better precision
- Much lower process costs for thicker section components
- Far superior thermal conductivity
- Electrical conductivity
- EMI shielding
7.4. Cost calculation
Several suppliers have responded to the inquiry with their offers. In this paragraph the offers will be discussed and eventually the supplier with the best offer will be picked to produce the product. The meeting with Fogmaker where the products were evaluated once more also resulted in new findings. These are elaborated in this chapter as well.

7.4.1. Initial inquiry
The first supplier is KH Metallgjuteri

Table 8 KH Metallgjuteri cost overview

<table>
<thead>
<tr>
<th>Material</th>
<th>ZN 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base price</td>
<td>18,05</td>
</tr>
<tr>
<td>Calculated component weight</td>
<td>0,047</td>
</tr>
<tr>
<td>Material costs</td>
<td>0,85</td>
</tr>
<tr>
<td>Casting</td>
<td>0,46</td>
</tr>
<tr>
<td>Tumbling</td>
<td>0,06</td>
</tr>
<tr>
<td>Total price including material</td>
<td>1,37</td>
</tr>
<tr>
<td>Total price for 10,000 handles</td>
<td>13700</td>
</tr>
<tr>
<td>Exchanging die</td>
<td>3000</td>
</tr>
<tr>
<td>Die casting tools (one year depreciation)</td>
<td>40000</td>
</tr>
<tr>
<td>Total price</td>
<td>56700</td>
</tr>
<tr>
<td>Price per piece (first year)</td>
<td>5,67</td>
</tr>
<tr>
<td>Price per piece (following years)</td>
<td>1.67</td>
</tr>
</tbody>
</table>

The second supplier is GT Gjuteriteknik

Table 9 GT Gjuteriteknik cost overview

<table>
<thead>
<tr>
<th>Material</th>
<th>ZP0410</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base price</td>
<td>17,79</td>
</tr>
<tr>
<td>Calculated component weight</td>
<td>0,046</td>
</tr>
<tr>
<td>Total price including material</td>
<td>2,27</td>
</tr>
<tr>
<td>Total price for 10,000 handles</td>
<td>22700</td>
</tr>
<tr>
<td>Die casting tools (one year depreciation)</td>
<td>47000</td>
</tr>
<tr>
<td>Total price</td>
<td>69700</td>
</tr>
<tr>
<td>Price per piece (first year)</td>
<td>6,97</td>
</tr>
<tr>
<td>Price per piece (following years)</td>
<td>2.27</td>
</tr>
</tbody>
</table>
Ackurat and Essentra were contacted with inquiries for plastic handles. Unfortunately Ackurat was not able to manufacture or supply a suitable handle, and Essentra was not able to provide products with the required ¼" inch BSP thread.

The cost indication for the production of the tube and pipe handle is about 10-13 SEK/p.p. Which is 80% more than the zinc handle the first year, and approximately six times as expensive as the zinc handle the following years.

7.4.2. Discussion of the inquiry results

During the meeting with Fogmaker on the 2014-04-16 both the client and the project group agreed on discarding the square/round handle with a bolt through it design. There are two big reasons for this decision.

- The design incorporates basic components with low purchase costs. However, these components will be put together by hand, as the batch size is relatively low. Resulting in high product costs due to high labour costs in Sweden.
- It looks cheap and unprofessional. If Fogmaker was to distribute the handles amongst its customers it would be bad for their reputation. It makes it look like Fogmaker does not sell quality products.

The plastic handles were the second and third best concepts according to the AHP analysis, however the cost inquiry showed that unfortunately these handles cannot be supplied by Fogmaker’s supplier Essentra, or produced by Ackurat. The price of the “cheap” tube concepts was high compared to the zinc handle, 6 times more expensive after the tooling has been depreciated in the first year. The zinc concept was rated as best in the AHP analysis, and this has been confirmed with the cost calculation.

Therefore the final design will be made from zinc and be based on the T-shape.
8. Refining the final concept

Now that the final concept has been selected it is time to optimize that concept. The way to do this is by taking slightly different shapes and dimensions for the handle. It makes it easier to compare different alternatives when looking at the cost and the ergonomics.

All of the handles shown in this chapter will be 3D printed and then tested. They will be tested by using them to lift up products. By doing this it will give a clear indication of what is comfortable for the hands and if it is possible to use the handle when one is wearing gloves for example.

8.1. Reference concept

The basic T-handle is the same as the original design that was made. The handle has ½ inch thread and it weighs 50 grams. This makes it the smallest and lightest design.

This concept will be used as the reference concept. All the other concept will be compared to this one. Since the material price per kilo is known it is possible to give an indication of the costs for the other concepts based on their weight. Because of this it is not required to get offers for all of the other concepts in order to be able to select the best concept.

![Basic T-handle](image)

Figure 15 Basic T-handle
8.2. Ergonomic study
Casted zinc_001 is the handle shown in Figure 16.

Figure 16 Casted zinc_001

Casted zinc_002 is the handle shown in Figure 17.

Figure 17 Casted zinc_002

Casted zinc_003 is the handle shown in Figure 18.

Figure 18 Casted zinc_003
Casted zinc_004 is the handle shown in Figure 19.

Figure 19 Casted zinc_004

On Thursday the 8th of May the handles were evaluated at Fogmaker. All of the handles were printed with a 3d printer so that they could be tested.

The next step was to test the handles in the factory. Since the handle prototypes were made from plastic it was not possible to lift heavy object with it. However, it still gave a reasonable indication of how comfortable the handle is.

One important limit for the dimensions of the handles is the space that is left in the transport box. As shown in Figure 20 it needs to be possible to wrap carton around the top of the fire extinguisher. This test showed that the handle needs to be less wide because it hits the carton at the moment.

Fogmaker likes Casted Zinc_003 the most. They believe that that handle is the most ergonomic. In Figure 21 the handle is shown being tested.

During the meeting Fogmaker also made it clear that they want their web address engraved in the handle and that they want a recycling logo on it as well. When working with casted zinc this should be possible. A visit to one of zinc casters will provide more information on what is possible. So there will be a meeting with KH Metallgjuteri to discuss Casted Zinc_003 and gain information on how to optimize the design to make manufacturing as cheap as possible.
8.3. The final design

The concept for the handle has been finalized. KH Metallgjuteri provided very valuable information on the how to make the design very easy to cast. All it needed were some minor tweaks to the design in order to make the casted zinc handle look much more refined. Making sure that every edge on the handle is rounded and that there is a draft in the extruded cut will create a smooth and clean surface. Furthermore it increases the tool life significantly, which leads to lower long term costs.

Several designs and renderings have been made to determine the optimal aesthetics.

- Web address of Fogmaker in plain text, extruded and cut versions.
- Web address of Fogmaker with the logo, extruded and cut versions.

And these designs can both be with or without the recycling logo. Fogmaker decides which one they think looks the best and will be produced. And therefore the designs have been send to Fogmaker for evaluation and selection.

It is possible to make the current design with an increase price of about 1 SEK per piece in comparison to the basic T-handle. The increase in costs are acceptable since the final handle is better than the original in almost every aspect. A tool depreciation of 1 year has been selected to calculate the costs. Tools are normally depreciated in 3 to 5 years, due to the relatively low tooling costs Fogmaker prefers to depreciate the tool in the first year.

With the currently used safety plug costing 2.61 SEK (€0.29), the zinc handle is 2.55 times as expensive the first year and just 1.9% more expensive every following year.

Table 10 KH Metallgjuteri cost overview

<table>
<thead>
<tr>
<th>Material</th>
<th>Zn 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base price</td>
<td>18,05 SEK/kg</td>
</tr>
<tr>
<td>Calculated component weight</td>
<td>0,096 kg</td>
</tr>
<tr>
<td>Material costs</td>
<td>1,73 p.p.</td>
</tr>
<tr>
<td>Casting</td>
<td>0,57 p.p.</td>
</tr>
<tr>
<td>Tumbling</td>
<td>0,06 p.p.</td>
</tr>
<tr>
<td>Total price including material</td>
<td>2,36 p.p.</td>
</tr>
<tr>
<td>Total price for 10,000 handles</td>
<td>23,600 SEK</td>
</tr>
<tr>
<td>Exchanging die</td>
<td>3,000 SEK</td>
</tr>
<tr>
<td>Die casting tools</td>
<td>40,000 SEK</td>
</tr>
<tr>
<td>Total price</td>
<td>66,600 SEK</td>
</tr>
<tr>
<td>Price per piece (first year)</td>
<td>6,66 SEK</td>
</tr>
<tr>
<td>Price per piece (following years)</td>
<td>2,66 SEK</td>
</tr>
</tbody>
</table>
Table 11 GT Gjuteriteknik

<table>
<thead>
<tr>
<th>Material</th>
<th>ZP0410</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base price</td>
<td>17.79</td>
</tr>
<tr>
<td>Calculated component weight</td>
<td>0.096</td>
</tr>
<tr>
<td>Total price including material</td>
<td>3.15 SEK/p.p.</td>
</tr>
<tr>
<td>Total price for 10,000 handles</td>
<td>31500 SEK</td>
</tr>
<tr>
<td>Die casting tools</td>
<td>47000</td>
</tr>
<tr>
<td>Total price</td>
<td>78500</td>
</tr>
<tr>
<td>Price per piece (first year)</td>
<td>7.85 SEK</td>
</tr>
<tr>
<td>Price per piece (following years)</td>
<td>3.15 SEK</td>
</tr>
</tbody>
</table>

A zinc prototype manufactured using additive manufacturing (3D printing) has been ordered and will be tested and inspected. After testing, Fogmaker will decide which supplier they will select for the production of the safety handles.

Figure 22 The final handle design

This handle has ¼ inch BSP thread. It will seal the high pressure valve with a steel rubber washer.
8.4. FEM analysis

An FEM study or a finite element analysis simulates forces and stresses on a model. In this case forces are put on the safety handles to simulate actual situations that can occur during the handles lifetime.

In the FEM study four different situations are simulated:

- Force while lifting: When the handle is used to lift up an object that weighs 320kg.
- Force from the side: When the handle has a weight of 320 pressing on the side.
- Force when falling upside down: When the handle falls on its head with a weight of 320kg.
- Torque: A weight of 160kg is put on one end of the handle to simulate torque.

The forces have been exaggerated for this analysis so that it is clear to see how the handle will react when exposed to impact or high forces. All of the simulation studies are attached in the appendix. A further explanation on where the forces are placed and how high the stresses and displacements are is part of the study.

A short summary of the analysis containing the conclusions to the studies:

- Force while lifting, Appendix VIII
  This study showed that when a very heavy weight is lifted with this handle it will deform as shown. It shows that the handle is able to lift 3200N or 320kg with a small deformation of 0,17mm. Basically, this concludes that the handle is over dimensioned by a lot, the handle needs to have these dimensions in order to offer an ergonomic handle.
- Force from the side, Appendix VI
  If someone would hit the handle from the side with a hammer or something like that, the handle should be fine in most cases. Displacement will occur up to 2,53mm but that displacement is located on a non-vital area. Hitting the handle from the side as simulated shows that the nut and the thread remain intact, which is crucial for sealing.
- Torque, Appendix IX
  A high torque on the handle shows that the nut and the thread will remain intact. This is very good in case the handle is twisted too tightly or if it is subjected to an impact force.
8.5. Failure Mode Criticality and Effect Analysis

The results of the FMECA analysis have been enclosed in appendix I and II. In this analysis all the failure modes of the safety handle have been listed and rated on severity, occurrence, and detectability, according to the description in paragraph 5.3. In this section the three highest risks are explained with the suggested actions.

The two most hazardous failure modes derived from these calculations cause are a broken safety lock and a broken steel-rubber washer, a combined failure of the both components will cause leakage of the Fire extinguisher. The severity of this effect is high as corrosive liquid will be released that could damage machines in its surroundings, in case of severe leakage the pressure could potentially hurt people in its environment. As the occurrence of this risk is very low no extra measures need to be taken other than to check the steel-rubber washer and the safety lock before shipment.

The failure mode with the third highest risk priority number is a broken valve block. This damage could occur due to manufacturing errors or impact during transport. As the safety handle is connected to the valve the impacts that strike the safety handle will transfer to the valve block. Small cracks in the valve block could trigger leakage of the fire extinguisher once installed or during transport. If the safety handle would break from the extinguisher while being lifted both the mechanic and the extinguisher can suffer severe damage. As the safety handle will expose the valve block to new stresses, a Finite Element Analysis should be performed to determine the strength of the connection in the valve block. The strength is expected to be sufficient, but it is useful to determine the safety factor involved in this new use of the valve.

![Graph 3 RPN of the safety handle system](image-url)
9. SWOT – analysis
This chapter describes a SWOT analysis of the zinc handle, as explained in Paragraph 6.5 this analysis subsequently presents the strengths, weaknesses, opportunities, and threats.

9.1. Strengths
Low environmental impact, the whole handle is manufactured in zinc, a material that is fully recyclable without effecting its material properties. The product can be shredded and reused in zinc production processes. This is an advantage over the use of Plastics, the plastics properties are influenced by its polymer chain lengths. This chain length can decrease by environmental exposure and by shredding the polymer (Bottenberg, et al., 2013). In addition a plastic alternative would consist of two materials as a metal insert is required for the threaded connection, this hampers the recycling process.

The handle provides a low cost solution as a zinc casted handle is surprisingly cheaper than other alternatives, with respect to the batch size of 10,000 products per year. The costs of the zinc handle without the steel-rubber washer are 3.06 SEK per part, just 17% more than the seal plug that is currently used. Which is much less than any of the other concepts.

The handle communicates Fogmaker’s corporate identity as manufacturer of reliable and high quality products. This is due to the ergonomic shape, Fogmakers engraved logo, and the reliable feeling that a metal product gives.

With the safety handle lifting the extinguisher has become much more ergonomic.

As the manometer is not used for lifting the extinguisher anymore the safety of the lifting process has significantly increased. The chances of damaging the manometer during the lifting and potentially releasing the high pressure liquid, are now remote.

9.2. Weaknesses
There are investment costs required for the production of a prototype and the casting tools. The opportunities to change the handle design are therefore costly. The tool investment costs are depreciated over 100,000 handles (representing 10 production years), if the production of the handles is ended before 100,000 handles are produced.

The protection of the vulnerable components of the safety handle is limited. As the T shape of the handle doesn’t cover the whole top of the extinguisher. However, the protection of these components is partially provided by the cardboard strip as well.

When handle is rotated when lifting the fire extinguisher it is possible to open the safety seal. This safety seal is only needed when if the safety lock is malfunctioning. In this case the fire extinguishing liquid will slowly escape. With the safety plug this was not possible as it is tightened with a hexagon key.
9.3. Opportunities
An opportunity to potentially save production costs could be reached by implementing a return system for reuse of the handles. With a product weight of about 100 grams it might be rewarding to request customers to return the handles so that they can be quality checked and returned. This would require administrative measures and participation of the customers.

The handle design can be applied to different products of Fogmaker by adding a ¼” BSP connection to the 2 or 3 cylinder extinguishers an ergonomic grip can be provided for such systems as well.

The packing ergonomics in the workplace can be improved by using an overhead crane with a hook that can be attached to the T-handle. In this way the physical stress experienced by Fogmaker’s employees when packing larger numbers of cylinders will be reduced significantly.

9.4. Threats
Zinc price is subject to changes, the material price is fluctuating and determined by the London Metal Exchange. When zinc prices are increasing the handle costs will increase as well (The London Metal Exchange, 2014).
E. Detection cylinder connection hub

The connection hub of the detection cylinder had to be redesigned as part of this project. The first chapter explains the project assignment in this section. After that the second chapter displays the list of requirements to which the redesign has to fulfil. Furthermore, the third chapter goes in to detail about the researching phase. The fourth chapter is about the concept generation.

10. Project description

The second part of this project is to redesign the connection hub of the detection cylinder. In Figure 23 the complete fire suppression system by Fogmaker is shown. This part of the project focuses on the detection cylinder. A connection hub or nipple is mounted on top of the detection cylinder. This hub connects the ball valve, pressure switch and the manometer to the detection cylinder.

![Diagram](image)

**Figure 23 Fire suppression system**

There are a several things that need to be redesigned in order to improve this connection hub. The pressure switch measures the pressure in the detection cylinder. Currently it measures the pressure before it leaves the ball valve. This is what needs to be improved.

The orange lines in Figure 23 illustrate the Teflon tubes. They are pressurized. When a fire occurs these Teflon tubes will burn, allowing the pressure to be released from the fire extinguisher and the detection cylinder. After the pressure is released from the detection cylinder a signal goes off, indicating that there is a fire in the engine compartment or wherever the system is installed.
If the ball valve remains closed the detection cylinder will never be able to let off a signal. The challenge is to redesign the connection hub so that the pressure switch reads the pressure after the ball valve and not in the tube. This means that when there is a fire, and the detection cylinder is closed, a signal will be sent anyways by the pressure switch. With this redesign the system becomes safer for the users as the chance of failure is greatly reduced. It is crucial that the person that operates the vehicle in which the fire suppression system is installed is warned when there is fire.

There are the different rules, standards and customer requirements this redesign has to comply to. For example, some customers need to install two pressure switches in the connection hub. One of the pressure switches gives a signal when the bottle is half full and the other one sends out another signal when the bottle is empty.

This assignment also comes with the task to integrate a pressure relief valve into the new redesigned connection hub. Which is a very important feature of the connection hub as the Fogmaker fire suppression systems are used all around the world. Imagine countries that may have extreme temperatures or in mines where these situations may occur as well., Saudi Arabia and northern Finland are just a few of these counties, there are many more. In extremely hot environments it is possible that the bottle bursts as the heat weakens the material and increases the pressure. A bursting or exploding bottle can cause tremendous injuries.

This can be prevented with a pressure relief valve. If the bottle starts to get too hot the pressure relief valve melts, bursts or opens allowing the pressure inside the bottle to be released. With this system the pressure will be relieved as soon as the pressure gets too high.

Furthermore, the valve that opens up the detection cylinder needs to be sealed. It has to indicate if the valve has been opened before. So as soon as the valve has been opened for the first time the seal breaks. This will help Fogmaker with servicing defect bottles as they are able to notice when the bottle was defect when it left the factory or if something went wrong at the client.

10.1. Use case analysis
Just as in the previous section the use case analysis follows the theories of Jackson (Jackson, 2010). By placing the system in a matrix with the context in which it is used it will become more defined. A well defined project definition leads to a better end result. In order to complete a project to the customer’s satisfaction it must be clear what is going on with the system and how it is used.

10.1.1. The fires suppression system
When installed the piston accumulator and detection cylinder are placed next to each other. The Teflon tube connects the detection cylinder with the piston accumulator. A valve shuts or opens the detection cylinder before the flow connects with the piston accumulator.

Most of the use cases have already been treated in the project description. How the valve needs to operate so that the pressure switch can work properly is explained in detail there. Same goes for the seal of the valve.
For the operator it is important to see if the valve is opened or closed. Currently the ball valve is not the clearest component for this task. It does say closed or opened but it is hard to read. Especially for the locations in which the systems are installed in; the engine compartment. These are generally dark and small places. Which makes a good indication important.

10.1.2. Context of the system

On the next page the context of the fire suppression system is shown. The way that the system is functioning is explained in a matrix. All of the components and the relations they have in respect to each other come together this matrix.

Figure 18 Fogmaker piston accumulator and detection cylinder
### Table 12 Behavioural description of the fire suppression use case

#### The fire suppression system

<table>
<thead>
<tr>
<th>Initial conditions</th>
<th>Mechanic</th>
<th>Fire</th>
<th>Piston Accumulator</th>
<th>Detection Cylinder</th>
<th>Optical and Acoustic Signals</th>
<th>Teflon tube</th>
<th>User/Driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>The mechanic has carried the piston accumulator and detection bottle to the engine compartment. They are in place.</td>
<td>Connects the teflon tube to the piston accumulator and the detection cylinder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connects the wiring for the optical and acoustic signals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Opens the detector bottle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Removes the safety lock from the fire extinguisher</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Finished mounting the fire suppression system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fire starts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Loses counterpressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Activates and extinguishes the fire</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Is being extinguished</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Is extinguished</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No more pressure in the piston accumulator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No more pressure in the detection cylinder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A signal is being sent to the user/driver</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Receives a signal that the fire suppression system has been activated.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Checks the damage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. **List of requirements**

The requirements are shown in this document. There are two different types of requirements, the absolute and the desired requirements. Both of them are shown in this document.

11.1. **List of Absolute Requirements**

This is the list of absolute demands created by Fogmaker AB. The final product has to be designed according to these demands.

**Table 13 The absolute requirements of the connection hub**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector bottle</td>
<td>Solution must fit/connect to current detector bottle</td>
</tr>
<tr>
<td>Pressure switch</td>
<td>Solution must have room for at least two pressure switches. One pressure switch must detect outgoing pressure (in detector tube) Thread must be suitable for Danfoss pressure switch (UNF 7/16).</td>
</tr>
<tr>
<td>Manometer (fitting)</td>
<td>Nozzle must be compatible with both UL version (37 mm) and small version (23 mm). Shall display filled pressure in detector bottle at all times no matter if detector bottle is disabled or armed.</td>
</tr>
<tr>
<td>Outlet fitting</td>
<td>BSP G1/8&quot; connection to Camozzi detector tubing connector, straight, T or angled.</td>
</tr>
<tr>
<td>Functional Temperature range</td>
<td>-30°C to +65°C Must be fitted with temperature fuse, evacuating the gas pressure at high temperature.</td>
</tr>
<tr>
<td>Pressure</td>
<td>Must function with working pressure of 35 bar Must be gas tight = no response on &quot;sniffer&quot;</td>
</tr>
<tr>
<td>Nipple flow rate</td>
<td>Must have sufficient flow to clear content in a 0.8 litre container of approximately 400 ml of media on &lt;5 seconds with starting pressure 24 bar. Applies to Novec.</td>
</tr>
<tr>
<td>Industry demands</td>
<td>Approved materials according to automotive industry. Must approve to component demands in SPCR 183 Must approve to UL component demands</td>
</tr>
<tr>
<td>Surface treatment</td>
<td>Approved by the automotive industry. Anodizing for aluminium.</td>
</tr>
<tr>
<td>Colour</td>
<td>Red or silver</td>
</tr>
<tr>
<td>General demands</td>
<td>Function for pressurization of detector tube shall be sealable. (Different seals for open/armed and closed/isolated position.)</td>
</tr>
</tbody>
</table>
11.2. List of Desired Requirements

These demands are wishes of the client. They don’t necessarily have to be fulfilled but it would make the client happy. The higher the rating the more desirable it is to fulfil these wishes.

Table 14 List of desired requirements for the connection hub

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>1</td>
</tr>
<tr>
<td>Pressure switches</td>
<td>5</td>
</tr>
<tr>
<td>Accessibility</td>
<td>3</td>
</tr>
<tr>
<td>Design</td>
<td>2</td>
</tr>
<tr>
<td>Nipple flow rate</td>
<td>2</td>
</tr>
<tr>
<td>Dimensions</td>
<td>3</td>
</tr>
</tbody>
</table>

- **Material**: Aluminium 6082 for nipple.
- **Pressure switches**: Preferably both detect outgoing pressure.
- **Accessibility**: Accessible when presence of outer assemblies (mounted detector bottle on extinguisher and/or in protection box, etc.).
- **Design**: Desirable to “sync” product look/design with detector bottle and extinguisher.
- **Nipple flow rate**: Desirable to have sufficient flow to clear content in a 0.8 litre container of approximately 400 ml of media in <5 seconds with starting pressure 24 bar. Applies to all mentioned medias, besides Novec where it is a demand, under Media resistance above.
- **Dimensions**: Rather not be higher than current nipple.
12. The researching phase

There are many options for the redesign of the detection cylinder connection hub. However, a selection has to be made between the most viable options. One of the options is changing the type of valve the system uses. There could be valves for example that make it easier to connect the pressure switch after the valve or valves that are easier to integrate in to the connection hub.

The researching has a large influence on the final product. It is the foundation upon which the concepts will be designed. Most of the research has been performed online. It consisted mainly of searching for the different types of valves that are on the market and looking for valve suppliers.

Currently Fogmaker uses valves that are originally made for air conditioning units. These valves are not perfect for the detection cylinders since they tend to have a bad fit with the connection hub, which can cause leakage.

This paragraph shows how the concepts have been created and what the motivation behind the ideas are. At first the list of requirements is shown in the first part. The concepts have to be designed according these demands. And in the second part the brain storming. The second part of the paragraph shows and explains the morphological chart. This chart has been used to generate the concepts.

12.1. Brainstorming and mind mapping

Brainstorming has proved to be very valuable. The amount of ideas gained from the brainstorming session are numerous and some of them are very promising. The brainstorming results have been put into a mind map. It makes it clear where all the ideas are coming from.

During the brain storming session the connection block has been divided into 5 smaller components. For these components ideas and solutions have been generated. All of these solutions are used in the morphological chart later on.

By combining these ideas together it will be possible to generate concepts. The concept creation process will is explained in more detail in the next paragraph.
Figure 19 Mind map for the connection hub
12.2. The morphological chart

To add some structure to this process a morphological chart has been made. In the chart there is a clear divide between the functions of the product and the means that can be used to perform these functions.

The products that are used to achieve the functions have been gathered through research and brainstorming sessions. The most suitable solutions have been put in the chart. By selecting a solution for each function the concepts can be generated.

There are four important functions for the redesign:

- Sealing:
  The sealing is there to lock the valve. If someone wants to open up the valve that means the seal needs to be broken first. It is easy to recognise if the valve or detection cylinder has been used. This was one of the demands for the redesign.

- Creating space:
  In order to make it possible to add the pressure switch after the valve and to make it possible to have two pressure switches on the connection hub in some cases it is necessary to increase the size of the current connection hub in some way. For each option the amount of space generated may vary.

- Valve:
  The valve is the device that makes it possible to let the pressure escape out of the bottle or to keep it inside of the detection cylinder. There are many types of valves. It can be possible to design a valve or to buy one.

- Trigger:
  The trigger is points to the way the valve is controlled. It could be a handle or something like that. The trigger affects the dimensions and design of the new connection hub. Just like the chosen type of valve does.
<table>
<thead>
<tr>
<th>Seal the valve from opening</th>
<th>Plastic sealing</th>
<th>Tie-rip</th>
<th>Padlock</th>
<th>Fogmaker sticker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating space</td>
<td>Nipple + valve + T piece</td>
<td>Nipple + valve + Nipple 2</td>
<td>Horizontal connector block</td>
<td>Nipple with holes; outlet</td>
</tr>
<tr>
<td>Valve</td>
<td>Ball valve</td>
<td>Carlinje valve</td>
<td>Schrader valve</td>
<td>Butterfly valve</td>
</tr>
<tr>
<td>Valve</td>
<td>Gate valve</td>
<td>Gate valve</td>
<td>Slide valve</td>
<td></td>
</tr>
<tr>
<td>Trigger</td>
<td>Flip switch</td>
<td>Knob</td>
<td>Rotational switch</td>
<td>Ballpoint mechanism</td>
</tr>
</tbody>
</table>

Figure 20 Morphological chart
12.3. Concepts generated from the morphological chart

Six concepts have been generated with the help of the morphological chart. Five of them can be seen in Figure 20. Underneath is an overview of the concepts:

- Concept 1 and 2, black line: Fogmaker sticker > nipple + integrated valve > needle valve > lever
- Concept 3, red line: Fogmaker sticker > nipple + integrated valve > cartridge valve > wheel
- Concept 4, orange line: tie rip > nipple + valve + t-piece > ball valve > lever
- Concept 5, yellow line: tie rip > fittings + valve > slide valve > sliding switch
- Concept 6, green line: plastic sealing > nipple + integrated valve > Schrader valve > rotational switch

12.3.1. Concept 1

The first line, black, has generated two concepts because there were two good ideas that used the same structure in the morphologic chart.

Concept one is based on the original nipple. Its different though because this nipple extends horizontally, instead of increasing the height of the nipple the width and length are increased.

The needle valve is placed between the manometer and the pressure switch as is required. It is possible to use another type of valve as well, for example a gate valve.

Extending the connection hub in the horizontal direction allows the nipple to have a lower height than the original nipple and to place the manometer next to the pressure switch. And of course a valve in the middle that opens or closes the detection cylinder.
12.3.2. **Concept 2**

As stated earlier, concept 2 uses the same components in the morphological chart. This time, the connection hub is extended in the vertical direction instead of the horizontal one.

The needle valve is placed on top of the connection hub. By integrating the valve in this manner, the current hub needs to be extended slightly. Placing the manometer and the pressure switches under each other should not be a big problem since there is enough space around the hub.

![Figure 24: Concept 2, closed with needle valve and Fogmaker aesthetics.](image1)

![Figure 23: Concept 2, sectional view that clearly illustrates the needle valve.](image2)

Needle valve hat opens or closes the detection cylinder. The pressure switch measures the pressure after the valve.
12.3.3. Concept 3
The third concept is following the red line shown in the morphological chart. It is similar to the second concept in the design. The difference can be found in the type of valve it uses. For concept 3 a cartridge valve is used.

The cartridge valve is mounted on top of a vertically extended connection hub. A cartridge valve can be seen in Figure 30. It should be possible to screw the cartridge valve in to the connection hub. Which is a good thing as Fogmaker can manufacture the connection hub and just buy the valves.

The cartridge valve Works by turning the knob on top of the connection hub.

Figure 30 Concept 3, overview of the concept design
12.3.4. Concept 4

An orange line is used in the morphologic chart to highlight the fourth concept. This concept uses the connection hub that is currently used and builds from there by adding a valve and a T-piece.

By using a T-piece it becomes possible to place the pressure switch on one outlet and the pressure outlet on the other. This should be an easy solution that can be implemented on a short term. In Figure 30 a concept sketch is shown.

Figure 31 Concept 4, illustration of the ball valve and the T-piece mounted on the detection cylinder.
12.3.5. Concept 5

For the fifth concept a yellow line was used in the morphological chart. Concept number five is another simple and easy to fix solution. It does look cheap and weak, but it is always good to consider the simplest of solutions.

This concept gets rid of the current connection hub and replaces it by standard fittings. It allows Fogmaker to assemble the hub with components that are very cheap and easy to replace. A fitting goes into the detector bottle, a valve is then mounted on that fitting and another fitting is mounted on that valve. By using T-pieces for the fitting it is possible to add the manometer and pressure switches in their positions. The idea is shown in Figure 32.

Figure 32 Concept 5 sketch
12.3.6. Concept 6
The last concept is following the green line. It uses a type of valve that is found in most bicycles; the Schrader valve. By pressing a pin the Schrader valve opens and it will release the pressure. These valves are also used for high pressure systems which proves that they are a valid option for the detection cylinder as well.

Just like concept two and three the connection hub is extended vertically. The Schrader valve is then screwed in on top of the valve.

Figure 25 Concept 6 sketch
13. **Concept ranking and selection**

It is important to find the best solution for the client. Just as during the other project the Analytic Hierarchy Process (AHP) is implemented to find the premier concepts.

The concepts have been ranked on the following criteria:

1. Ergonomics
2. Costs
3. Reliability
4. Flow rate
5. Aesthetics

According to the AHP, the criteria are measured against each other to create weight factors. For example, ergonomics are compared to costs to find the importance of each criteria. This happens by applying a number that indicates which criteria is more important for the client.

**Table 15 The ranked criteria**

<table>
<thead>
<tr>
<th>n</th>
<th>Criteria</th>
<th>Comment</th>
<th>RGMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ergonomics</td>
<td>Visual, handling and accessibility</td>
<td>23%</td>
</tr>
<tr>
<td>2</td>
<td>Costs</td>
<td>Low production costs</td>
<td>39%</td>
</tr>
<tr>
<td>3</td>
<td>Reliability</td>
<td>Reliability of the system</td>
<td>23%</td>
</tr>
<tr>
<td>4</td>
<td>Flow rate</td>
<td>Higher is better</td>
<td>5%</td>
</tr>
<tr>
<td>5</td>
<td>Aesthetics</td>
<td>Customizability and uniqueness</td>
<td>10%</td>
</tr>
</tbody>
</table>

What Table 16 shows is that the costs are the most important weight factor in the ranking process. The next step is to rank each concept according to each criteria.

In total there are six concepts that are weighed. This will result in a table that highlights which concepts are the best. Before that is shown another table shows how each concept is ranked for the ergonomics and the result of this ranking.

**Table 16 The results of ranking for ergonomics**

<table>
<thead>
<tr>
<th>n</th>
<th>Criteria</th>
<th>Comment</th>
<th>RGMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Concept 1</td>
<td></td>
<td>17%</td>
</tr>
<tr>
<td>2</td>
<td>Concept 2</td>
<td></td>
<td>23%</td>
</tr>
<tr>
<td>3</td>
<td>Concept 3</td>
<td></td>
<td>15%</td>
</tr>
<tr>
<td>4</td>
<td>Concept 4</td>
<td></td>
<td>8%</td>
</tr>
<tr>
<td>5</td>
<td>Concept 5</td>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>6</td>
<td>Concept 6</td>
<td></td>
<td>27%</td>
</tr>
</tbody>
</table>
Table 17 Ranking the concepts on ergonomics

<table>
<thead>
<tr>
<th>Criteria</th>
<th>more important?</th>
<th>Score (1-9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept 1</td>
<td>B 2</td>
<td></td>
</tr>
<tr>
<td>Concept 2</td>
<td>A 1</td>
<td></td>
</tr>
<tr>
<td>Concept 3</td>
<td>A 3</td>
<td></td>
</tr>
<tr>
<td>Concept 4</td>
<td>A 4</td>
<td></td>
</tr>
<tr>
<td>Concept 5</td>
<td>B 2</td>
<td></td>
</tr>
<tr>
<td>Concept 6</td>
<td>A 1</td>
<td></td>
</tr>
<tr>
<td>Concept 7</td>
<td>B 4</td>
<td></td>
</tr>
</tbody>
</table>

This is done for all the each criteria. Finally all of this information can be compiled into a table. As discussed earlier, this table shows that the concepts with the highest rating are the best.

Table 18 Result of the AHP

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight factors</th>
<th>Concept 1</th>
<th>Concept 2</th>
<th>Concept 3</th>
<th>Concept 4</th>
<th>Concept 5</th>
<th>Concept 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ergonomics</td>
<td>23.00%</td>
<td>17.00%</td>
<td>3.91%</td>
<td>29.00%</td>
<td>6.67%</td>
<td>15.00%</td>
<td>3.45%</td>
</tr>
<tr>
<td>Low costs</td>
<td>39.00%</td>
<td>12.00%</td>
<td>6.68%</td>
<td>23.00%</td>
<td>6.68%</td>
<td>17.00%</td>
<td>6.63%</td>
</tr>
<tr>
<td>Reliability</td>
<td>23.00%</td>
<td>18.00%</td>
<td>6.44%</td>
<td>28.00%</td>
<td>6.44%</td>
<td>16.00%</td>
<td>5.68%</td>
</tr>
<tr>
<td>Flow rate</td>
<td>5.00%</td>
<td>17.00%</td>
<td>0.85%</td>
<td>8.00%</td>
<td>0.85%</td>
<td>9.00%</td>
<td>0.45%</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>10.00%</td>
<td>17.00%</td>
<td>1.70%</td>
<td>29.00%</td>
<td>2.95%</td>
<td>17.00%</td>
<td>1.70%</td>
</tr>
<tr>
<td>Score out of 100%</td>
<td>17.58%</td>
<td>21.54%</td>
<td>15.91%</td>
<td>17.46%</td>
<td>11.58%</td>
<td>16.18%</td>
<td></td>
</tr>
</tbody>
</table>

So the conclusion of this ranking is that the first, second and fourth concepts are the most interesting for further development.
14. **Refining the design**

The best concepts that come out of the Analytic Hierarchy Process are presented to and discussed with Fogmaker to find the best way to move forward in the project. An extensive research on the internet about valves that might be suitable for this system proved that there are barely any that can be used. The problem is the operating pressure inside the detection cylinder. Either the valves found are used for high pressure (about 250 bars) or for low pressure (about 10 bars).

The best idea for moving forward is to continue working with the connection hub. Either by integrating purchase parts in a new block or by designing a block with an integrated valve. As stated above there are difficulties with finding the correct valves for the new connection hub. The conclusion of the whole online research is that it is only possible to either buy custom made valves or using integrated valves.

At the moment there are many insecurities about the possibilities for the connection hub. Consulting an expert in the field of hydraulics will help to continue the development.

14.1. **Consulting a hydraulic expert**

Stig Wahlström is a company that is divided into three smaller companies. Their branches are specialised in hydraulics, automation and electronics. They also manufacture and design custom made hydraulic connection blocks and valves. Furthermore, they have extensive experience in working in the automotive branch. Which is the branch that Fogmaker is very active in as they design fire suppression systems for engine compartments.

Since the project group members are no experts on the matter of integrating valves in the connection hub or valves in general it deemed wise to contact them.

14.2. **Starting point of development**

All of the concepts that have been designed thus far have been presented in great detail. The first two concepts are very interesting to Stig Wahlström as they have similar ideas in mind.

When series of production become larger than 5000 valves per year it is more cost effective to work with custom valves that are specifically designed for their application. Since Fogmaker requires 18000 connection hubs every year this is the recommended solution.
A needle valve will most likely be used for the connection hub. This is the same valve that has been used in concept one and two, confirming that the original ideas were good and practical. Combining the best of a needle valve and a ball valve the new valve can have an open or closed knob that rotates 180 degrees, making it clear if the system is opened or closed.

A bursting metal membrane is the cheapest and most reliable option for releasing pressure. It can be designed as part of the connection hub that has a smaller wall thickness. It will make sure the pressure is released under certain pressures. However, the detection cylinder must be replaced once the pressure relief bursts.

A pressure relief valve is the other option. When the pressure reaches a certain level the pressure relief valve opens and automatically lets some pressure escape. This will lower the pressure level in the bottle. Once the pressure drops down under a certain level the valve closes itself again. With this option the detection cylinder will not lose all of its pressure if the maximum pressure level is exceeded. This prevents the fire suppression system from activating as there will remain some pressure in the bottle to pressurize the Teflon tubes. However, because this is a more complicated solution it is more expensive and harder to implement. There is more chance of leakage, and therefore making the whole system less reliable.
15. **Failure Mode and Effect Analysis**

Just like the FMECA for the safety handle this analysis has a detailed description in the appendix of the report. In this paragraph all the failure modes of the fire suppression system have been listed and ranked according to the FMECA.

Instead of taking the detection hub for the ranking the fire suppression system is included in order to show the relation between both systems and its components. Since the fire suppression system has failure modes that are closely related to the detection cylinder this is the correct way to perform this analysis. For example, when a fire breaks out the detection cylinder has a certain reaction that affects the connection hub and its components.

This paragraph focuses on the failure modes that have the highest risk priority number rating (Figure 26) and the actions that can be taken to lower this rating.

### 15.1. Increasing pressure inside the detection cylinder

The highest threat in the fire suppression system is increasing pressure in the detection cylinder. Increasing pressure is cause by heat. Since Fogmaker’s systems are used all over the world it happens in some countries that due to heat the pressure builds up in the detection cylinder. If the pressure surpasses a certain level the bottle explodes. If the bottle explodes the whole fire suppression system is activated, which means that any fire that might occur due to the explosion will be contained. However, the explosion can cause serious damage to the vehicle. Which can lead to a vehicular accident and eventually injuries or casualties. This leads to a high severity.

A pressure relief in the connection hub will allow the pressure to escape. With a pressure relief it is no longer possible that the bottle will explode. This shows why it is important to redesign the connection hub.

It is also not very easy to detect for the user. Therefore it is helpful to give the user instruction about the fire suppression system so the user can act accordingly to allow the detection cylinder to cool down.

![Connection hub FMECA](image)

*Figure 26 Connection Hub RPN ranking*
15.2. Closed detection cylinder

In second place on the ranking comes the risk of having a closed detection cylinder when the fire suppression system is installed. A closed detection cylinder can be caused by a failure during assembly. When the detection cylinder is closed once the Teflon tube melts there will be signal to the user. The user might keep on driving, further damaging the engine and increasing the chance of having an accident.

The new connection hub design will take away this risk as the user is notified as soon as the Teflon tube loses pressure. Allowing the user to act accordingly and prevent further damage.
16. **SWOT-analysis**

This chapter describes a SWOT analysis of the final connection hub concept, as explained in Paragraph 6.5 this analysis subsequently presents the strengths, weaknesses, opportunities, and threats.

### 16.1. Strengths

The connection hub concept will be further developed by Stig Wahlström, due to their expertise on the field of hydraulics the product is very **reliable**. The risks involved in the use of purchase parts that are not custom made for Fogmaker’s application are therefore significantly reduced, increasing the chances of a successful project.

By using a valve that combines the principles of a needle and a ball valve a 180 degrees rotation of the valve switch is sufficient for operating the valve. This increases the **optical indication** whether or not the system is opened.

With Stigh Wahlströms experience the most **cost effective and compact** design can be guaranteed.

A bursting membrane pressure relieve system is the most **reliable and leak proof** alternative, whilst being the cheapest option. By designing the membrane as the weakest part of the system an explosion of the pressurised bottle is prevented.

### 16.2. Weaknesses

As the development of the connection hub is still in the concept phase it has not been possible to perform a detailed **cost calculation**. In further stages of the project several cost calculations and indications will be created, unexpectedly high costs will endanger the project’s success.

A new connection hub will require **changes in the assembly manual** for mechanics and customers.

The UL approved **manometer** design is slightly **fragile**, both the current connection hub and the new concept do not provide additional protection for this manometer.

### 16.3. Opportunities

**One Computer Aided Manufacturing program** can be used for the production of both the connection hub with one and with two pressure switches.

The aesthetics of the connection hub are improved as an integrated valve looks more reliable, improving the **customer value** of the connection hub and the complete fire suppression system.

The **pressure bottle can be integrated** in the connection hub if the required volume in the pressure bottle can be decreased. This will be more cost effective, and eliminates points of possible leakage.
16.4. Threats
Due to the close collaboration with Stig Wahlström the development and production of the connection hub will strongly depend on Stig Wahlström. The production of the connection hubs is threatened by the possibility that the company is no longer able to manufacture the valves.
F. Evaluation
This section presents the evaluation of the projects and the applied methods. Subsequently a conclusion of the projects is included.

17. Analysis
The analysis takes a look back at the methods that have been used during this project and evaluates how effective they have been and which impact they had on the project.

17.1. Project definition
It has been very useful that all risks of the project were analysed and that a clear description of all project facets was made. This has greatly improved the communication between the stakeholders, and reduced the risks of project failure.

As mentioned in the method section a large percentage of projects runs overtime and over budget, and many don’t deliver what has been promised. The initial project planning showed 3 empty weeks at the end. In the plan of approach it’s mentioned that these weeks are reserved as project slack, or if necessary used to further develop the projects or continue with another one. It is very common for projects to require more work than initially estimated, and the same count for our project.

Especially the safety handle project (section B) required more work than estimated. The projects scope did not include the contact with the manufacturer. Also there are more prototypes created than expected, as real zinc models are ordered in addition to 3d printed plastic models. At this moment the zinc handle is ready for production.

17.2. Concept phase
According to Stutton & Hargadon (1996) brainstorming is a very useful technique for idea generation. The application of brainstorming techniques and rules to both projects have proven to be very productive. Multiple brainstorming sessions have been applied in an iterative style, so that the maximum length of a brainstorm was one and a half hours.

In the methods section the importance of a morphologic chart has been explained. However, dividing the safety handle in sub solutions would not be beneficial for the project. Therefore no morphologic overview has been created for the safety handle. In the development of the connection hub a morphologic chart did create a valuable overview of the brainstormed sub solutions and the concepts derived from it.

The application of the analytic hierarchy process to select the preferred concept has proven to be useful in the selection of the best safety handle concept. However, the quality and reliability of an AHP is strongly influenced by the experience of the contributors. This can be seen by the changes in the AHP after the discussion with Fogmaker. An AHP was not applied to the connection hub project as from an early point in the project it was clear that input from valve experts was needed for a valuable judgement of the concepts.

17.3. Refining the concepts
The most basic of engineering tools is the calculation of stresses within products to be able to optimize the design. In the safety handle concept FEM analysis have been applied at several stages in the process. The final concept has a safety factor of nineteen where a
A safety factor of two would be sufficient. This is due to the ergonomic requirements of the safety handle. A thinner handle has a smaller area of contact with the lifting hand, with equal weight this results in a higher pressure (Newton/mm) and less ergonomic lifting.

The cost calculations for the safety handle are really reliable as they consist of true quotations of manufacturers, analysed in close collaboration with Fogmaker’s purchase department.

The Failure Mode Effect and Criticality analysis have given valuable insight in the systems reliability. However, an FMECA covering the whole system would be more valuable. As there is no data available of the failure rates of the safety handle and the connection hub the FMECA’s strongly depend on estimations based on experience. The quality of the FMECA’s will improve as real failure rates can be used.

The ergonomic testing of the safety handle has been very useful, by creating 3D prints all involved stakeholders could quickly see, feel, understand, and judge the design of the different concepts. The plastic 3D models give a clear indication of the shape and size, a zinc 3D printed model can be tested more thorough as it has 70% the strength of a zinc casted product. Thus, it is possible to lift an extinguisher with the zinc printed handle, in contrast to the weaker plastic products that had insufficient tensile strength for lifting the extinguishers.

In paragraph 5.5 it has been claimed that a SWOT analysis is a clear and structured way to describe a system. Chapters 9 and 14 present a clear description of the concepts according to the SWOT structure, which has proven to be a valuable technique.
18. **Conclusion**

As mentioned in the introduction this project is aimed at (re)designing two components of Fogmaker’s fire suppression system, by using the product development method described in Section A.

The first step of this method is to define and analyse the problem, thereafter concepts have been created by brainstorming solutions to this problem. From a ranking, created using the Analytic Hierarchy Process, the zinc casted handle is indicated as the best concept. To verify this ranking a cost inquiry for the three highest ranked concepts and one additional concept has been requested from several suppliers. This proves that a zinc handle is the most cost effective solution. The ergonomic design of the zinc casted handle has been tested by 3D printed prototypes and reviewed by a zinc manufacturer. At the time of writing this report a zinc prototype is being tested. If the zinc prototype is approved the production of a test series is the only step that remains to be taken before full scale production can be started.

Likewise the connection hub project started by defining the project, followed by brainstorming in combination with analysing already existing valve solutions. In contrast to the safety handle project the created concepts were not ranked by the Analytic Hierarchy Process. As the expertise of a valve manufacturer was required for a credible ranking. Stig Whalström has provided this expertise, and will continue the development of the connection hub concepts. This connection hub will involve a specifically designed needle valve and a membrane that functions as a pressure relieve valve. After approval of Fogmaker Stig Whalström will manufacture the connection hub.

These two projects have proved that even projects within the same company may require different product development methods. For instance, a morphologic overview was not required for the safety handle project as it cannot be divided into sub functions. On the other hand the connection hub project did not benefit from an AHP ranking as consultancy of valve experts was needed. However, the main structure of all product developments are rather comparable, consisting of a project definition, concept phase, and evaluating and refining the best concept.
References


Appendixes