Fire extinguisher mount for vehicles

Adapted for mining conditions and emergencies

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Industrial Design Engineering, master's level
2018

Luleå University of Technology
Department of Business Administration, Technology and Social Sciences
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Published and distributed by
Luleå University of Technology
SE-971 87 Luleå, Sweden
Telephone: +46 (0) 920 49 00 00

Cover: Marika Linde

Printed in Luleå Sweden by
Luleå University of Technology Reproservice
Luleå, 2018
Acknowledgement

First off would I like to thank Boliden for the opportunity to do this thesis work. I would also want to give an extra thanks to my supervisor from Boliden, Samuel Bäckman. Thank you for your support throughout the entire project. Your input and especially your belief in my capabilities and knowledge during this project have been uplifting. I would also like to thank Aptum and everybody there that helped me during my visit at both their workshop as well as the Renström mine. Your input and knowledge gave me and this project a great foundation to work from. The result of this project would not have been as successful without that early contribution.

Secondly, would I like to thank Svensk konstruktionstjänst and every one that works there. Thanks for letting me perform my thesis work at your office and for making me feel welcome from day one. Big thanks to my Supervisor Martynas Alijouius at Svekon. Thank you for answering all my questions and for helping me whenever I needed it. This project would not have been what it is without your help and commitment.

Thirdly, would I like to thank my supervisor at Luleå University of technology, Peter Thörlin. Thank you for your support and guidance during this project.

I would also like to thank my family and friends for supporting me throughout this journey! Your input, love, and support have made it so much easier.

Last but not least, would I like to give a special thanks to my partner Mattias. Thank you for making my journey, your journey as well. You have been my rock, not just though this thesis work but through the entire course of this education. I would not have been able to do it as well as I have without your constant support and love. Thank you!

Marika Linde
Stockholm, June 15, 2018
This report revolves around a project for Boliden which is a thesis work for a master in engineering within industrial design engineering. This project had a primary focus of developing a new mount for fire extinguishers that will be suspended on vehicles in Boliden’s mines. The foundation of the project was an accident in Boliden’s mine Aitik where a fire extinguisher exploded due to damages caused by the vehicle mount in combination with vibrations. The objective of the project is to identify the main problem with the vehicle mounts used today in Boliden’s mines and solve it.

The process used in this project is a fairly standard process that is separated into four phases; Context immersion, Ideation, Conceptual design and Final design. The last two stages focused on prototyping and testing to finalize the design, whereas the beginning of the process was trying to get a grasp of the problem. This included understanding the unique environment of the mines as well as getting to the bottom of the problem with the vehicle mount. Interviews and observations were conducted during a visit to Boliden’s mine, Renström, in Skellefteå to investigate the problem.

The conclusions from the Context immersion was that the main problem with the vehicle mounts was that they were not adapted for the mining conditions at all. A large number of vibrations and a lack of vibration damping for the mount was the leading cause for the damages on the fire extinguisher. This caused the vehicle mount to fail and in the process also damage the fire extinguisher.

The solution to this problem turned out to be a more robust product using a stronger material with higher damping to suspend the fire extinguisher. This made the vehicle mount cope with the vibrations in a better way. A quick release mechanism was also implemented that assists with the vibration durability as well as make the fire extinguisher easy and fast to release. The fast release, as well as the ease of use, makes the vehicle mount adapted for emergencies as well. The durability and the use of the new vehicle mount were reassured by a vibration analysis made in NX 12, as well as a short usability test.

**Abstract**

**Keywords:** Fire extinguisher, vehicle mount, mine, vibrations, quick release, emergency, industrial design engineering, product development.


I slutet av Kontextfasen fastställdes det att huvudproblemet var att hållaren inte var tillräckligt anpassad för gruvmiljön. Den stora mängden vibrationer från miljön i kombination med en brist av vibrations dämpning för hållaren var orsaken till att skador uppstår på brandsläckare.

Lösningen på problemet var en ny hållare som var mer robust samt att materialet som används för att hålla brandsläckaren var starkare samt hade högre dämpningsgrad. Ett snabblås lösning var också implementerad som också bidrar till ökad vibrationstålighet, den gör också att brandsläckaren går snabbt och enkelt att ta loss i nödsituationer. Hållbarheten samt användbarheten säkerställs genom en vibrationsanalys utförd i NX 12 samt ett kort användartest.

Sammanfattning

Nyckelord: Brandsläckare, fordonshållare, gruva, vibrationer, snabblås, nödsituation, teknisk design, product utveckling.
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1. Introduction
1. Introduction

This master thesis in Industrial design engineering at Luleå University of technology was conducted in the spring of 2018 between mid-January to early June. This project was executed for Boliden to make their mines even safer and to reduce the number of fire extinguishers that are discarded due to fatigue damage. The main work of the project was conducted at the engineering firm Svensk Konstruktionstjänst’s (SveKon) office based in Stockholm. There was also an intense visit to Boliden’s mine Renström. This visit gave a better understanding of the problem at hand, the unique environments and the product.

1.1. Background

Every vehicle used in Boliden’s mines is equipped with fire extinguishers that are suspended to the vehicles. The environment that these vehicles drive in as well as the vehicles them self can cause a significant amount of vibrations. The vibrations are then transferred to the vehicle mount of the fire extinguishers, which indirectly affects the fire extinguishers negatively.

In 2013 there was there an accident in Boliden’s mine Aitik involving a fire extinguisher, where it exploded during service. After this accident was an investigation conducted to determine what the cause for the accident was. One conclusion of the inquiry was that the vehicle mount of the fire extinguisher was one of the underlying causes. The fire extinguisher had been subjected to continuously vibrations and blows from the vehicle mount causing fatigue damage. The fatigue damage on the tank for the extinguishing agent developed over a long time and caused it to burst.

Since the accident has Boliden issued more caution surrounding the fire extinguishers, as they are now more aware that they may suffer from fatigue damage. If any fire extinguishers exhibit signs of damage they are replaced, this prevents any further accidents from happening. The system may be a reasonably successful system when it comes to preventing accidents. It is, however, very costly for both the environment and the company. It costs the company considerable money every year to replace these fire extinguishers. It also waste a lot of natural resources when more fire extinguishers are produced, which is hurtful for the environment. To minimize this waste of both money and resources has Boliden decided to replace the vehicle mount for the fire extinguisher, as it is the primary cause of the problem.

1.2. Stakeholders

The stakeholders in this project are mostly connected to Boliden’s organization, but some external stakeholders also exist. These stakeholders will be affected in different ways if the result of this project would be implemented in Boliden’s mines and they are listed below.

Boliden as a company will be affected by saving money when they do not have to continuously replace fire extinguishers, due to them experience fatigue damage.

The workers at Boliden’s mines will be affected if the final result will be implemented. The different workers that will be affected in the mines are listed below.

Machine operators in the mines will be affected as they are the primary user of the vehicle mount in case of a fire.

Mechanics in the mines will be affected as they are the ones that fix every problem related to the vehicle mount used today. They repair or replace components that break and hopefully will a successful result make their workload less.

Service technicians will be affected as their routines probably will change both when it comes to installing and supervising the vehicle mounts and fire extinguishers.

Protection workers will be affected as they oversee the safety equipment in the mines and will have a new product to manage.

The manufacturers of the fire extinguishers used in Boliden’s mines today will be affected when Boliden discards less fire extinguishers.

The producers of the current vehicle mounts will also be affected as their product will be replaced in Boliden’s mines.

The environment will be affected positively as this will reduce the manufacturing of fire extinguishers. If the project is successful, then Boliden will no longer need to replace as many fire extinguishers due to them being damaged. A decrease in the number of discarded fire extinguishers is positive for the environment, as this means there will be fewer resources wasted.
1.3. Objectives and aims
This project aims to reduce the number of fire extinguishers Boliden needs to replace due to fatigue damage. This will make the work environment safer as fewer fire extinguishers will be damaged which increases the risk for accidents. A decrease in the wasteful use of fire extinguisher will also be a contributing factor, which will save Boliden money.

The objective of this project is to identify the main problem with the vehicle mounts used today in Boliden’s mines and solving it. The solution may be in the form of redesigning the current product or developing an entirely new one.

To reach these objectives and aims have two research questions been developed. These two questions will help with guiding the work throughout the project. The research questions are:

- What is the main problem with the vehicle mounts used today?
- Can a vehicle mount for fire extinguisher be adapted for both emergency use and use in mines as well as have resistance against vibrations?

1.4. Project scope
There is a limit of the time that will be spent on this project, as it is a thesis work. The project as a whole will last for 20 weeks of full-time work which represents 800 hours in total. The time limit constricts how much can be done and the work needs to be adjusted to fit this limit.

No detailed cost calculations or production plan will be done in this project. There might be some small calculations done to get an overview of cost and how the production will be made, but there will be no in-depth analysis.

The material selection will be simplified, meaning that a long and detailed search will not be conducted. Different materials will be explored but a detailed search with a screening of all types of materials to find unusual materials will not be conducted due to time constrictions.

1.5. Thesis outline
The outline of this thesis is listed and explained below.

Chapter 1: Introduction
The first chapter introduces the project, and the problem at hand, an explanation of why the problem exists and how it was identified is presented as well. It also sets up the objectives and aims, identifies the stakeholders and set up the perimeters of the project.

Chapter 2: Context
The second chapter explains the context of the project by explaining the environment in mines, the importance of fire protection as well as different aspects of it. It also covers the different vehicle mounts that are used today and the problems that exist.

Chapter 3: Theoretical framework
In this chapter is the theoretical framework connected with this project presented which is the scientific and academic foundation that many decisions will derive from.

Chapter 4: Method and implementation
The fourth chapter describes the overall process. The methods used in the different phases of the process and how they were implemented are also explained. It ends with a discussion about the methods used to give insight into the selection of some methods and how the implementation of them can have affected the result.

Chapter 5: Result
The result of the whole project is presented in this chapter and is separated into each phase of the process. At the end of the chapter is the final design presented in detail.

Chapter 6: Discussion
In this chapter before the references are the result discussed with the theory in mind.

Chapter 7: Conclusions
At the end is a discussion about the result and if it fulfills the objectives and aims set at the beginning of the project.

Chapter 8: References
The final chapter lists all the references used in this thesis according to the reference style of APA.

Appendices
Last but not least is the appendices that are referenced in the thesis listed in the order that they are mentioned in the text.
2. Context
2. Context

In this chapter is the current state explored, this involves the unique mining environment, fire safety within mines, vehicle mounts on the market and problems related to them when used in mines.

2.1. Mining environment

Boliden is a mining company and has a total of six mines; Aitik, Kylylahhti, Garpenberg, Tara, Kevitsa and the Boliden area (although the Boliden area is counted as one, it consists of four separate mines). These mines are located in Sweden, Finland, and Ireland, with most mines in Sweden. Boliden’s mines are both open pit and underground mines, but there is a more substantial percentage of underground pits (Boliden AB, n.d).

Most of Boliden’s mines are sulfide ore mines (Boliden AB, 2018) that is considered more environmentally hazardous then iron ore mines (Naturvårdsverket, 1995). When mining the ore the natural degradation process, weathering, is accelerated as more of the minerals are exposed. The most dangerous weathering is the one of metal sulfide. It causes the environment to get acid due to oxidation of the sulfides to sulfate (Naturvårdsverket, 1995).

This acid environment in the mines affects both the environment as a whole and particularly the local environment in the mines. As the environment in the mines is acid a direct cause is that everything in the mine corrodes. It does not matter if the material is stainless steel or have been galvanized. Everything in a mine corrodes eventually, all that is needed is a small break in the protective seal and the material will start corroding.

To mine the ore within the mines different mining equipment is used. This equipment often generates a significant amount of vibrations (SveMin, 2005). The vibrations from the vehicle themselves in combination with the already rough driving conditions result in the vehicles being exposed to a significant amount of vibrations. These vibrations are then transferred to the vehicle mount as well as the fire extinguisher.

2.2. Fire safety in mines

Fire safety in mines is critical, especially in underground mines. There are complex layouts in them which can lead to dead-ends and closed off areas where acid deficiency can occur (Ingason, Hansen, Kumm & Nyman, 2010). Toxic smoke is also formed when there is a fire (Ingason et al., 2010; Gruv- och mineral industries Arbetsmiljökommitté (GRAMKO), 2016) which is harmful to humans.

There were 83 fire incidents in the GRAMKO organization in Sweden in 2016 and of those were 32 caused by vehicles, see Figure 1. This amount is not a significant increase from the previous year of 2015. It has however been a substantial increase in fire incident caused by vehicles being overheated (GRAMKO, 2016).

2.2.1. Fire protection systems

As mentioned earlier, is one of the most dangerous risks in an underground mine fire and the toxic smoke that is formed (Ingason et al., 2010; GRAMKO, 2016). The smoke can spread very quickly at the speed of 3-4 m/s. This means a kilometer of mining galleries can be filled within minutes. Ventilation is one big part of counteracting this as they remove the smoke from the mines (GRAMKO, 2016). Making it an essential part of fire safety in underground mines (GRAMKO, 2016). Boliden does have rescue chambers in all their mines, which is equipped with air, water, and communication that can last for up to six hours (Boliden AB, 2018).

All vehicles (not including regular cars) that are driven in the mines are equipped with extinguishing systems as well as two hand-held fire extinguishers (Service technician A, personal communication, February 15, 2018). The extinguisher systems are mainly used to suppress the fire inside the machine and to stop it from getting worse or spreading (Service technician A, personal communication, February 15, 2018). The system is not meant to extinguish the whole fire, that is supposed to be done by the handheld fire extinguishers that are mounted on the vehicle (Service technician A, personal communication, February 15, 2018).

![Figure 1: Circle graph fire incidents in 2016](image)
2.2.2. Fire extinguishers

Many vehicles are moving around all the time in a mine. Every vehicle must have at least two fire extinguishers of the type 55A 233BC, with 6 kg of extinguisher agent (Service technician A, personal communication, February 15, 2018), see Figure 2. For more information on what that means see chapter 3.6. Fire extinguishers. The most common brands of fire extinguishers used are Presto and Dafo, other brands are also used but only in small quantities (Service technician A, personal communication, February 15, 2018). Both the Presto and the Dafo fire extinguisher of the type 55A 233BC have a diameter of 150mm on the extinguisher tank. They do however vary in length as well as the shape at the bottom. The Presto extinguisher can stand on its own whereas the Dafo extinguisher needs a cylindrical foot in order to stand.

The fire extinguishers used are meant to be used in industries instead of home environments. The difference between the two is in the handle. The industry fire extinguisher has a handle in stainless steel instead of plastic (Service technician A, personal communication, February 15, 2018). This handle supposed to handle the rougher environment that is in an industry setting better. There is, however, the only difference, as the rest of the extinguisher is precisely the same. Meaning that there are no extra reinforcements made to the extinguisher tank for it to be able to handle the harsher environment better.

2.2.3. Inspections of fire extinguishers

SVEBRA (2016) recommends that fire extinguishers should regularly be inspected, with the standard time interval being one month. However, if the fire extinguisher is in a harsher climate, should it be done more frequently. When the inspection takes place six steps should be performed (SVEBRA, 2016):

1. That the fire extinguisher is in its correct place and is clearly marked
2. That the fire extinguisher is easy to access and remove from the vehicle mount
3. That the safety catch is in place and sealed (the fire extinguisher is unused)
4. That the instruction is visible and readable
5. That there is no visible outer damage to the fire extinguisher
6. That the pressure gauge needle is in the green area, only applies to pressurized fire extinguishers

Figure 2: Regular car with two fire extinguishers of the type 55S 233BC
The fire extinguishers on vehicles used in mines should be inspected daily before the start of every shift. At the driver seat in every vehicle is there instructions on how to perform daily supervision of handheld fire extinguishers (GRAMKO, 2016). There should also be instructions on what to do during a fire (GRAMKO, 2016). However, some protection workers in Boliden’s mines do not think this is performed daily, as I should, and puts the blame on human factors (Safety worker A, personal communication, Mars 2, 2018). The inspection only consists of the steps that are listed above and does not include checking the fire extinguisher for damage that is connected to the vehicle mount (step 5 only includes damage that is caused by falling rocks and such). Most of the focus of the inspection is put on checking that the pressure gage is in the green area, as this is crucial for the use of the fire extinguisher.

2.2.4. Common damages on fire extinguishers

The most common damages that occur on the fire extinguishers in the mines are corrosion and fatigue damage (Service technician B, personal communication, February 16, 2018), see Figure 3. The fatigue damage appears in places where the fire extinguisher is in contact with the vehicle mount. It does however only occur when the vehicle mounts are not functioning the way they should (Service technician B, personal communication, February 16, 2018). The primary cause for the damage is due to constant vibrations from the vehicle that the fire extinguisher is mounted on, but only when in use.

The corrosion damage occurs when the fire extinguisher has already suffered damage. The damage might be in the form of the paint scraping off or even fatigue damage, as mentioned above (Service technician B, personal communication, February 16, 2018). The cause of this damage is the acid environment in the mines due to the type of ore mined.

2.3. Vehicle mounts

Ordinary vehicle mounts for fire extinguishers are used on vehicles as there is none specially made for mining conditions. There are mainly four different types of mounts used to suspend fire extinguishers on vehicles. However, are only two of them are used in Boliden’s mines. The characteristic feature for all the mounts is that the fire extinguisher is kept in place by straps that are locked with a clasp. This clasp is very easy to open and close and is the unwritten standard when it comes to clasps on vehicle mounts for fire extinguishers (Service technician A, personal communication, February 15, 2018). The reason for this is due to them being well suited for emergencies as they are simple to use as well as securing the fire extinguisher securely and robustly. The closing mechanism is based on a lever, and this helps with fastening the strap tightly against the fire extinguisher. This tightness is essential as it prevents damages on the fire extinguisher.

Figure 3: Fatigue damage on fire extinguishers used in the Renström mine
Type 1: Navy holder

The first type of vehicle mount is made of stainless steel and only uses one strap to secure the fire extinguisher. The fire extinguisher is kept in place at the bottom of the mount by a cylinder that is made to be snugly fitted to the bottom cap of the fire extinguisher, see Figure 4. This vehicle mount is the only one not using a small steal base at the back. It is also more incased then the other vehicle mounts. There are no rubber dampers to lessen the impact on contact areas between the fire extinguisher and the vehicle mount. It does, however, use rubber dampers to lessen the wear on the straps, as the edges are sharp and the vibrations make the straps break due to wear.

Type 2: Standard holder

The second type of vehicle mount is made in steel, and the fire extinguisher is held in place by two straps, one at the top and one at the bottom, see Figure 5. The steel base is placed at the back and is bent at both ends around the fire extinguisher, without touching it. These ends are covered with rubber dampers. These dampers are supposed to soften the impact of the mount and the fire extinguisher if they were to touch. There are also dampers on the protruding arms from the back of the mount. These dampers are here to dampen the contact areas between the fire extinguisher and the vehicle mount.

Type 3: Standard holder with ring

The third type of vehicle mount is a variation on the second type as the base is relatively similar. The main difference is that the fire extinguisher is only kept in place by one strap at the top and a metal ring at the bottom, see Figure 6. This metal ring is supposed to catch the fire extinguisher if the straps do break, as a fail-safe. Unfortunately does this metal ring cause considerable damage on the fire extinguisher when used in mines. This is the main reason why Boliden does not use them. They are however used within other mining companies (Service technician A, personal communication, February 15, 2018).

Type 4: Protective box

The fourth possible type of vehicle mount that can be used is protective boxes. The fire extinguisher is once again kept in place by straps within the box, see Figure 7. These boxes can be in both plastic and metal. These boxes are rarely used in mines, as the acid environment in the mines is accelerated by the boxes, making the environment even damper (Service technician B, personal communication, February 16, 2018; Service technician A, personal communication, February 15, 2018). The protective box also puts another action to do in an emergency. Making it possible for more errors to occur when releasing the fire extinguisher.
2.3.1. Problems related with the vehicle mounts

The vehicle mounts that are used in the mines is not customized for the unique environment that is in the mines. Causing multiple problems to exist, the majority being related to vibrations. The problem with the vibrations are mainly that they are transferred from the vehicles to the vehicle mounts, see Appendix 4 for an in-depth correlation.

The main problems that occur are wearing on the straps, missing rubber dampers as well as flaws in the design of the mount. Most of these problems lead to undesired contact between the fire extinguisher and the vehicle mount. This contact does often lead to fatigue damage in the long run.

Wear on straps

The purpose of the straps is to keep the fire extinguisher in place. It is vital that there is no wiggle room between the straps and the fire extinguisher. Since this wiggle room causes constant wear from the straps to the fire extinguisher, which causes fatigue damage.

Another problem is that the fire extinguisher can move around when the straps are not tight against it. That the fire extinguisher can move means that it can touch undesired parts of the mount as well as wearing against the straps themselves. This wear and contact does, in the long run, lead to fatigue damage on the fire extinguishers. This damage eventually leads to cracking and material failure in the fire extinguisher.

Wear on straps often came from the straps chafing against the metal part of the mount where the straps are attached. The straps are attached to the vehicle mounts in slightly different ways on all types. The principle is, however, the same for all. A long strap with one piece of the clasp in each end goes through one or two holes on the protruding arms on the vehicle mount, see Figure 8.

Figure 8: Wear on straps on vehicle mounts in the Renström mine.

Figure 9: Replaced straps on a vehicle mount in the Renstöm mine.

The chafing primarily occurs because of the vibrations of the mount. The edges of the vehicle mount being too sharp also contribute. The wear of the straps happens under an extended period on all vehicle mounts. It is, however, more rapid in type one and three, due to sharp edges on the first one and worse quality on the straps on the third.
That the straps break is not only a problem due to it causing fatigue damage. It is also a safety issue when it comes to the actual use of the fire extinguisher, as the straps can be difficult to replace. This difficulty is due to the clasp being pre-fastened to the straps and the clasp being too big to be fitted through the holes on the mount easily. Instead of replacing the straps with correct straps are ratchet straps used, see Figure 9, as they fit through the holes on the mount. The ratchet straps are problematic as they do not secure the fire extinguisher tight enough, causing wear and eventually fatigue damage. They are also more difficult to loosen which can be disastrous in an emergency.

Rubber dampers

Rubber dampers are used to dampen the vibration transmission between the vehicle mount and the fire extinguisher at possible contact points. They are often located at the top and the bottom of the mount as well as around the arms that hold the straps.

missing rubber dampers only occurs on the second type of vehicle mount. These mounts use a different type of damper than the other ones. These dampers are in the form of a tube that is dragged over the end edge, see Figure 10. The problem here is that nothing is holding the rubber damper in place except friction. This leads to the rubber damper often being wiggled off due to vibrations. An increase in the possibility of metal hitting metal is inevitable when the dampers are missing. Something that can lead to fatigue damage.

The most significant structural flaw when it comes to vehicle mounts for fire extinguishers is related to the third type. This type of vehicle mount has a metal ring at the bottom that the fire extinguisher is supposed to rest on. The ring also serves as a fail-safe as the fire extinguisher will stay in the holder if the strap fails. The biggest issue is that fire extinguisher is not secure enough with just one strap. This makes the bottom of the fire extinguisher hit the metal ring, even when the strap is intact. The metal ring is unfortunately not covered with any rubber dampers, making the impact very severe. The impact of the ring and fire extinguisher does, therefore, cause fatigue damage very rapidly.

2.3.2. Placement of the fire extinguisher

When it comes to the placement of the mount and the fire extinguishers onto the vehicle, a few problems exist. These problems are both related to the mount as well as the environment. The biggest obstacle is finding a place on the vehicles were the mount can be suspended, that also is protected. This is important as it is common that the vehicles bump into the mining walls. When they do, the vehicle mount might be damaged. This can be solved by placing the mount in a more protected area of the vehicle.

![Figure 10: Rubber damper on type](image)

![Figure 11: Altered vehicle mount.](image)
It can, however, be proven hard to place the vehicle mount in this protected area as there are limited holes on the mount as well as attachment points on the vehicles. It is not optimal to drill new holes on the vehicle as this increases the risk of corrosion, see Figure 12, although this might be the only option at times. It also happens that the vehicle mount is altered to suspend it, see Figure 11.

These problems cause the placement of the vehicle mount to vary a lot from vehicle to vehicle. It might sometimes be placed high above the head and sometimes below the waist of the user. It can also be placed at an angle or straight, as well as standing up or lying down.

The shape of the first type of vehicle mount also makes it harder to install on vehicles, then the others. This is due to it needing to be fastened with more bolts as it has a broader back piece.

Some attempts have been made to place the mount in areas that are not as affected by vibrations to protect them. This might be inside the cabin or in a cabinet that exists on the outside of the vehicle. This is however mostly applied to trucks that drive in the mine, as they are the only vehicles with enough room inside the cabins as well as external cabinets. Another option is to use protective boxes. They do however take up considerable more room, and they also increase the chance of corrosion on the fire extinguisher.
3. Theoretical framework
3. Theoretical framework

The theoretical framework for this project has its roots in industrial design engineering, as it revolves around product development where both industrial design and mechanical engineering aspects are essential. Industrial design aspects that are important to this project are human interaction, human-centered design, and usability. Material knowledge about different material damages and how to design to prevent it is mechanical engineering aspects.

One aspect that is extra important in this project is safety and how to design safe products as it is about a safety product. To ensure that a product is safe to use human interaction should be taken into consideration. Human interaction in emergency situations in particular in this project. Because reactions in emergency situations tend to be different from normal reactions and can affect interactions with products. That is why it is essential to understand what design aspects to take into consideration when designing for emergency situations. In order to do this human behavior and how this affects interactions with products needs to be explored.

The product under development in this project is supposed to be used in a unique environment. This aspect is as important and should also be taken into extra consideration. Aspects that are related to the mining environment are corrosion, vibrations, and fatigue. These aspects affect products that are used in mines negatively. They may primarily, have negative impact on some materials, and it is essential to understand how design can help to counteract these negative impacts. To structure how all these different aspects interact and what role they play an explanatory map was made, see Figure 13.

3.1. Product design

Industrial design engineering is a combination of two different fields, mechanical engineering, and industrial design, and came to be because there was a need for engineers that knew both fields (De Vere, Melles & Kapoor, 2010). As a product that is well engineered but is hard to use or even unsafe is not a good product. Neither is a product that is aesthetically pleasing, but is unreliable and flimsy in its construction. It is only with the knowledge within both fields that the development of useful products is possible (Cross, 2000). Therefore, has an industrial engineer to be familiar with all stages of the developing process for products (De Vere et al., 2010).

Industrial design engineers are competent within the design of complex technical problems but also design aesthetics and human factors. It is vital for an industrial design engineer to understand the technical part of products as well as the human factors. However, it is also essential to understand what the design of a product expresses. For example, if a product does not look safe, the user will not care if it is both technically safe and safe to use. As the feeling that it is unsafe is dominant to the user. This aspect of user feelings stresses the importance to take the perception of the user in mind as well in the design process (Smets, 1995).

![Figure 13: Explanatory picture of the theoretical framework](image-url)
3.2. Safety: safe design

That a product that is meant for survival and emergency situations is safe to use is extremely important as they can be the difference between life and death. If these products are unsafe and likely to be used in a harmful way, then they put the person using it into an even more dangerous situation.

To know what safe design is a definition of safety needs to be explored. Safety has been defined by the International Organization for Standardization (ISO) within its standard ISO/IEC guide 51. This standard recommends how to include safety aspects into other standards and its definition of safety is “freedom from risk which is not tolerable”. Were risk is defined as the probability of harm and how damaging that harm might be. Harm is later defined as damage to the health of people, property or the environment (ISO/IEC Guide 51:2014).

This safety definition may be interpreted to mainly be concerned with the safety of product use and the consequences of this, both positive and negative. The safety, in this case, applies to the intended user, which often is extended further to include all possible users (Wegge & Zimmermann, 2007). The standard ISO/IEC guide 51 includes a separate definition for inherently safe design which is “measures taken to eliminate hazards and/or to reduce risks by changing the design or operating characteristics of the product or system”. Were hazards are defined as a potential source of harm, where harm is defined in the same way as before (ISO/IEC Guide 51:2014).

But how do you establish that a product is safe? According to Boy (2011), can this be done by simulations of use and also by verification after the product is in use. However, this only makes the product safe in theory which can be vastly different from the reality. The most important to have in mind is that a product can be considered safe when there is no risk of harm when the user does make errors (Boy, 2011).

It is extra important to take the human interaction and capabilities into consideration when designing for products that are meant to be used in emergency situations (Bruck & Thomas, 2010). In order to do this, it is important to understand how humans behave and react in these types of situations as this probably will affect how they interact with a product.

3.2.1. Usability

Usability can be used to increase safety within a product (Van Eijk, van Kuijk, Hoolhorst, Kim, Harkema & Dorrestijn, 2012) as a product that is easy to use invites for less mistakes to be made in critical stages. The ease of use of a product is often referred to as usability, and there are many different ways to define and look at it (Van Eijk et al., 2012). The International Organization for Standardization (ISO) has one of the most accepted definitions (Van Eijk et al., 2012) and it is “Extent to which a product can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use” (ISO 9241-11:1998). Where effectiveness is defined as accuracy and completeness to which the users achieve specific goals. Meanwhile, efficiency is defined as the resources expended in relation to effectiveness. Satisfaction is focused on the use of the product and the attitude of the user with aspects of the comfort of use in mind (ISO 9241-11:1998).

Nielsen (1993) gives another widely accepted and used definition that explains the complexity of usability. Nielsen puts an emphasis on the importance of looking at usability as not being one dimensional but a system of many components. The components mentioned being learnability, efficiency, memorability, errors and satisfaction (Nielsen, 1993), see Figure 14. This definition is similar to Jokela, livari, Matero & Karukka (2003) way of looking at the ISO 9241-11 definition of usability. Jokela et al. (2003) views usability as a function which makes it a very complicated issue. Nielsen’s way adds more supporting attributes to the human interaction with the product, which is one aspect that has been critiqued with the ISO standards definition (Quesenbery, 2003).

Chen, Germain & Rorissa (2011) gives this last usability definition that tries to overcome the shortcomings of other definitions such as the ISO standard’s definition. This definition puts a primary emphasis on familiarity within functions, high reliability, and accommodation.
of the area of use. It also puts a focus on the cognitive function of the user, by adapting things for the user. This enables the users easily understand, learn and interact in a way that is satisfying to them (Chen et al., 2011). Chen et al. definition of usability is the one that will be used in this project when designing. It will be used as it is the only definition that takes the cognitive functions of the user into consideration. The cognitive functions play a significant role in this project, as interactions with products differ during emergencies. However, will the definition that is given by Nielsen (1993) be used when testing the usability of the product, as its aspects are more accessible to measure.

3.2.2. Human centered design

Trying to implement a human-centered design approach to the design process is a good idea if the design is supposed to be safe. Safe design relies heavily on human interaction to reduce the risk of fatal errors being made and human-centered design is a design process that focuses on making products that are adapted to the physical and psychological capabilities of the human user. According to (Greenhouse, 2012) is the aim within human-centered design to make products that are adapted for the user and not the other way around, where the user must adapt its natural behavior to fit the product. To be able to do this the designer use research and data concerning cognitive behavior, physical capabilities and task requirements

The International organization for standardization defines human-centered design as “approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques” (ISO 9241-210:2010).

There is, however, a fine line of designing for the user and designing for general human abilities which the ISO standard clarifies. Human-centered design is more concerned with other stakeholders than just the user, which is the primary emphasis in user-centered design (ISO 9241-210:2010). A blinded focus on only the user capabilities is something that Donald (2005) considers to be harmful. Because if you only focus on the user and develop only for them, the product might be very well suited for them, but not for everyone else. It could even be so bad that the product might be so ill-fitted for others that it could be considered dangerous (Donald, 2005). It is, therefore, necessary to also consider other stakeholders interests and trying to balance them with the users.

3.2.3. Emergency reactions

It is important to understand how humans react in emergency situations as humans tend to act and react differently when they are in an emergency. This difference in the reactions does then affect interactions with products and the environment. Cognitive functions also play a role when it comes to usability as well as safety, which makes it essential to understand how user react in the environment the product is supposed to be used in.

In an emergency is the goal to survive and the best way to do that is with goal-driven ways of action. The biggest obstacle to executing this goal driven way of action in a survival situation is a lack of attention (Leach & Ansell, 2007). There are two ways a person may react with attention to the environment in which the person is in, stimulus-driven and goal driven (Barrett, Tugade & Engle, 2004). It is common that the stimulus-driven attention is more dominant than the goal-driven during emergencies. This does, in turn, lead to people having a hard time having flexible interaction with the environment they are in, which puts them in even more danger (Leach & Ansell, 2007). This lack of flexibility might be because the responses that occur in the human body when exposed to danger is not adapted to interact with modern products and systems. As these reactions are a part of evolution and adapted to simpler less sophisticated systems that occur in nature (Rahman, Balakrishnan & Bergin, 2011).

When a person is in an environment that poses a threat to their life they get emotionally aroused which in turn accelerates the person’s cognition (Rahman et al., 2011). This affects a person’s orientation, decision making and actions, making them automatic. This emotional arousal might reside at three different levels, too high, too low and just enough (Rahman et al., 2011). If the levels are too low, this causes the person not to feel a sense of urgency which leads to slow decision making. Too high levels will cause impairment within the cognitive, perspective and physical abilities that in turn make it harder to orientate make decisions and act upon them (Rahman et al., 2011).

When the emotional arousal is just enough the person is at its best abilities and have the best chance of surviving (Rahman et al., 2011). This human reaction is however not adapted to modern systems and products, which may cause the reaction to be unsuccessful (Rahman et al., 2011). To work around this, products that are meant for emergency situations need to be customized for these reactions. To do this, the design needs to be based on direct perception and meaning is supposed to be found by perception and affordance and not by logical reasoning (Rahman et al., 2011).
Direct perception is the foundation for affordance (Gibson, 1986, as cited in O’Neill, 2008) and something that according to Rahman et al., 2011 a product that is supposed to be used in emergency situations is supposed to be based on. It is therefore vital to understand what the difference is between direct perception and ordinary perception as well as what it is, in order to use it in design.

Perception is explained by the Oxford English Dictionary (2018) as “The process of becoming aware or conscious of a thing or things in general; the state of being aware”. This process organizes the stimuli being received and gives it meaning, which makes it possible for a person to understand its surroundings and think (Bohgard et al., 2010).

The way a person interprets stimuli is based on two different factors, which is internal and external. The external factors are based on the stimuli received, how big it is, the contrast, intensity and how frequent it is. The internal factors are focused on the person perceiving the stimulus, on their previous experiences, needs, feelings, and expectations (Bohgard et al., 2010).

Gibson’s theory of direct perception is according to Rahman et al., 2011 that you can perceive the environment and its potential for action directly without involving memory or inferences (Gibson, 1986, as cited in Rahman et al., 2011). The critical part to take away from this definition is that the potential for action is what drives cognition and that it is not based on semantics or symbols (Rahman et al., 2011).

### 3.2.3.1. Affordance

Affordance is an aspect that Rahman et al. (2011) states are essential when it comes to designing products for emergency situations. The original idea of affordance had nothing to do with cognitive processing and thinking but is based on direct perception. Affordance is the relationship between perception of a person and the surrounding environment. Affordance is both objective and subjective, since it is the relationship between actual physical properties of the environment and the subjective experience of a person perceiving it (Gibson, 1986, as cited in O’Neill, 2008).

Affordance can be divided into two classifications, action and function based (Rahman et al., 2011). Where the action affordance is centered on the action capabilities of a person, such as grasp, pull. The function affordance is focused on the change that a system goes thru caused by the action. If a system or product has action affordance that correlates with its function the whole product is made more natural and less cognitive when it comes to information processing, which is more suited for products meant for emergency situations (Rahman et al., 2011).

An excellent example of a product that has both these aspects is a handbrake in a car, see Figure 15. The action affordance here is grabbing the brake and pulling it in the opposite direction of the moving car. The functional affordance is, however, stopping the car from moving forward. These two correlates here in a beautiful way as the action relates to the function. If you want something to stop moving what do you do. You move the object in the opposite direction until it stops, which is what you do when using the handbrake, making the action natural and intuitive (Rahman et al., 2011).

### 3.2.3.2. Perception

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![Figure 15: Example of how action affordance and functional affordance can correlate.](image-url)
The difference between direct perception and perception lies therefore in how we process the given stimuli. In ordinary perception two factors are taken into consideration external and internal (Bohgard et al., 2010), but in direct perception only external factor is used as the memory, and cognitive process is not involved (Gibson, 1986, as cited in Rahman et al., 2011; Gibson, 1986, as cited in O’Neill, 2008), see Figure 16.

3.2.3.3. Attention

Attention is what divides a human’s cognitive function in the current situation, and it revolves around two actions, shutting stimuli out and taking stimuli in (Bohgard et al., 2010; Raftopoulos, 2009). Attention is important as every situation that a human is in contains too many stimuli to process, which makes it essential to be able to select what stimuli to process and not. The stimuli chosen is often the stimuli that are relevant to responding to the environment (Raftopoulos, 2009).

The more the attention is divided the quality of understanding goes down (Bohgard et al., 2010). Attention has a strong relationship with perception as both are important and works together to make a person aware of its surroundings (Bohgard et al., 2010). In emergency situations one of the most significant issues concerning decision making is a lack of attention, as it makes people react inflexible with the environment (Leach & Ansell, 2007), it is, therefore, vital to understanding how a product can evoke more attention. To design for heightened attention three different principles can be applied:

- Minimizing time and effort, it takes to gather information
- Closeness
- Using multiple sources of information (Bohgard et al., 2010).

Another way of catching the users’ attention in a short amount of time is color, especially if the environment the product is in is busy with visual cues. This is due to specific colors awakes associations or forces the user to react (Sherin, 2011). When trying to attract attention with design saturated colors are the way to go, as they are perceived as exciting and dynamic (Lidwell et al. 2010) due to them being more vivid and brighter (Sherin, 2011). An important aspect to have in mind when using saturated colors is to be careful when combining them, as saturated colors have a tendency to visually interfere with each other and cause eye fatigue (Lidwell et al. 2010).

Figure 16: Cognitive functions for direct perception.
3.3. Vibrations

The environment in mines is heavily exposed to vibrations which cause the vehicle mount for fire extinguishers that are used in mines to be exposed to it in a significant amount. To understand how this may affect them a greater understanding of vibrations, what damage it causes and how to reduce it is essential.

Vibrations occur when a body is disturbed from its equilibrium position by an external force which forces the body to start oscillating (Schmitz & Smith, 2012). Where the amplitude is the size of the oscillation and the frequency is the number of complete fluctuations that is made within a second and is measured in Hz, see Figure 17. The frequency is although rarely as perfect as it is shown in Figure 17 (SveMin, 2005).

The exciting force that initiates the vibrations can be sorted into two categories based on their source, internal or external. The external is based on forces outside the system and does not occur based on the object and its function, whereas internal does (Karnovsky & Lebed, 2016).

There are three general types of vibrations based on how they are initiated; free vibrations, forced vibrations and self-excited vibrations. Free vibrations are when a body is affected by an external force, which causes it to move from its equilibrium position and vibrate. As there is no more external force after the initial one, the vibration eventually dies down due to damper. Which is when vibrations die down due to energy loss caused by friction, fluid motion, etc. (Schmitz & Smith, 2012).

Continuous applied external force causes forced vibration and after a while, the system will reach steady state, which is when the vibrating frequencies match the forcing one. If the forcing frequency is the same as the systems natural frequency resonance occurs. Resonance means that the system reaches its maximum magnitude. If the input force does not overcome damping, the vibration will eventually die down as it cannot sustain constant magnitude. When the continuous force eventually stops being applied to the system the vibration turns in to free vibrations and dies down. Self-excited vibrations are also called flutter, and it occurs when a steady input of force forces something to vibrate near its natural frequency (Schmitz & Smith, 2012).

3.3.1. Vibration reduction

Vibrations are often something that is undesirable as it can cause damage in materials such as fatigue damage (Karnovsky & Lebed, 2016; Ashby, Shercliff & Cebon, 2007) causing systems to fail (Karnovsky & Lebed, 2016). It is therefore essential to understand how to reduce them and what methods and approaches that can be used to reduce undesired vibrations within systems. These methods and approaches can be sorted into three different categories: Lowering the source’s vibrational activity, passive vibration protection, and active vibration protection. Passive vibration protection is based on damping the vibration with mechanical actions whereas the active vibration protection is based on a more automatic approach. Passive vibration systems can be made up by vibration isolation, vibration damping and vibration absorption (Karnovsky & Lebed, 2016).

![Figure 17: Overview of a simple oscillation](image)
One way of reducing vibrations in a system is by increasing the damping capacity of it, which is done by increasing the damping capacity or by increasing the stiffness (storage modulus). The loss modulus is the product of these two aspects which makes it a measurement for the damping of a material (Chung, 2001).

Typical materials used for damping is metals as well as polymers. Metals are used due to their capability to dissipate energy with movement in grain boundaries and dislocations during vibrations. This fact with the combination of metals having high stiffness gives them a high loss modulus (Chung, 2001).

A common material used for damping is also elastomers as they are very viscoelastic, unfortunately, are they not very stiff resulting in a low loss modulus. However, polymers both stiff and have high damping capacity, which results in a relatively high loss modulus (Chung, 2001).

**Vibration isolation** is based on introducing a new object into the system that weakens the connections between the system and the source of the vibrations. This might be done in the form of an elastic element (Karnovsky & Lebed, 2016), see Figure 18 object A.

**Vibration damping** is where a new object is introduced into the system that makes the energy in the system go down (Karnovsky & Lebed, 2016). One way of doing that is introducing a new material that absorbs the energy due to its high loss coefficient (Ashby et al., 2007), see Figure 18 object B.

**Vibration absorption** introduced absorbers into the system, which create additional excitation that counteracts the current excitation within the system (Karnovsky & Lebed, 2016), see Figure 18 object C.

### 3.3.2.1 Vibration damping

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### 3.3.2 Vibration measurement

It can be essential to understand what vibrations that affect the fire extinguisher mounted on a vehicle in a mine and measurements of these vibrations is a way to do this. An accelerometer often used as the sensor when measuring vibrations (Hanly, n.d.; SveMin, 2005). The accelerometer is placed on the vibration object directly and records the mechanical energy that affects it (Hanly, n.d.).

An easy way to use an accelerometer to measure vibration is a data logger. This is a small device that contains an accelerometer, data acquisition system, power, and memory, which makes it easy and convenient to use (Hanly, n.d.).

### 3.3.3 Vibration analysis

Vibration data that have been required needs to be analyze afterward to make it understandable. Hanly (n.d.) states that vibration analysis is done to predict and understand how a system that is being designed will react to a specific vibrating environment.

A vibration analysis often aims at identifying the frequency of the vibrations, this can be hard as most vibration is a combination of sine waves with different frequencies (SveMin, 2005; Hanly, n.d.). One way to do a frequency analysis is by transforming the data into a Fast Fourier Transformation (FFT) graph. An FFT is a summation of the sine waves present in a vibration oscillation and presents them by their frequency and amplitude (Hanly, n.d.).
3.4. Corrosion

A common material damage that occurs in mines is corrosion, which is a chemical attack on materials (Ashby et al., 2007; Johannesson, Persson & Pettersson, 2013) that causes irreversible damage (Ashby et al., 2007). Oxidation is the driving force behind corrosion as most engineering material is not an oxide and which is the most stable state for most elements to be. This causes materials that are used for engineering purposes to always strive to go back to its oxide state by oxidizing. This process is however prolonged but can be accelerated by some factors, such as heat, acids and fresh or saltwater (Ashby et al., 2007). As the environment in mines are acid due to mining sulfide ore and releasing sulfates (Naturvårdsverket, 1995) means that the corrosion process that takes place when a material is exposed to an acid environment is relevant and needs to be explored further.

Sulfates, nitrates, chlorides, and acetates (which are elements in some strong common acids) are more stable than the metal is. Forcing the metal to reacts with the acid and in the process releasing the hydrogen (Ashby et al., 2007). A corrosive environment, such as a mine, can negatively affect materials fatigue strength and cause corrosion fatigue (Johannesson et al., 2013).

3.4.1. Protection against corrosion

Even though corrosion sometimes can be seen as beautiful is it mostly seen as something undesired as it can have significant negative effects on materials (Ashby et al., 2007). To minimize the risk of corrosion, guidelines can be implemented.

**Sacrificial anode:** The principal of a sacrificial anode is that one material lies lower on the scale of reduction potential. This means that if two metals are connected in a corrosion cell, the material that lies the lowest on the scale is the one that is attacked and therefore protecting the other metal. This is, however, something to avoid if both metals used are of vital importance as this will make one of them corrode (Ashby et al., 2007).

**Plating:** This protection method is also based on the same principle as the one with the sacrificial anode. Except here a piece of metal is coated with another metal that lies beneath it on the scale. This means that the covering metal is the one that corrodes even if the plating is scratched and the metal beneath is exposed. One common plating type is galvanization, where zinc is used to coat iron or steel (Ashby et al., 2007).

**Coating:** Is the last resort and is used when the above methods cannot be implemented, and it entails separating the metals to stop them from forming a corrosion cell. This is done by coating the metal in paint or polymer powder coating. This method is however only useful for as long as the coating stays intact, as nothing protects the metal from forming a corrosion cell once it is exposed (Ashby et al., 2007).

3.5. Fatigue

Anything that is exposed to constant loads or vibrations are in the risk zone for fatigue damage. Fatigue is material damage that occurs during high stress that hardens the material and makes dislocation tangles to appear and accumulate. This is then the starting point for a crack that grows until the material reaches its limit and a fracture occur (Ashby et al., 2007). Fatigue damage is the most common damage that occurs on fire extinguishers in mines and is caused by the vehicle mount and vibrations in particularly. It is therefore vital to understand which vibration types that cause this and what can be done to avoid critical failure in materials.

Vibrations with low amplitude, such as acoustic vibrations do not cause any permanent damage to materials which high amplitude vibrations do (Ashby et al., 2007). High amplitude vibrations cause damage depending on how high the stress is and for how long it affects the system. If the system is affected by stress over the yield stress, it causes failure within a few cycles, known as low-cycle fatigue. The system can also be affected by stress that is lower than the yield stress but for an extended period with more cycles. The material will eventually break too, known as high-cycle fatigue, but only after being exposed to an extensive amount of cycles (Ashby et al., 2007; Johannesson et al., 2013).

3.5.1. Designing against fatigue

To make sure that a product is safe from fatigue calculations, strength and material data, as well as different design strategies can be used. Four different dimensional strategies can be applied when designing to avoid failure by fatigue (Johannesson et al., 2013).

**Infinite life** is used when the product is exposed to a large number of cycles and low stress, below the yield stress (Johannesson et al., 2013).

**Safe life** means that cracks are not allowed to start forming or propagate during the products lifetime (Johannesson et al., 2013).

**Fail-safe** introduces alternative load paths during static load, which means some local fatigue damages can be accepted (Johannesson et al., 2013).

**Damage tolerance** means that the product is designed to last for finite life as well as introduces alternative load paths (Johannesson et al., 2013).
A product's lifetime is described in number of loading cycles and is determined by stress amplitude, number of load cycles and notch, this relationship is described by Wöhler curves. The stress scale in a Wöhler curve indicates the stress and number of cycles required for it to be 50% chance of the material to fail, it can also be used for other probability scenarios as well. The fatigue limit is the stress amplitude at the number of cycles that is the limit life for a product. If the stress amplitude is less than the fatigue limit then, at least in theory, are there no limitations to its life (Johannesson et al., 2013).

Wöhler curves are used when the amplitude is constant, which rarely is the case in reality, where the stress amplitude is random, static and varied (Johannesson et al., 2013). This is the case when it comes to the stress that vehicles, particularly mining machines, are put under, and if the product were to be dimensioned after the maximum amplitude and a long lifespan then the product would be made too heavy and expensive. To design for these particular scenarios load collectives are used, which are gathered from measurements made in the field. The load collective is then used to either replicate the measured operating mode from the field for testing or calculate the product’s lifespan with the following function (Johannesson et al., 2013).

In order to understand the field of fire protection as well as the product better a knowledge of fire extinguishers is needed. In mines are powder fire extinguisher used and a powder fire extinguisher has nine main components that are important (Presto, n.d.), see Figure 20. The extinguisher agent tank on a fire extinguisher is always pressurized with about 7-15 bar. When using the fire extinguisher the foam exits via the standpipe, valve, hose and nozzle (Dafo ,n.d.). To release the foam, the pressure handle is pushed down towards the carrying handle. The safety catch protects against unintended release of the foam by being in the way in between the carrying handle and pressure handle and needs to be removed before use (Presto, n.d.).

The powder extinguishers power comes from negative catalysis where the powder cancels the combustion process. The powder also forms a protective coating on the object that is on fire and makes it harder for it to reignite (Presto, n.d.).
of fires. The different extinguisher agents are; powder, foam, water, carbon dioxide and liquid for grease fires. There are also different efficiency ratings when it comes to a fire extinguisher, which is regulated by a European standard, SS-EN3. Where a letter indicates what types of fire the fire extinguisher is suitable for, see Figure 19, and a number indicates the efficiency (Svenska Brandskyddsföretag (SVEBRA), 2016). A higher number means that the fire extinguisher is more effective. The fire extinguishers are also labeled with the amount of extinguisher agent that they contain, in kilogram or liter (Svenska Brandskyddsföretag (SVEBRA), 2016). There are recommendations on what fire extinguishers that is suitable to be used on vehicles within the mining industry, which can be seen in Table 1, (GRAMKO, 2016).
4. Method and implementation
4. Method and implementation

In this chapter, an overview of the different methods used in every phase of this project can be found. The overall process is also presented alongside an explanation of every phase. The chapter is sorted into the different phases and begins with explaining the design process as well as the planning process.

4.1. Process

A product development process is commonly separated into different phases to help practitioners in the field to structure their work and make it easier to manage (Buijs, 2003). The process is always a sequence of steps that make it possible to develop a product (Ulrich & Eppinger, 2012). How the process is divided can be varied, but the gist of it is always the same.

Some processes only emphasized the product development and cut out the production part, such as the process presented by Johannesson (2013). In Johannesson’s process, the product is customized at the end, based on the production method. A production plan is however not part of Johannesson’s process. Other differences that may occur in a design process is how the phases are divided. Some have the ideation and concept development as one single phase, such as Johannesson et al. (2013) as well as Phai et al. (2007). Whereas others like Wikberg Nilsson, Ericson & Törliind (2015) separate them into two different phases.

The product development process can be varied in many ways to fit the project at hand (Wikberg Nilsson et al., 2015). This means that the product development process can be customized and divided into different phases, if the core stays the same. The process used in this project has therefore been customized to fit the project scope. The process used is a combination of different processes, which together fit this project perfectly. The process is separated into four different phases: Context immersion, Ideation, Conceptual design and Detailed design, see Figure 21. This is similar to the process presented by Wikberg Nilsson et al. (2015). There is, however, an additional phase at the end focused on manufacturing adaptation and finalizing the product. This final phase is more like the final phase in the process explained by Johannesson et al. (2013). The process also takes a human-centered approach as the human factors will be taken into consideration in every step of the process. A summary of the different phases of the process is presented below.

**Context immersion** is the first phase and is focused on establishing an understanding of the problem and the different stakeholder’s views and needs.

**Ideation** is then used to come up with different ideas and rough concepts that solve the problem and satisfies the stakeholder’s needs.

**Conceptual design** is where the rough concept gets refined and where the final selection of one concept is made. This stage is very iterative and will mainly consist of prototyping and testing.

**Detailed design** is the final phase in this project, and the goal here is to complete the design of the product as well as adapting it for manufacturing. The end goal is to make a prototype that can be tested and evaluated by Boliden after the project.

![Figure 21: Process picture of the process used](image-url)
4.2. Project planning

It is critical to plan before a project starts as it simplifies the process. Some things are essential to decide during the planning portion of a project, such as objectives and aims, project scope, project organization, time plan and a budget (Johannesson et al., 2013). The scope, objectives and aims, project organization and the budget were the first things of the project to be defined. This was coordinated with both the university and Boliden to make sure everyone agreed.

Then the planning moved on to the process of the project and time management, where the overall process and deadlines were set up. After the process and the different phases were defined a rough list was set up that contained what needed to be done in the project. The moments were then sorted into which phase in the process and in which order they should be performed. Afterward were these moments planned in time, starting backward. This was done to make sure that the next moments had enough time to be executed well.

These moments were then put into a Gantt schedule, which is a time managing method. It shows the different activities in a project and when they are supposed to be performed in a perspicuous way (Johannesson et al., 2013). A simplified version of the Gantt schedule in this project can be found in Figure 22.

4.3. Context immersion

In this phase was an understanding of the problem at hand explored. To do so was initially a questionnaire, benchmarking and a literature review performed. This was then followed by a field study to one of Boliden’s mines, Renström, and Aptum’s workshop in Skellefteå. The field study consisted of semi-structured interviews with stakeholders as well as observations. The collected data from the above methods were then analyzed. Finally, was a product specification made before the Context immersion phase could end.

4.3.1. Mind mapping- planning

Mind mapping is a creative tool that is used to think outside the box (Anderson, 1993). That is why mind mapping was used to help kick-start the planning process in this phase.

A mind map starts with a statement in the center, which the whole map that revolves around. Initial thoughts or reaction to this statement is then recorded around it. They are then explored further with questions, thoughts, observations or answers. When all thoughts have been exorcised onto the paper, the map is studied for insights or underlying connections (Anderson, 1993).

Mind mapping were used to kick start planning, first was one mind map done over the process step ahead as a whole. The main thoughts or ideas were then made into separate mind maps were the subjects were explored further. These mind maps were then examined and structured. In this way was every thought and question that existed in the beginning of the process documented, sorted and made sense of. The mind maps were later used as a foundation when planning for interviews, observations, questionnaire and benchmarking.

4.3.2. Questionnaire

A questionnaire was used to gather information from safety workers in Boliden’s mines concerning the vehicle mount for the handheld fire extinguishers. This method was used as there are only a few safety workers in every mine making them hard to get a hold of. Questionnaires make this more manageable as they can be done at a distance (Bohgard et al., 2010).

A questionnaire is an information gathering method where the respondents answer questions in written form (Bohgard et al., 2010). It can be considered a structured interview done at a distance as the questions are pre-determined in detailed like a structured interview (Bohgard et al., 2010).
The questionnaire was sent out to four safety workers at Boliden’s mines electronically using Google Forms. The selection of which safety workers that would receive the questionnaire was done by the Boliden representative. The questionnaire was ultimately sent out to four safety workers that he thought would answer. The questions were focused in three main areas, which were; oversight of fire extinguishers, damages on fire extinguishers, and usage of fire extinguishers. To see the questionnaire in full see Appendix 1. A small sample group was used, resulting in the questions being more open to a larger extent (Cohen, Manion & Morrison, 2007). Open questions are also more suited when trying to get a grip of a particular situation and where answers are unknown (Cohen et al., 2007) which were the case here as well.

4.3.4. Observations

The interviews were performed at the same time as the benchmarking and the observation during a field trip to the Renström mine and Aptum’s workshop. This gave more information as the views of the respondents could be collected alongside the products discussed. The primary respondents were three service technicians that worked at Aptum, as they have a vast knowledge when it comes to fire safety in general and the vehicle mounts used in Boliden’s mines. Shorter interviews were also conducted with four mechanics that work in the Renström mine, where they fix broken machines and vehicle mounts for fire extinguishers among other things.

4.3.3. Semi-structured interviews

To get a better understanding of the environment that the product will be used in was observations performed. Observations were also done to get a better grip on the relationship between vehicle mount, fire extinguisher, and the environment. The observations included seeing and experience the rough environment in the mines. It also consisted of seeing the vehicle mounts suspended on the vehicles and how the surrounding environment affects them.

Observations are in short, a way to understand the user and the situation in which a product is used (Bohgard et al., 2010). The strength of observations lies in the fact that it is firsthand information and that some things that may be missed otherwise are picked up (Cohen et al., 2007).

4.3.3.1. Telephone interview

A telephone interview was conducted with one of the safety worker that answered the questionnaire. The interview was done to get more in-depth answers in some areas touched by the questionnaire. The questions asked were follow up questions on the result from the questionnaire. Most of them were however very similar to the ones asked in the questionnaire. Th big difference is that the answers given was more in depth and could be discussed. The primary focus was mainly put on questions concerning the use of the vehicle mount and important aspects of it.

Semi-structured interviews are based on both predetermined and open questions which makes it possible for both the interviewer and the respondent to steer the interview (Bohgard et al., 2010). It also gives room for the interviewer to ask follow up questions and scramble the order of the topics (Bohgard et al., 2010). This made it possible to change the direction of the interview when some areas were discovered to be more critical and relevant than others. The areas that were important to cover within the subject were predetermined before the interviews for them to not get skipped or forgotten during the interviews (Bohgard et al., 2010), see Appendix 2 for pre-structured areas for investigation and questions used.
Before the observations were performed, a few areas and question that should be answered by the observation were determined. These areas were in the form of weight, size, and form of the vehicle mount and the fire extinguisher used. They also consisted of how and where they were suspended on the vehicles as well as the contact surfaces of the vehicle mount and the fire extinguisher, see Appendix 2. The observations were then performed at the Renström mine, see Figure 23, as well as the workshop of Aptum. Observations about how easy it was to suspend and release the fire extinguisher were also made, primary at the Aptum’s workshop.

4.3.5. Benchmarking- vehicle mounts for fire extinguishers

Benchmarking was used to get a better understanding of the different types of vehicle mounts for fire extinguishers that already exists on the market. Benchmarking is used to compare features or components of a product with competing products to improve (Pickering, & Chambers, 1991). It is used to see how a company’s product performs against a product that excels within that area that is looked at, to sort out why that is and how to change it (Pryor, 2007).

The primary focus was put on mounts for vehicles as they differ from ordinary fire extinguisher mounts. The difference lies in the fact that they are not stationary which makes the demand for the fire extinguisher to be held in place greater. Although ordinary mounts were also investigated to understand the difference between the two.

The benchmarking was performed in two steps. First, an online research where different industries and forms of transportation were looked at. The second part was done during the visit to Aptum’s workshop and Boliden’s mine Renström. Here were the different vehicle mounts that were used in mines identified and compared. Different areas of the vehicle mounts that were problematic were also identified to see what can be improved upon. Other areas that the vehicle mount was used in were also visited to see how it worked in that environment.

4.3.6. Literature review

A literature review is used to gather knowledge within an area or to see what is known within an area already (Bohgard et al., 2010). It consists of searching for already published scholarly articles, books (Bohgard et al., 2010; Milton and Rodgers, 2013), checklists, standards or guidelines (Bohgard et al., 2010). This can be done through different databases regarding different areas (Bohgard et al., 2010).

In this literature review was the LTU library’s search engine used, as it contains many different databases. It also makes it easy to make specialized searches were words can be sorted out or combined. The International organization of standardization website and their search engine was also used, when looking for standards and definitions. The areas that were researched in this literature review were; industrial design engineering, safety and design, and relevant material damages and emergency reactions. When searching for information within these areas were peer-reviewed works, and standards first looked for. However, if desired information could not be found through them, books and other articles were used instead. For some areas, such as fire safety, was published guidelines and professional recommendations used.

The search words used, were: Vibrations, forced vibrations, color, semiotics and product development, emergency situation, cognitive functions, human behavior, safety, design, fire extinguisher, usability, product development and industrial design engineering.

4.3.7. Analysis

When the data from the methods mentioned above had been gathered was it a need to analyze. This was done to see what data was gathered and to make sense of it. The first step was to sort the material that had been gathered. This was done in different categories which ranged from the different vehicle mounts to the fire extinguisher used. This gave a first overlook of all the information that belonged to a particular area. This made it easier to use the data in the different analysis that followed.

4.3.8. FTA- Fault tree analysis

Fault tree analysis (FTA) was used to analyze the different types of vehicle mounts that was used in Boliden’s mines. The FTA made it easier to see what correlations that exist between different errors. A FTA is a logical analysis that is done to establish these correlations in systems and products (Bohgard et al., 2010; Johannesson et al., 2013). It does so by visualizing the errors and how they are connected (Bohgard et al., 2010; Johannesson et al., 2013).

The FTA starts with one top error or event that is then broken down and connected to smaller errors or events that must occur for the primary error to happen events (Bohgard et al., 2010; Johannesson et al., 2013). The connections are based on logical gates that are used to show the correlations between two errors or events (Bohgard et al., 2010; Johannesson et al., 2013).
A FTA was done of the vehicle mounts that were identified during the benchmarking. The top error was “Fatigue damage occurs”, it was then broken down into smaller errors that had been observed or had been informed about during the interviews.

4.3.9. Product specification

A product specification specifies what a product is supposed to do and can be used to develop solutions and to evaluate them later (Johannesson et al., 2013). This was the main reason why a product specification was established at the end of this phase. To structure the product specification, the different criteria were sorted into functions and limitations, as well as demands and requests. Were demands being something that have to be fulfilled whereas requests is something that can be fulfilled to different degrees and is therefore equipped with a weighting factor between 0-4 (Johannesson et al., 2013).

Here the FTA and the gathered information from the interviews, literature review, benchmarking, questionnaires and observations were used as a foundation to develop the product specification. Firstly, were the primary function of the vehicle mount identified and limited. Moving on to environmental factors, regulations and basic user needs later. The weighting factor was primarily based on the data required earlier and was balanced between how much it was a vital part of the function and if it would affect the stakeholders positively or negatively if it were fulfilled. The product specification was then discussed with both the supervisor from Boliden as well as Svekon to make sure no aspects were missed and not taken into consideration.

4.4. Ideation

The ideation process was mainly conducted alone by the project member. The primary method used was mind mapping. However, was ideas and inputs from others brought into the individual ideation process through the workshop and directory method. Finally, were the ideas made into concepts using a morphological matrix. The concepts were then developed further before evaluating them.

4.4.1. Sketching

Sketching is a fundamental aspect of the ideation in a design process (Onkar & Sen, 2010). Onkar & Sen states that sketching is most commonly used in the early stages of a design process when ideas for concept are supposed to be generated. It is common due to its characteristics is well suited for this stage of the process as it is intuitive, easy to use in order to generate ideas, explore them in detail as well as communicating them (Onkar & Sen, 2010), as the common expression states “a picture says more than a thousand words”.

These were the reasons why sketching was used as an integrated part of the ideation process in this project, as it makes the process of generating ideas easier and more understandable.

Sketching was used in the early stages of the ideation phase to visualize ideas and to explore them in every method used. In the later stages where sketching used to explain the final concepts. Making it easier to communicate how they are supposed to work with different stakeholders.

4.4.2. Mind mapping- ideation

Mind mapping can be used to organize and understand a problem better (Martin & Hanington, 2012), which is the main reason why this method where the first initial method used during ideation. Mind mapping is a visual tool for thinking. This makes it ideal to generate ideas for problems that have many related pieces, as it can be used to explore thoughts and connecting them with one another (Martin & Hanington, 2012).

The process of making the mind map was the same here as when it was used in the Context immersion, see 4.3.1. Mind Mapping- planning. An initial function, problem or solution where put in the center of the paper and then was other thoughts and solutions put around it. Instead of just using words was small sketches made to explain ideas better and to explore them more. If a mind map generated an exciting thought or a new idea that needed to be explored further a new mind map with that idea in the center was started. If a mind

Figure 24: Picture of ideation using the method mind mapping.
map stopped being interesting or new ideas were not being generated anymore, and the mind map was left alone for a while. The mind map was then reexamined later where new ideas might be generated and added. This process of creating new mind maps and adding to old ones was a way of simulating brainstorming. Even though it was done alone, as the old ideas had a way of kick-start new ones and so on.

The mind map turned out to be a great tool to generate ideas when ideating alone. That is why the method was used throughout the ideation process, see Figure 24. Where the other method served as inspiration for new mind maps. The ideas from all the mind maps were then looked over and used in the morphological matrix to generate concepts.

4.4.3. Directory method- inspiration
A directory method is used to gather inspiration in an ideation process. It consists of information gathering by searching for solutions to a similar problem (Johannesson et al., 2013). This can be looked at as a kind of inspirational benchmarking as the fundamental principle is the same. The inspiration can come from patents, folders, journals and art (Johannesson et al., 2013).

This method was used to get some inspiration on how to reduce vibrations. It was also used to explore how to release something quickly. The primary search was focused on finding different ways to do it and how it has been implemented in products. The obvious start was other already existing vehicle mounts for fire extinguisher. This had already been looked at but where now explored on a more detailed leveled by looking at different patents within the area. The patent search was then expanded into a generic level where pictures of different products and categories were examined.

At the end of the directory method was the gathered information used as inspiration when making mind maps. This was done straight after the search was ended to have all the ideas and inspiration still fresh in the mind. Words like “quick release” and “dampening whole system” were used as centered words in these initial mind maps.

4.4.4. Workshop
A workshop is a creative session were different participants work together. This is an excellent method for getting more ideas and views into the design process from other sources than the project team (Martin & Hanington, 2012). As this project is executed by one person with a few supervisors the importance to get others point of views in was important. This was the main reason why a workshop was used.

The workshop was executed with three engineers from SveKon as well as a student within industrial design engineering from Lindköping university (that was also doing her thesis work at SveKon). First was a review of the gathered material from the context immersion presented toward the group. This was done as none had any earlier in-depth knowledge of the problem at hand. A short question session was then held to discuss the problem and the different aspects of it.

When everybody understood the problem, a brainstorming session was held where everyone gave different suggestions on how the problem could be solved, bouncing off each other’s ideas. The problem that the brainstorming was focused on was the breaking of the straps and if there are other ways to suspend the fire extinguisher then the current one. A fire extinguisher was brought along as a prop to help the discussion forward. The fire extinguisher was used to explain ideas as well as ignite new ones.

4.4.5. Sorting of ideas
There was a need to sort through the ideas before trying to combine them as there were many ideas that had been generated during the ideation. This was done by looking over every mind map that had been made. First were the ideas that were not plausible sorted out. The ideas that were similar or based on the same concept were then sorted together.

This gave a good overview of the range of the ideas generated. Some areas that were underdeveloped could now be identified and explored further, by making more mind maps. When all areas felt well explored and developed the groups were looked over again. The ideas that felt underdeveloped or partly done were put in the morphological matrix. Whereas some ideas were left alone as they already were developed into functioning concepts.

4.4.6. Morphological matrix
A morphological matrix is a concept generating method where different ideas are combined to make one total solution (Johannesson et al., 2013). This method was used to combine different ideas that had been generated earlier into concepts.

The way of doing this is by using a matrix where sub-functions are listed on the vertical axis of the matrix, and the solutions for every sub-function are then listed on the correspondent horizontal axis. These different solutions are then combined to make one total solution that solves all the sub-functions, this can generate unique concepts as well as a big quantity (Johannesson et al., 2013).
4.4.6. Evaluation

After the development of ideas into concept was it a need to evaluate them to decide which ones should be chosen for further development in the next phase. This evaluating process was done in two steps one using the product specification and one using the stakeholders.

4.4.6.1. Evaluation and screening with the product specification

The evaluation process of concepts can be made with different methods and in different stages. The first evaluation of the concepts should be done after the ideation process to sort away concepts that do not fulfill set requirements (Johannesson et al., 2013).

Concepts that is not plausible is also sorted away. This can be done by using the product specification and common sense (Johannesson et al., 2013).

The surviving concepts are then developed further in between every evaluation stage, which uses different evaluation methods (Johannesson et al., 2013). A screening with the product specification was used directly after the ideation. First was the concepts that were not realizable sorted away, as the morphological matrix can produce a lot of those, before moving on to screening with the product specification.

Sorting away the non-realizable concepts were done by eliminating the concept that was made up of conflicting subfunction, where one canceled out the functional aspect of the other one. When the non-realizable concepts had been sorted out the evaluation continued with the help of the product specification. Some demands in the product specification were overlooked as they could not be applied in this stage, such as the demand for resilience against corrosion as that is a material demand and no material selection had been made for most of the concepts. The demands were then used to screen the concepts; all concepts that did not fulfill a demand were eliminated.

4.4.6.2. Stakeholder evaluation

Before the phase could be ended was a short evaluation workshop held with some stakeholders. The stakeholders that were present was a Boliden representative, an Aptum representative as well as a representative from SveKon. The workshop revolved around the four concepts that were left, and the goal was to get the stakeholders views and input on them before starting further development. The evaluation workshop started with a short presentation of every concept and how they were supposed to work. After
4.5. Conceptual design

The conceptual design phase was a very iterative phase that had its prime focus on prototyping and testing the concepts. A mock-up would first be made and then evaluated with different tests, which were analyzed. This resulted in some changes and eventually another mock-up that also went through testing, this circle of prototyping and testing is described by Hallgrímsson (2012), see Figure 25. Parallel with the prototyping process was a linear process made for the third concept, which was more focused on gathering vibration data and finding the right kind of dampers.

4.5.1. Prototyping

Prototyping is when you use different models, materials, and methods to try to get a better understanding of a solution and determine what works and what does not. It is an excellent way to test different variations of a solution as well as different design aspects of it. The overall goal of prototyping is to explore a problem and to evaluate alternative solutions for it (Wikberg Nilsson et al., 2015). A vital aspect of the prototyping process is iterating. Every prototype made gives valuable information about what works and not. That in turn gives way for other prototypes where the new knowledge can be explored further (Hallgrímsson, 2012). This circle of exploration with different iterations was used throughout the conceptual design phase, first were small sketches of the prototype done before they were made and evaluated.

Prototypes can be made in many different ways, sizes, and finish. A prototype can be done in cardboard, paper, clay or by 3D-printing. A prototype that is made to test functionality or ergonomics is a mock-up and is most commonly used early on in the design process (Wikberg Nilsson et al., 2015). Mock-ups where the only type of prototypes made in this phase of the design process, as the functionality of the concepts was in focus here. The mock-ups were however made in different ways and materials, ranging from cardboard to 3D-printing.

Concept 1: Functionality prototyping and testing

For the first concept was two different version of the concept tested to decide which one worked the best. Mock-ups were made of both versions using cardboard, metal wire and hot glue, which were tested and evaluated. Three iterations of both mock-ups were made before a decision of which one to continue with was decided.

The two versions were evaluated against each other using a pros and cons list, which Johannesson et al. (2013) states are an easy and common method used for evaluation in this part of the process. The winning version where then further worked on by making a CAD model with some small test. Three iterations were made before the functionality were defined enough and working.

Concept 2: Functionality prototyping and testing

For the second concept was only one version of the concept tested and evaluated. A CAD model was generated from the beginning due to the function of the mock-up being based on the material being harder than cardboard and therefore needed to be 3D-printed. There was three different iteration made in CAD with tests and changes before it was 3D-printed. The 3D-printed mock-up where then assembled and tested, where notifications for change were made.

4.5.2. Vibration protection

The result from the literature review in context phase was reviewed and analyzed to determine what kind of vibration protection method that should be implemented in the third concept. The different valid options were then discussed with the supervisor from SveKon. The discussion was focused to see how they could be implemented in the best way and what problems that could appear. One vibration protection method was chosen and a short brainstorming session alone was made to see how it should be implemented.
4.5.3. Benchmarking - vibration protection product

A short benchmarking of products with a similar way implement vibration damping to Concept 3 was done to see if any products exists. The benchmarking focused on products that used the same vibration protection method and had a similar execution as the concept. The benchmarking was done in order to see if a product that already existed could be implemented instead of developing a completely new, as that would be extremely costly.

4.5.4. Vibration measurements

Vibration data was required to determine if the final concept would be able to survive the conditions in the mines as well as get a better understanding of the mining conditions. Due to time limitations was the task of recording the vibration data outsourced to an entrepreneur that works in the Garpenberg mine. Instructions were sent to the entrepreneur, a short conversation via phone was also held to ensure nothing was unclear, the instruction can be found in Appendix 3.

The vibration data collection was done with a data logger from MIDÉ Technology called Slam Stick C, see chapter 3.3.2 Vibration measurement for explanation what a data logger is. The data logger was put on the front of the fire extinguisher located on a vehicle in the mine, see Figure 26. The data logger was then started and recorded for 1.5 hours. The data logger was set to record frequencies lower than 3600 Hz, which was recommended in the manual when the frequency range was not known beforehand. Two separate tests were done on three different vehicles to give a range of measurement, which SveMin (2005) recommends you do, as this gives an assurance that the data collected is not from unusual conditions. See appendix 3 of full list of vehicles tested.

4.5.5. Vibration analysis

The vibration data collected was then analyzed using Slam Stick Lab 1.8.0, which is a free program that comes with the data logger used. Every file was first open and reviewed in a time-acceleration graph, where interesting areas were identified, which could be steady state vibrations or impacts. These areas of interest were then analyzed further by making a FFT graph of a time period on every axis. The different FFT graphs that were produced was then compared and analyzed before some conclusions were drawn.

4.5.6. Pugh's relative decision matrix

The second evaluation of the concept was made after they had been developed further, which Johannesson et al., 2013 recommends doing. The method used to evaluate the concepts the second time was Pugh's relative decision matrix, as explained by Johannesson et al., (2013). It was used as it gives a good understanding if a concept is better than a reference and how it compares in different areas. It also gives a good overlook of a concept strengths and weaknesses, which can be useful when deciding as well as what needs to be improved when further developed.

Pugh's relative decision matrix is based on comparing how concepts perform within a specific criterion against an already existing product that is relatively similar. The product reference used to evaluate the concepts was the standard holder presented in the Context chapter under section 2.3. Vehicle mounts. Johannesson et al., (2013) suggests that the selection criteria used in the matrix should be based on the product specification, but that they should be simplified and separated into sub-criteria if the demand is complex. This was done using the demands that were applicable.
4.6. Detailed design

In this phase was the further development of the last concept done, which consisted of finalizing the functionality, adapting the design for manufacturing, developing technical drawing as well as producing a fully functioning prototype for some final usability testing.

4.6.1. Functionality prototyping and testing

After the conceptual design phase was mainly three functional aspects of the vehicle mount not finished, the locking mechanism, the angle of the groove in the male half and the handle for the safety pin. In order to finalize these aspects was some further prototyping and testing done. The prototypes were done by 3D-printing, see Figure 27, they were then evaluated and tested.

4.6.1.1. Angle of groove

The angle of the groove in the male half of the quick release mechanism needed to be tested to determine if it worked the way it should. A 3D-print of the quick release mechanism was made to test this. The 3D-print was assembled and tested, before another iteration was made. There were ultimately two iterations made.

4.6.1.2. Locking mechanism

The first step was to research different solutions for locking a pin in place. A brainstorming session was then done with the supervisor from Svekon to see how the solutions could be. The most important thing was for the locking mechanism to keep the safety pin in place. The different locking mechanism was also evaluated against how they would affect the action affordance of the safety pin. Because it is essential for the action affordance to be the same as the functional affordance. Ease of use was also taken into consideration as some locking mechanisms seemed to be difficult to use, which is a big downside and dangerous in an emergency. One solution was chosen and implemented on the vehicle mount, it was also tested and fine-tuned using a 3D-printed mock-up.

4.6.1.3. Handle

It was mainly the shape, size and position of the handle that needed to be decided and developed further. First was different alternative of handles sketched, where the shape of it and how it could be attached to the safety pin was in focus. Then was rough CAD-models made of some of the handles based on the sketches which were put into the CAD-model of the rest of the vehicle mount. This was done to see how visible the different option was in the construction, before one was chosen.

The handle needed to show the user in what direction the handle should be pulled which means it needs to mediate this with its design. To explore what design would do this was small and simple sketches from the
4.6.2. CAD

CAD-models of every component of the vehicle mount were made in the program Solidworks 2016. These CAD-models were a continuation of the ones used in the previous phase for the mock-up. Now other dimension was added and holes for assembly were also put in.

4.6.2.1. Manufacturing adaptation

As the final prototype in this project was intended to be outsourced to real manufacturers was there a need to adapt the design of the product for the intended manufacturing method. The intended manufacturing method was water jet cutting. It is an easy and cheap way to manufacture small batches and was suited for plastic, which was the intended material. These two parameters were used when going through each component when adapting them for manufacturing. Here was the supervisor from SveKon consulted on every component as he has the experience to know what would work and not when it came to manufacturing.

4.6.2.2. Slimming down the design

As some components of the vehicle mount are supposed to be placed permanently on the fire extinguisher is it essential for them not to be too bulky and take up too much space as this could affect the use. To make sure this was not the case was some changes made to the components that are placed on the fire extinguisher making them smaller and thereby less protruding from the fire extinguisher.

4.6.2.3. Technical drawings

A technical drawing is a document that should contain everything needed to manufacture a component. It explains the shape, size, material, finish and tolerances of the component and should be understandable without looking for information elsewhere (Simmons, Maguire & Phelps 2012). It is essential to make technical drawings for the components that will be send to an external manufacturer. The technical drawings were made using Solidworks as well as templates from SveKon. This was done to make the process more manageable as well as making them easier to understand by the manufacturer.

Finally, was anthropometric measurements of the hand used to scale final CAD-model to the right size. The CAD-model of the rest of vehicle mount was also used to size the handle, to make sure it was visible from behind the fire extinguisher.

The final version of the CAD-handle was then 3D-printed and tested with the safety pin to give a realistic feeling when testing it. Here was the size, the grapple and the overall feeling of the handle tested and evaluated.

![Figure 28: Sketches done during linework analysis of handles.](image)
4.6.3. Material selection

The material selection was started with a short literature review to see what materials that had the capabilities to reduce or dampen vibrations. A discussion with the SveKon supervisor was also held to discuss the different options and how that would affect the manufacturing price as well as the construction. After a material type had been decided was a discussion with the SveKon supervisor held to decide what specific material should be used.

4.6.4. Vibration analysis

Initially was the intention to do a full dynamic vibration analysis in the CAD program NX 12, this did however turn out to be too complicated to be performed within the timeline given. Instead was a more straightforward frequency analysis performed. The analysis focused on the calculation of the natural frequency of the product to make sure it was not the same as the common frequencies found in the earlier vibration analysis. Because if the natural frequency and the frequency of the forced vibration applied to the system is the same than resonance will occur (Schmitz & Smith, 2012).

Calculating the natural frequency by hand is possible, it is however very complicated due to the calculation of the stiffness, which is one of the fundamental parameters in the formula. Instead of manual calculations was the natural frequency calculated using NX 12.

First was a simplification of the model made to make the calculations easier. All the components that are supposed to be bolted together to one solid part were modeled as one singular object, very similar to the first CAD version with three components. Small radii were removed as this would affect the FEM mesh later.

A FEM and simulation was made using the simplified Cad model, the simulation set up used was SOL 103 real eigenvalue. A FEM mesh was created with material properties that were the same as the real material before constraints were applied. To simulate the fire extinguisher was a few constraints that gave stiffness, weight and that constricted the movement applied to the part of the mount where the fire extinguisher would be connected. When the different components were constrained correctly was the simulation solved. The result from the solution was then compared to the result of the earlier vibration analysis done before any conclusions could be drawn.

4.6.5. Final prototype

The technical drawings were sent to a manufacturer that produced a full functioning final prototype. This prototype was assembled, see Figure 29, at arrival and then shortly evaluated. Some small alteration had to be made to make it possible for assembly. Moreover, were notifications made of changes that could be implemented in a future iteration.

4.6.6. Usability testing

The final prototype was then exposed to a short usability test. This was done to see if the prototype was easy to use and if vital errors would occur. The test was performed on five people. It consisted of the test subject removing the fire extinguisher from the wall. Every participant got the same instructions before performing the short test.

The aspects that were evaluated during the test was errors, satisfaction, and learnability, which is three of the five usability aspects that Nielsen (1993) mentions. These three was the ones examined as the other two are related to usage over time, which is hard to evaluate after one use. The satisfaction of the use was examined by asking the participants short questions about the use directly after the test.
4.7. Method discussion

Below is a discussion about some of the methods that was fundamental to the process. It discusses their role as well as the way they were implemented and how this could affect the result.

4.7.1. Context immersion

The data collection in the Context immersion phase was a fundamental stage in the project as it builds the foundation and decided the direction in which the project would go. It was therefore crucial that the data and information that was gathered was genuine and authentic. To establish that this was the case was different methods of data collection used that complement each other. It was also essential to talk to as many different stakeholders as possible as all of them could have different and valid points. During the field study was both mechanics that work in the mines as well as service technicians interviewed, whereas safety workers were questioned via a questionnaire. All stakeholders were asked similar questions that were tailored to their area of expertise to get different views on the same area. This gives the data more validity as it comes from very different sources.

As mention were most stakeholders interviewed such as mine mechanics, service technicians, and safety workers, however, one crucial stakeholder was not interviewed, the user. The lack of interaction with the user was due to lack of time for both parties, which made a meeting challenging to set up. This lack of interaction with the user might have effects on the results as the understanding of them is such a fundamental part of this design process. As this understanding could not be made in person was it instead made on a theoretical basis. By understanding general emergency reactions was the user included. This effort might have closed the gap of knowledge somewhat, but it is hard to know.

4.7.2. Benchmarking

Benchmarking was done in several different instances in the process, which have had an enormous effect on the result. The use of benchmarking throughout the process made it possible to see what had been done in an area when an idea or solution presented itself. This gave both inspiration to continue when significant faults were noticed or incentive to stop when it already had been done very well. If the benchmarking had not been done continuously could the product presented in the end would not be as good and fit the hole in the market as well as it does.

4.7.3. Ideation

To make the ideation process as successful as possible was different methods used. Firstly, was a workshop held to give different views and ideation into the ideation that was performed by one person. This new insight and ideas kept the ideation alive longer as well as making it more fruitful in the end. The use of a method such as mind mapping that might not be a very conventional ideation method but that is suited for use by one person also proved successful as well.

4.7.4. Vibration analysis

The different vibration analysis’s that have been done during both the conceptual design phase as well as the detailed design phase can have affected the final result. Especially the final vibration analysis of the natural frequency of the product. The result may differ from the result that could have been produced in another CAD program that analyzes the natural frequencies, but as NX was the program available was it the one used.

The way that the different components was constrained in the CAD program could also have affected the result, as it might not have been done correctly and do therefore not mirror the reality in the right way. The choice of analyzing these specific parts and the simplified version of them can also have affected the result, but at the time was limited was this the best way to do it, even though it could have affected the accuracy of the result produced.
5. Results
5. Results

In this chapter will the result of the different phases of the project be presented. The final result of the whole project will be presented at the end in detail.

5.1. Context immersion

The main portion of the result of the context immersion is presented in the Context chapter of this report. However, the benchmarking of other vehicle mounts for fire extinguisher beside the three used in mines is presented here as well as one ordinary mount to show the difference that exists between the two, the first draft of the product specification is also presented.

5.1.1. Benchmarking

There are different mounts used for fire extinguisher depending on where it is supposed to be suspended. If it is supposed to be stationary is it only suspended by a hook in a grapple that is on the fire extinguisher often with extra support to keep it straight. If the fire extinguisher is supposed to be suspended on an object that is movable the mount changes as the fire extinguisher needs to be more secure to make sure it does not move around and get damaged. To do so, the fire extinguisher gets suspended by straps instead of hooks and dampers are installed to avoid damage, caused by contact between two surfaces for an extended period.

5.1.1.1. Ordinary mounts

As mentioned above, are fire extinguishers that are stationary suspended by a hook and kept straight by extra support. This extra support comes in two different forms, one that is just a long metal back with two supporting arms protruding from the back. The other one comes in the form of two skinny legs that are equipped with rubber dampers at the ends, see Figure 30. There might be some variation in how many supporting legs or arms there is and how many hooks are used.

There are also other mounts for stationary fire extinguishers that are more like the mounts used for vehicles. These have a supporting shelf at the bottom and a clamp at the top that holds on to the fire extinguisher. They are however mostly made for smaller sizes of fire extinguishers, such as 2 kg, which is more commonly found in homes.

5.1.1.2. Vehicle mounts

No vehicle mount is specially made for mining condition, and these mounts are used on a wide variety of vehicles. They are used on everything from city buses, commuter trains, boats used by the navy, movable staircases used for airplanes to ordinary trucks, see Figure 31.

Figure 30: Ordinary mounts.
Most of the vehicle mounts for fire extinguishers meant for vehicles looks and work in the same way as those used in the mine. There are however some variations that exist besides those which differ slightly. The thing that differs the most is what clasps are used, and some use ordinary belt buckles and other use some variation of the standard clasp that is mostly used. It also exists some vehicle mounts that use metal straps instead of fabric. Another thing that can vary is the form of the mount, the most common change is a variation of type three where the ring has been replaced by a supporting shelf instead. These variations are mostly used for a smaller fire extinguisher, such as 2 kg.

5.1.1.3. Differences
The main differences that have been identified are the use of the grapple on the fire extinguisher as well as straps used for securing the fire extinguisher. The straps are a distinct difference as the fire extinguishers suspended on moving objects needs that extra security to stop them from falling off. The grapple, on the other hand, could maybe be utilized in a better way on vehicle mounts as they exist on all fire extinguisher even those used on vehicles. The grapple is also often in the way on the mounts meant for vehicles.

5.1.2. Fault tree analysis- FTA
The result from the FTA showed that the main issues with the vehicle mount today is that the mount is exposed to a significant amount of vibration. This causes the mount to brake and therefore damage the fire extinguisher. This can be seen in the FTA in Appendix 4. The problem is that the vehicle mount is not designed with a failsafe mindset, which causes the failure of the mount to have severe consequences. The most common failure to occur with the vehicle mount is that the straps brake, as mention in more detail in the Context chapter. This failure causes the
fire extinguisher to move around and wear against unintended areas of the mount, that the designer has not predicted and therefore have not equipped with dampers. This causes damages to the fire extinguisher as the vehicle mount brake, but if the failure could be predicted the consequences of them could be lessened by designing for them.

5.1.3. Product specification

Every demand and requirement in the product specification is derived from the information gathered during the Context immersion. Some demands and request are derived from regulations and others from environmental factors, the whole product specification is presented in Table 3.

Table 3: The product specification

<table>
<thead>
<tr>
<th>Demands</th>
<th>Requests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Function</strong></td>
<td></td>
</tr>
<tr>
<td>★ Be able to suspend a fire extinguisher of the type 55A 233BC, with 6 kg extinguishing agent</td>
<td>★ The fire extinguisher should be removable from the vehicle mount</td>
</tr>
<tr>
<td>★ The vehicle mount should be able to suspend on different vehicles</td>
<td>★ The vehicle mount shows that the fire extinguisher is damaged (1)</td>
</tr>
<tr>
<td><strong>Limiting</strong></td>
<td></td>
</tr>
<tr>
<td>★ Be able to carry at least 8.9 kg. Which is the weight of a 55A 233BC fire extinguisher with 6 kg extinguishing</td>
<td>★ The information text on the fire extinguisher should not be covered by the vehicle mount</td>
</tr>
<tr>
<td>★ The vehicle mount should be adaptable to other sizes of fire extinguishers</td>
<td>★ The vehicle mount should be able to suspend different brands of fire extinguishers</td>
</tr>
<tr>
<td>★ The fire extinguisher should not be removable when the vehicle is in service</td>
<td>★ The fire extinguisher should be removable from the vehicle mount</td>
</tr>
<tr>
<td>★ The materials in the vehicle mount should be suited for mining conditions, most important is that it should not corrode.</td>
<td>★ The vehicle mount should dampen vibrations in some way</td>
</tr>
<tr>
<td>★ The shape of the vehicle mount should not facilitate corrosion. It should not have gaps where acid water could seep into</td>
<td>★ The fire extinguisher should be held tightly by the vehicle mount to avoid fatigue damage</td>
</tr>
<tr>
<td>★ The vehicle mount should not have the same natural frequency as the frequencies that the vehicle transfer to the mount</td>
<td>★ The fire extinguisher should be held tightly by the vehicle mount to avoid fatigue damage</td>
</tr>
<tr>
<td>★ The materials in the vehicle mount should be suited for mining conditions, most important is that it should not corrode.</td>
<td>★ The action affordance should be the same as the functional affordance</td>
</tr>
<tr>
<td>★ It should be easy to understand when using for the first time</td>
<td>★ Errors should be rare when using the vehicle mount and should not be fatal</td>
</tr>
</tbody>
</table>

*Components should be easy to replace if they break (4)  
The vehicle mount should be able to suspend on different vehicles (3)*
5.2. Ideation

The context immersion had resulted in a better understanding of the problem with the vehicle mounts that is currently being used in Boliden’s mines. The main thing that had been discovered was that vibrations mainly caused the damage of the fire extinguishers in combination with failure of the mount, which was caused by vibrations. There are three possible ways of solving this problem which is:

- damping the vibrations transferred to the vehicle mount
- changing to a more durable way of suspending the fire extinguisher
- changing the how the straps currently is attached to the rest of the vehicle mount.

These three areas were the focus of the whole ideation. The primary focus was eventually shifted to trying to come up with a more durable way of suspending the fire extinguisher as the other two options quickly were depleted or solved.

5.2.1. Mind mapping- ideation

During the ideation process was a total of 22 mind maps made with an average of two to three well thought out ideas per mind map, see Table 4 for what areas the mind maps were in. Most of these ideas were similar but with some variations and some were further development and expansion of another idea. The focus of the mind maps shifted after use of the directory method as well as after the workshop. These methods influenced and inspired the thought process.
There are a few different patents for vehicle mounts for fire extinguishers, and most were similar to the mounts used today but with different variation in locking mechanisms. There were four patents found for a quick release mechanism. One was based on short arms holding the fire extinguisher which could be easily opened by pulling on the fire extinguisher. Another was based on having to halves fit together with a double pin connected to a handle, this one was somewhat like most ideas of quick release done so far.

The widen internet search, resulted in a lot of inspiration when it came to the quick release on a fire extinguisher. This was an area of the market that had been missed in the initial benchmarking in the context immersion phase. The inspiration and the new-found solution was then utilized and explored further in mind maps, see Figure 32.

5.2.2. Directory method- inspiration

The result of the workshop was 13 number of ideas, a list of the ideas with explanations can be found in Appendix 5. Some ideas had already been explored already, but some of them were explored further and became more interesting. One of those ideas were quick release. The fact that it moves the wear and damage from the fire extinguisher to the mount instead were first brought up during the workshop. This fact made the idea even more appealing as it is the only idea so far that does this.

Another interesting idea that was brought up during the workshop was the fact that the grapple used for an ordinary mount is not utilized in any way in the mount for vehicles. This was also an opportunity to try to move the wear from the critical part of the fire extinguisher, as the grapple in some way is external from the rest of the extinguisher tank.

Besides the ideas, was the result of the workshop a complete concept. This concept focused on a change of materials and manufacturing process but keeping the design the same as now with some small changes.

Figure 33: Mind map with utilizing grapple in the center.
5.2.4. Sorting of ideas

The sorting of the ideas resulted in six different groups of ideas that were similar or based on each other. In Figure 34-35 are the idea groups presented with some sketches of the ideas as well as a broad explanation of the ideas in that group. Most of the group feature ideas that are based on a fast release of the fire extinguisher, where some are more focused on securing the fire extinguisher safely with no chance of it accidentally releasing and other were just focused on it just being able to hold it.

**Cylinder support**- The cylinder support is based on ideas that were made to keep the fire extinguisher in place, but that does not secure it enough to hold it on its own.

**Arms**- Are a solid version of the straps used today, using the same locking principle as well.

**Quick release**- This is a quick release mechanism where the fire extinguisher is held in place by a safety pin and if it is released the fire extinguisher can be removed. The quick release is pretty much the same in every idea, but the location of it varies.

**Strap development**- This is ideas that are directly correlated with improving the vehicle mount used today mainly focused on the straps and their attachment points.

**Vibration dampening**- Ideas that are related to implementing different types of vibration dampening at different locations.

**Hook**- These are the ideas that are based on a hook that utilizes the grapple that the ordinary mount uses to suspend the fire extinguisher.

Figure 34: Four of the groups of ideas.
One group was based on ideas to dampen the vibrations that are transferred from the vehicle to the mount. There were mainly two different places where the damping could be placed, within the mount to dampen the vibration transfer to the fire extinguisher or outside the mount to dampen the vibration transferred to the mount. A concept that was based on damping the vibration in the attachment points of the vehicle mount was made based on these ideas. This would hopefully stop the mount from being damage which is a big problem today.

5.2.5. Morphological matrix

The morphological matrix that was made and used is presented in Table 5. The ideas used for the “bottom: support” row was all taken from the group Cylinder support. The ideas in the “top: holding with fast release” row was taken from the groups, arms, quick release, strap development and hook, where two ideas were from the hook group.

The morphological matrix resulted in a total of 13 different concepts, see Appendix 5 for a list of all concepts and what combinations that made them.

![Diagram of Vibration dampening and Strap development]

Figure 35: Two of the groups of ideas.

Table 5: Morphological matrix with ideas.

<table>
<thead>
<tr>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bottom: support</strong></td>
<td><strong>Top: holding with fast release</strong></td>
<td>Arms with current lock</td>
<td>Casted straps</td>
<td>Normal hook</td>
</tr>
<tr>
<td></td>
<td>Solid cylinder</td>
<td>Cylinder with open front</td>
<td>Tool suspension</td>
<td>Solid cylinder with rotation</td>
</tr>
</tbody>
</table>

5.2.6. Evaluation

In this section is the result of the evaluation process of the concept that had been generated so far.

5.2.6.1. Evaluation- Screening with the product specification

The result from the first screening of the concepts were three concepts, where one was based on vibration dampening. The thought was to combine this concept with another one. To see the full result of every stage of the screening process see Appendix 6.

5.2.6.2. Stakeholder evaluation

The evaluation with the stakeholder resulted in another concept being sorted away, see Appendix 6. The concept sorted away was the one changing the material of the current vehicle mount. It was eliminated because it was not deemed to be too different enough from the vehicle mount used today. Meaning that the usability problems with the old ones still were present.
Another aspect that was brought up was the need for the handle to be easy to operate with protective gloves, which the drivers use when driving vehicles in mines and ultimately would be wearing when using the mount and fire extinguisher.

5.2.7. Concepts

At the end of the conceptual design phase remained three different concepts. These concepts were Concept 1: quick release, Concept 2: Solid arms and Concept 3: Vibration damping, they are presented below in Figure 36.

Concept 1: Quick release

This concept is based on a technique already implemented on vehicle mounts for a smaller fire extinguisher. Here the thought is to make it more usable by having a big handle on the front of the fire extinguisher instead of a small one in the back which existing vehicle mounts have. There will be a supporting bottom cylinder that holds onto the lower part of the fire extinguisher to make it possible only to have one action to perform when the fire extinguisher is needed. The most significant benefit with this concept is the fact that it moves the were from the fire extinguisher to the mount instead.

Concept 2: Solid arms

This concept is a solid version of the vehicle mount used today, where the upper half cylinder arms hold the fire extinguisher in place. This concept also has a supporting bottom cylinder that holds onto the lower part of the fire extinguisher to make it possible for faster release.

Concept 3: Vibration damping

This concept is not a complete concept but will be combined with one of the above concepts in the end. The main idea here is to have the dampening separate from the vehicle mount and that it is used when attaching the mount to the vehicle. It will either be only at the attachment points or over the whole back side of the mount.

Figure 36: Presentation of concepts.
5.3. Conceptual design

The result from the conceptual phase was a few mock-ups that were tested and evaluated. At the end of this phase was one final concept remaining.

5.3.1. Prototyping

In this section is the result of the prototyping of the two concepts presented and what decisions were made based on these results.

5.3.1.1. Concept 1

The functionality tested with the mock-ups for the first concept was the quick release mechanism, where the different versions were one that resembled the most common quick release mechanism used for smaller fire extinguisher and one that was newly designed, see Figure 37.

The version chosen for further development was the one most commonly used on smaller fire extinguisher already, the prototype to the left and middle in Figure 37. It was chosen because it was more stable, simpler and would ultimately be easier and cheaper to manufacture. Some aspects such as the usability in an emergency were not as good as on the new design, but not bad enough for it to be excluded as it was deemed fixable.

The next mock-ups made in CAD had a more significant emphasis on modifying the quick release mechanism to make it more usable without losing its stability. Different angles of the notch were tested to make it possible to remove the fire extinguisher by pulling it straight out instead of up. It was essential to see what angles worked without the fire extinguisher hitting the wall when the notch was in 90 degrees from the wall, which enabled that move. This resulted in the portion beneath the notch being 1 mm smaller. This made it possible to turn without collision until the notch was at 90 degrees, see Figure 38.

Figure 38: Cad mock-ups of Concept 1

5.3.1.2. Concept 2

The functionality tested with the mock-up for the second concept was a clamping mechanism using a torsion spring for the lower arms. The purpose was to test if the solution could hold a cylindrical object in midair as well as releasing it easy when pulled straight out.

The result of the 3D-printed mock-up and the following tests was that the clamping mechanism with the torsion spring could hold a cylindrical object in midair. It could also release it with a simple pull straight out, see Figure. The tests also revealed that the whole mechanism would have to be sized up to be able to hold the fire extinguisher. This was due to it needing a stronger torsion spring which means it would have to be a lot bigger, resulting in bigger surrounding.
5.3.2. Vibration protection

There are three different ways to reduce vibrations according to Karnovsky & Lebed (2016) which are: Lowering the source’s vibrational activity, passive vibration protection, and active vibration protection, see theory chapter section 3.3.1. Vibration reduction for more information.

Lowering the source’s vibrational activity is eliminated as the vibration source cannot be affected here and active vibration protection is also not a valid option as these systems are complex and often very expensive. This leaves us with the option of passive vibration protection, which according to Karnovsky & Lebed (2016) can be split into three sections; vibration isolation, vibration damping, and vibration absorption, again see theory chapter section 3.3.1. Vibration reduction for more information. Vibration absorption is unfortunately complex and can take up much space which makes it unsuitable for this instance. Vibration damping and vibration isolation are both viable options and can be implemented in a good way.

The best option here is, however, vibration damping as it consists of materials that are not sensitive to corrosion, which vibration isolation is, as it is based on springs. Vibration damping also dissipates the vibration energy which means that less energy is introduced to the system, which is preferred. These are the main reasons why the vibration protection system was chosen for vibration damping.

The implementation method of vibration damping was having two separate halves of rubber that were connected to the attachment points. One was to be placed in between the mount and the vehicle and one between the mount and the bolt attaching the mount to the vehicle, see Figure 39. This would ensure that the vibrations would not be transferred from the vehicle or the bolts to the mount.

5.3.2.1. Benchmarking-vibration protection products

to Concept 3, which use rubber as vibration damping as well as being attached to the attachment points. It exists a few different versions that can be fitted in between the mount and the vehicle, it also exists some that are the same as the one in Concept 3, but not as many.

After this discovery was a decision made that Concept 3 would not be developed further, due to it being costly to produce a mold for manufacturing for this small quantity. This in combination with the fact that already accessible products exist makes it unnecessary to develop an entirely new product that would only vary slightly but be extremely costlier.
5.3.3. Vibration analysis

The measured vibrations from the vehicles in the mines showed a difference in the overall characterization of the vibrations between the different vehicles that were tested, see Figure 40. The main difference was the portions that had larger acceleration. All vehicles had the same steady state vibrations that laid in-between the larger spectrums of high acceleration vibrations.

First was an FFT graph produced of the steady state vibrations, which were located at the different time interval for all tests. As suspected did all tests, show a similar steady-state vibration when it came to the frequency as well. The larges peaks of acceleration occurred in the spectrum between 0-200 Hz and had acceleration up to 0.008g for tests 1-4 and 0.025g for test 5-6. However, it was vibrations up to 1400 Hz, but these vibrations had accelerations that were extremely small at less than 0.001g.

A second round of FFT-graphs was then made on the spectrums with larger amplitudes. Here were the frequencies similar again and the larges peaks occurred in between 0-200 Hz with acceleration up to 0.035g, see Figure 41 for test 2s´ FFT, all FFT graphs can be
found in Appendix 7. There was however a difference when it came to test 5-6 were another smaller peak was found at 1000 Hz with acceleration 0.0015g in the z-direction, see Figure 42, it was also seen in the x-direction but not as proponent.

The conclusions that can be drawn are that there is most activity in the frequency range in-between 0-200 Hz independently on what vehicle that is driven and what axis is looked on. The mean accelerations recorded are all small and well below 1g.

### 5.3.4. Relative decision matrix

The result from the evaluation using the relative decision matrix was that the first concept, quick release, was chosen as the final concept. It would, however, be combined with already existing vibration damping products when implemented. The reason for the quick release concept being chosen was the fact that it had the best total score by one point over concept 2, see Appendix 6 for the whole relative evaluation matrix. The advantage of moving the wear from the fire extinguisher was also taken into consideration when the matrix was overlooked even though it was not criteria in the matrix, as it was deemed an important aspect. This aspect in combination with the matrix score resulted in Concept 2 being chosen.

### 5.4. Detailed design

The detailed design phase was focused on finalizing the design of the quick release concept, and the result of every change made are presented.

#### 5.4.1. Functionality prototyping

Below is the result of the functionality prototyping that was performed, separated into each function that was developed.
5.4.1.1. Angle of grove

The angle of the grove in the male half of the quick release mechanism needed to be tested to determine if it worked the way it should. To do so was a 3D-print of the quick release mechanism made which were assembled and tested. The result of the first iteration was that the angle of the grove was not steep or deep enough. Which resulted in an increase in the angle of the grove as well as a decrease in the draft angle in the grove, which performed better.

During the research for locking mechanisms was a total of four methods found that could be implemented on the vehicle mount and are listed in the Table 6 above. The locking mechanism that was chosen was the one using a locking pin and a grove on the safety pin. This due to it having the best performance overall. Another bonus was that it had already been implemented on a mount for a tank, proving it could handle an environment that have a lot of vibrations.

5.4.1.2. Locking mechanism

The fine-tuning needed for the locking pin was to determine what locking pin to use as well as how deep the grove should be to give enough resistance for it to be held in place without it being difficult to pull out. The size of the locking pin was decided together with the supervisor from SveKon as he had experience from constructions using the locking pin. The groove depth was then determined by making a safety pin with four different depth of the grove, see Figure 43, and testing them out in a 3D-print of the quick release mechanism using the locking pin, see Figure 44.

Here was the result that the groove with the depth of 0.6 mm was the one that gave enough resistance while also keeping the pin in place. This was, therefore, the depth finally used in the groove of the safety pin.

Table 6: Locking alternetives to the safety pin.

<table>
<thead>
<tr>
<th>Type</th>
<th>Easy to use</th>
<th>Affect action affordance</th>
<th>use on both sides</th>
<th>Stay in place</th>
</tr>
</thead>
<tbody>
<tr>
<td>locking bolt</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Pressure spring</td>
<td>No</td>
<td>No</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>Semi locking bolt</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>locking pin</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figure 44: Test set up for locking pin and handle.
5.4.1.3. Handle

The result of the CAD-models of the different handles can be seen in Figure 45. The final shape chosen was number 3 in Figure 45, as this was a stable construction as well as the most visible if the hole for the safety pin was moved down to the center of the quick release mechanism.

The linework analysis showed that the handles using sides that had a slight angle inward expressed movement forward in a better way than those with straight sides or sides that were angled outward. The handles that had an arced center that was more spanned in the middle also expressed movement forward. These two quantities together also expressed movement forward but did so more so if the handle was elongated. The last constellation was the one they used when making the CAD-models.

The two handles made in CAD can be found in Figure 46. One is very similar to the one the linework analysis was done on whereas the other one was based on the first but with a different connection to the safety pin. The last one was eventually chosen as the final one as it elongated the handle in a good way that made it more visible behind the fire extinguisher. It also had a better overall design, was more stable as well as made more room for the hand, which is an advantage.
5.4.2. CAD

The CAD-model of the mount was initially made up of three different main components, see Figure 47.

5.4.2.1. Manufacturing adaptation

After the parts in the initial CAD-model had been customized for manufacturing was the components count to six unique parts (not including the handle and safety pin and bolts) which were; half cylinder, male half, female half, base and stationary pin.

Half cylinder and male half

The half-cylinder was first intended to be one component together with the male half of the quick release mechanism. This part was separated into two parts instead of as the first component was too complex and would not be able to be manufactured using the chosen method.

Female half

The first change that was done to the female half was first to separate it from the base plate that attaches to the vehicle, as the first intended component could not be manufactured by the intended method, water jet cutting. The now separate female half of the quick release mechanism was split so that it instead was made up of two identical components that attach to the base plate. This change also led to the stationary pin being separated from the female half and made into a separate component. This was also done to make it possible to choose a more durable material and also make it easier to replace if it would break, which is a possibility as it will carry much weight.

5.4.2.2. Slimming down the design

The slimming down of the components that are going to be attached to the fire extinguisher resulted in a change of the shape of the half cylindrical component as well as the attachment points between the cylindrical halves and the male half. The shape of the cylindrical halves was slimmed down by taking away the extended parts for the bolts. This did, however, result in a total thickness increase by 10 mm to the outer diameter to fit the M4 bolts needed to assemble the two halves.

The attachment points between the cylindrical halves and the male half were changed from being located on the inside of the cylindrical halves to be on top of them, see Figure 47. This resulted in the male half being located closer to the fire extinguisher and therefore less in the way then it was before.
5.4.2.3. Technical drawings
The CAD-model finally resulted in 6 number of technical drawings that can be used when manufacturing the components of the vehicle mount. A technical drawing was not made for the handle as it was too complex to be manufactured with water jet cutting. The handle was instead 3D-printed.

5.4.3. Material selection
The result from the literature review done on materials that are suited for vibrational damping can be found in the Theory chapter under section 3.3.2.1. Vibration damping. The material group that was decided on was plastic, as it has dampening effects as well as being durable, reliable and not easily corroded. Steel could be used, as some studies that the steel has damping properties due to energy loss in dislocations during vibration (Chung, 2001) however can it be hard to temper the metal in the right way to make this work. The final material chosen was POM on the recommendation of the SveKon supervisor, as it is hard and durable.

5.4.4. Vibration analysis
The solution from the NX eigenvalue simulation generated ten different modes and their natural frequencies for each component, see Appendix 8 for all modes and their natural frequencies. A mode is the deformation that would occur at resonance at a natural frequency of an object, see Figure 49 for the mode for the lowest natural frequency for the base attaches to the vehicle. The lowest natural frequency for the female part was 3265 Hz and for the male was it 2557 Hz. This means that the natural frequencies for both components tested were much higher than the highest frequency recorded in the mine. This means that the components are not in the risk of hitting resonance when mounted on the vehicle.
5.4.5. Final prototype

The main problem that was discovered during assembly was that the extra space of 1mm that had been put in between components was too much. This especially played a role between the contact areas of the male halves and the cylindrical halves. The edge there should help stabilize the construction, but was not doing it well enough as the gap is too big, see Figure 50. This caused the male half to have a slight undesired rotation. The gap also caused a problem as it made the locking mechanism move slightly too much. Meaning that the male half could move in the y-direction slightly too much in between the female halves. If a new prototype is made or if the vehicle mount goes into production these gaps need to be decreased.

Another discovery was that the removable part of the vehicle mount that is placed on the fire extinguisher did not stay in place without the safety pin. If the safety pin was removed, the fire extinguisher falls to the ground. This was caused because of the weight of the fire extinguisher not being taken into consideration earlier.

5.4.6. Usability testing

The usability testing showed that the vehicle mount is easy to understand when used for the first time. It also has an extremely low error count. Four out of five were able to remove the fire extinguisher without making any errors when using it for the first time. The error that was made was that the handle was not visible enough. This was mainly caused by the handle and the background having the same white color. This error caused the participant to only focus on the visible black parts and could therefore not remove the fire extinguisher. However, this error was easily recovered as it was fast made clear that the fire extinguisher could not be removed without the handle.

A problem that could have occurred was that the fire extinguisher fell to the ground when the safety pin had been removed. This proved, however, not to be a problem, as every participant first put their hand on the fire extinguisher making sure to hold it tightly before removing the safety pin.

Some comments that were made after the test that could be improved upon were:

- The safety pin having too much resistance
- Not enough room behind the handle for the hand
- Maybe the handle could be changed for a lever or something else.

Figure 50: Gap between male half and cylindrical half.
5.5. Final design

The final design of this project is a mount for fire extinguishers on vehicles and utilizes a quick release mechanism that makes it easy to remove the fire extinguisher in case of a fire, see Figure 51. The mechanism also moves the wear from the fire extinguisher to the mount, which makes the chance of fatigue damage on the fire extinguisher smaller.

Components

Figure 51: Final design.
5.5.1. Components
unique parts, as well as a few different bolts, washer, and nut. All components are listed below with accompanying figures.

Unique components

Male half- The male half are connected to two of the cylindrical halves, which are attached to the fire extinguisher, see A in Figure 52.

Base plate- The base plate is the part of the vehicle mount that is connected to the vehicle. The female halves are attached to the middle of the base plate, see B in Figure 52.

Female halves- The female halves are attached to the base plate, see C in Figure 52.

Cylindrical halves- The cylindrical halves are the ones suspending the fire extinguisher. They are connected in pairs at the top and the bottom of the fire extinguisher. See D in Figure 52 for the cylindrical halves before they are connected to the fire extinguisher.

Stationary pin- The stationary pin is held in place in the female part and helps to secure the female and male half together. The Stationary pin is held in place by two locking rings on each side of the locking pin. See E for locking pin and F for locking rings in Figure 53.

Figure 53: Stationary pin components.

Figure 52: Unique components.
**Locking pin**- The locking pin is what locks the male and female part together and is attached to the handle, see G in Figure 54.

**Handle**- The handle is attached to the locking pin and enables it to be pulled out of the quick release mechanism. See H in Figure 54 for the handle.

**Other components**

**MC6S M4X22 bolts**- Two are used to attach the male half to the cylindrical halves, and two attach the cylindrical halves, see I in Figure 55.

**M6S M4X20 bolts**- Four of them secures the females halves to the base plate, see J in Figure 55.

**M4 Washer**- Are placed in between every bolt, nut, and component. A total of 16 washers are used, see K in Figure 55 for the washer.

**M4 insert**- Is used to get durable threads, as plastic threads would easily break, see L in Figure 55.

**M4 locking nut**- Are used to secure the bolts in place, a total of 2 nuts are used, see M in Figure.

**Locking rings**- Are dimensioned for a pin with a diameter of 6mm, see F in Figure 53.

**Locking spring**- The locking spring is used to lock the M6S M4X10 bolts- Are used to attach the locking spring to one of the female halves, see N in Figure 56.
5.5.2. Function

The primary function of the quick release mount is, of course, to suspend a fire extinguisher as well as releasing it quickly when the fire extinguisher is needed. To release the fire extinguisher is there a quick release mechanism that makes this easy and fast. The vehicle mount suspends the fire extinguisher by using two cylindrical holders.

5.5.2.1. Quick release mechanism

The quick release mechanism used is based on an already implemented mechanism that is used on smaller fire extinguisher then those used in mines. It is separated into two halves, one male and one female, these halves fit together, see Figure 57. The halves are secured by a removable safety pin as well as a stationary pin in the female half. There is a nock in the main part where the stationary pin on the female half fit. This secures the lower part of the quick release mechanism. The male half can be removed from the stationary pin by turning the male half 10 degrees and then pulling it straight out. The small degree turn is there to ensure that the male half is held secure in the z-direction when the safety pin is in place.

**M4 distance** Have the outer diameter of 6mm and the inner diameter of an M4 washer. It is also 1.4mm thick. It is placed inside the locking spring to help to secure it, see O in Figure 56.

**Locking pring** The locking spring is what locks the locking pin in place. See P for locking pin and O for locking rings in Figure 56.

Figure 56: Components locking mechanism.

Figure 57: Quick release mechanism.
5.5.2.2. Safety pin

As the whole quick release mechanism is kept together by the safety pin is it vital that it not release unintentionally. This means that there needs to be a safety catch on the pin to stop this from happening. The safety catch here is based on a locking spring from Lesjöfors, see Figure 56. This locking pin is kept in place by two M6S M4X10 bolts on either end of the hole where the safety pin is supposed to be placed. A distance is inserted in the hole of the locking spring, to keep it in place better, see Figure 56 for the ingoing parts of the safety catch. When the safety pin is pushed through the hole to secure the quick release locking mechanism, it also pushes through the locking pin. The locking pin then locks into place into a groove on the safety pin, see Figure 58. This makes it impossible for the safety pin to be removed unless significant external force is pulling it out.

Figure 58: Locking pin when it is locked.

This safety catch of the safety pin is simple to use and adapted for emergency situations in a good way as the action affordance, and functional affordance correlate, which is to pull the pin and handle straight out. The side of which the handle is placed on can also be adjusted to fit the machine it is placed on. This is possible as the holes were the locking spring is attached are on both sides of the female half, see Figure 59. This is an important detail as the handle needs to be on the side that is first visible when exiting the vehicle.

5.5.2.3. Handle

The handle on the safety pin is designed in a way to make it visible and to make the function of it clear. The size of the handle is also fitted for the average man hand with a working glove, as to fit the user when the handle is used. The color of the handle is green to make it stand out against the red foreground. It also stands out to the sometimes yellow or red background, as green in a contrasting color to red.

Figure 59: Holes for installing locking mechanism.

5.5.2.4. Cylindrical halves

The fire extinguisher is held in place by two cylindrical holders, one on the top and one on the bottom, see Figure 60. These cylindrical holders are separated into two identical halves that are held together by MC6S M4X20 bolts and self-locking nuts. The cylindrical halves have the same inner radius as the fire extinguishers outer. Except being 1 mm shorter, resulting in them putting pressure on the fire extinguisher when bolted together. This pressure secures the fire extinguisher and suspends it in the air. The two cylindrical holders are then attached to the male half of the quick release mechanism with MC6S M4X20 bolts.

Figure 60: The cylindrical halves attached to the fire extinguisher.
5.5.3. Use

Three steps need to be done to remove the fire extinguisher from the vehicle mount before it can be used, see Figure 61. These steps are kept as simple as possible with actions that are natural and intuitive in order not to cause problems when needed in an emergency situation. The actions are listed below.

1. The safety pin is removed, by pulling the handle straight out.
2. The fire extinguisher is tilted down 10 degrees and pulled straight out.
3. The fire extinguisher is used as normal to extinguish a fire.

There is, however, a need to hold on to the fire extinguisher between the first and second step. This is due to the notch and permanent pin not securing the fire extinguisher enough for it to stay in place during the short period in between these two actions.

5.5.4. Fulfillment of product specification

It is important that the final product fulfills the product specification made in the beginning. This final design fulfills 18 out of 19 demands and 2 requests out of 3.

Below are the most important ones explained and explored further, whereas the rest is presented in Table. The primary function mentioned in the product specification, which is that it should be able to suspend a fire extinguisher of a certain type, is fulfilled. Cause if it was not it would not be a mount. The test done on the vehicle mount at the end shows that it is able to suspend a fire extinguisher without any problems.

The second most important function listed in the product specification is that the fire extinguisher should be removable from the mount. This function is fulfilled in a way, but not in a literally sense. This is due to the vehicle mount being split in two parts and one being permanently located on the fire extinguisher, this do mean that the fire extinguisher is not removable from the mount which means that the demand is not fulfilled. However, is the underlying meaning of the demand that it should be easy to remove the fire extinguisher from the vehicle in order to use it and this demand is definitely fulfilled. As the fire extinguisher is easy to use even thou it still has a portion of the mount attached to it. This makes it clear that this demand unfortunately suffer from a formulation problem as the final solution was not even imaginable when the product specification was made and therefore not included in the formulation. That is why it is important to look at the actual meaning instead in order to see if it fulfilled, which it is.
When it comes to the demands regarding use of the fire extinguisher and it being adapted for emergencies are all demands fulfilled, which the usability test shows. The mount is easy to remove and the action affordance is the same as the functional affordance which is essential for use in emergency situations. The safety pin in the quick release mechanism is also secure and does ensure that the fire extinguisher does not get unintentionally released. The rest of the demands and requests that the vehicle mount fulfills are listed in Table below.

<table>
<thead>
<tr>
<th>Demands</th>
<th>Requests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Function</strong></td>
<td></td>
</tr>
<tr>
<td>✔ Be able to suspend a fire extinguisher of the type 55A 233BC, with 6 kg extinguishing agent</td>
<td>✔ The fire extinguisher should be removable from the vehicle mount</td>
</tr>
<tr>
<td>✔ The vehicle mount should be able to suspend on different vehicles</td>
<td>✗ The vehicle mount shows that the fire extinguisher is damaged (1)</td>
</tr>
<tr>
<td><strong>Limiting</strong></td>
<td></td>
</tr>
<tr>
<td>✔ Be able to carry at least 8.9 kg. Which is the weight of a 55A 233BC fire extinguisher with 6 kg extinguishing</td>
<td>✔ The information text on the fire extinguisher should not be covered by the vehicle mount</td>
</tr>
<tr>
<td>✔ The vehicle mount should be adaptable to other sizes of fire extinguishers</td>
<td>✔ The vehicle mount should be able to suspend different brands of fire extinguishers</td>
</tr>
<tr>
<td>✔ The fire extinguisher should not be removable when the vehicle is in service</td>
<td>✔ The vehicle extinguisher should be removable from the vehicle mount</td>
</tr>
<tr>
<td>✔ The shape of the vehicle mount should not facilitate corrosion. It should not have gaps where acid water could seep into</td>
<td>✔ The vehicle mount should dampen vibrations in some way</td>
</tr>
<tr>
<td>✔ The vehicle mount should not have the same natural frequency as the frequencies that the vehicle transfer to the mount</td>
<td>✔ The fire extinguisher should be held tightly by the vehicle mount to avoid fatigue damage</td>
</tr>
<tr>
<td>✔ The materials in the vehicle mount should be suited for mining conditions, most important is that it should not corrode.</td>
<td>✔ The fire extinguisher should be held tightly by the vehicle mount to avoid fatigue damage</td>
</tr>
<tr>
<td>✔ The fire extinguisher should be easy to remove in order to use it</td>
<td>✔ The action affordance should be the same as the functional affordance</td>
</tr>
<tr>
<td>✔ It should be easy to understand when using for the first time</td>
<td>✔ Errors should be rare when using the vehicle mount and should not be fatal</td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
</tr>
<tr>
<td>✔ The vehicle mount should not have the same natural frequency as the frequencies that the vehicle transfer to the mount</td>
<td>✔ The vehicle mount should be suspendable on different vehicles (3)</td>
</tr>
<tr>
<td>✔ The materials in the vehicle mount should be suited for mining conditions, most important is that it should not corrode.</td>
<td>✔ Components should be easy to replace if they break (4)</td>
</tr>
<tr>
<td>✔ The fire extinguisher should be easy to remove in order to use it</td>
<td>✔ The vehicle mount should be suspendable on different vehicles (3)</td>
</tr>
<tr>
<td>✔ It should be easy to understand when using for the first time</td>
<td>✔ The vehicle mount should be suspendable on different vehicles (3)</td>
</tr>
</tbody>
</table>

Table 7: Fulfillment of product specification.
6. Discussion
6. Discussion

In this chapter will the final design be discussed regarding the use of, the user environment as well as resistance against vibrations. The final result will also be positioned, and some recommendation regarding the future will also be given.

6.1. Final design

The final design of this thesis project is a vehicle mount for fire extinguishers that is adapted for use in mines as well emergency use. The central area of use for the mount is in emergency situations as this will be the instance when the fire extinguisher will have to be used and therefore taken away from the vehicle.

6.1.1. Use of the vehicle mount

A product is safe to use according to Hale et al. (2007) in the user parameters that the designer has identified and designed for. Humans also interact with products differently in emergency situations than in normal cases (Bruck & Thomas, 2010). This makes it very important that a product meant for emergency situations be designed with an understanding of these reactions to establish that the product is safe to use.

Rahman et al. (2011) states that it is essential for a product meant for emergencies to have the same action and functional affordance. This relationship can be found in both actions that are performed when releasing the fire extinguisher from the mount. For the first action of releasing the safety pin is the action affordance that you should pull the handle against you and out of the vehicle mount, this is the same as the functional affordance, which is to pull out the safety pin, see Figure 62. When it comes to the second action of releasing the fire extinguisher, is the functional affordance that you want to pull the fire extinguisher against you, This is the same as the action affordance once again. This little detail makes the release of the fire extinguisher from the vehicle mount very easy to understand by the user even when they are in an emergency situation.

Another way that the vehicle mount is suited for emergency situations is that it is designed in a way that awakes more attention in the user, which is essential as a lack of attention is a problem for humans in emergency situations (Leach & Ansell, 2007). The primary method used to awake more attention in the user is the principle mentioned by Bohgard et al. (2010) which is minimizing time and effort it takes to gather information. This principle was mainly used on the handle to make it visible and easy to find. The main thing done here to accomplish this was to make the handle big, the shape also makes the handle visible from its position from behind the fire extinguisher. It is also recognizable as a handle at first glance.

The color of the handle was also made green which is a contrast color of red which makes it stand out from it. This color might, however, be proven problematic and needs to be tested out as green is not often used as a warning color. It is however often used as a color that indicates escape which could be implemented here. It is hard to say if the underlying meaning of the color could interfere with the understanding and use of the product without testing. This is something that Sherin (2011) states is problematic when using colors to evoke feelings or reactions as the reactions to different colors can vary between people, and it is hard to foresee them beforehand.

Figure 62: How the action affordance and the functional affordance correlate in the final design of the vehicle mount.
It is also important that the use of the fire extinguisher is not affected by the fact that a piece of the vehicle mount is permanently attached to it. As you can see in Figure 63, the use is not affected by the attachment to the fire extinguisher. It also does not affect how well you can carry the fire extinguisher. This is due to the attachment being placed on the extinguisher tank and the use being connected to the handle at the top on the fire extinguisher. This means that the use is not affected by the attachment and is as easy as it normally is.

Ease of use is something that is a big part of usability (Van Eijk et al., 2012) which also is an essential aspect of establishing that a product is safe to use as the risk of fewer errors in crucial moments (Boy, 2011). The usability of this product was tested, and it shows that the error rate is low. The one error made was also easy to recover from and was not fatal. The vehicle mount was also extremely easy to understand and use at first hand. The product is in short is very usable and have high usability, which makes it very accusable and safe to use.

6.1.2. Mining environment
The vehicle mount will be used in mines which have an extraordinary environment, and these environmental aspects do affect the vehicle mount in a direct and very prominent way. The aspects that affect the mount the most is the overwhelming amount of vibrations as well as the acid water in the mines.

The vehicle mount is mainly made of plastic which cannot corrode like metals do (Ashby et al., 2007), which eliminates the corrosion problem for most of the mount. However, is not all components of the vehicle mount made out of plastic due to in not being strong enough for certain areas, such as bolts, nuts and the safety pin, which all will carry a lot of the load. Here have the metals chosen been of stainless steel which does not corrode as quickly. The areas where the metal will be used are also tight spaces that should not allow the acid water in, which could cause crevices corrosion which Ashby et al. (2007) states is a common problem when joining two parts together.

That the material of the vehicle mount is plastic also helps with vibration damping, which is a passive vibration system for reducing vibrations that Karnovsky & Lebed (2016) mentions. This vibration reduction method is based on using materials that reduce the vibrational energy that goes into a system. This means that the use of plastic instead of metal makes the vibrational energy that transfers from the vehicle to the fire extinguisher less at least in theory. This is hard to know for sure without real-life tests and comparisons between the two.

![Image](image_url)
6.1.3. Vibration durability

As mentioned before does the environment in the mines cause the vehicle mount to be exposed to a lot of vibrations, which makes it essential that the mount can withstand a large amount of vibrations. An enormous contribution to making the mount more durable and able to withstand vibrations is the fact that it is more robust and uses a more durable material, especially for the part that suspends the fire extinguisher. This vehicle mount has hard plastic whereas it before was straps made of fabric. This means that the chance for the part that holds the fire extinguisher to break has been reduced. This in turn leads to less risk of damage on the fire extinguisher, as damage only occurred when the vehicle mount was not holding the fire extinguisher tight.

Another aspect of this new mount that makes it less likely to damage the fire extinguisher is that the wear that was on the portion that holds the fire extinguisher, which was the straps, have now been moved to a portion of the vehicle mount that does not come in contact with the fire extinguisher. This means that the mount will not negatively affect the fire extinguisher even if it would break where the amount of wear is the most. This is the most positive change from the vehicle mounts used today where the most noticeable wear is on the most significant part of the mount, the one holding the fire extinguisher.

Figure 64: Bolt tracks on base.

6.1.4. Impact on stakeholders

As mentioned at the start of this project will the implementation of this new vehicle mount have an impact on the stakeholders. For the primary stakeholder, Boliden, will the impact be that the wear and damage on the fire extinguishers on vehicles hopefully goes down. It will also give a safer work environment for their workers as they no longer need to worry about the damaged fire extinguisher. When it comes to the workers in Boliden’s mines are the ones that will be most directly affected the most machine operators as they are the ones that will use this new product. They will be positively affected as the new vehicle mount is easier to use and does not damage the fire extinguishers which could put them in danger.

The service technicians will also be affected positively as the new vehicle mount is designed to be easier to suspend on the vehicle than the ones used today. The base of the mount that is supposed to be suspended to the vehicle has longer bolt tracks, see Figure 64. This was something that was requested as this would make the suspension of the mount much easier. This has however not been tested yet, but if tests were to show that some changes need to be done to the bolt tracks to make the mount easier to suspend then that can be done.
6.2. Recommendations

Two scenarios might happen after this project is finished, the first one being that the vehicle mount presented in this thesis goes through some further development and is then implemented and the second one being that the vehicle mount is not implemented. Below are some recommendations for both scenarios.

6.2.1. Before implementation

If the vehicle mount presented and developed in this thesis is to be implemented in Boliden’s mines are there some things that should be done before that could happen. Firstly, should some vibration testing be performed on the mount as the vibration analysis that was planned did not give a conclusive result. This vibration testing could be done with a shaker using the recorded data from the Garpenberg mine to simulate the reality. This vibration testing should be done to establish that the vehicle mount will not break during service but also to see how the mount reacts in an active vibration environment.

Another recommendation that is related to the vibration durability of the vehicle mount is an implementation of vibration dampers at the attachment point. This was a concept that was developed in the conceptual phase but scrapped when it was discovered that the product already existed in many iterations. The idea of vibration dampers in the attachment point to protect the mount from the vibrational damage is a good idea and should still be implemented. So the recommendation is first to see how the mount manages on its own and then see what vibrational dampers that exist on the market could be implemented to prolong the durability and lifespan of the vehicle mount.

After the vibration testing of the vehicle mount is there still a good idea to have a trial period of implementation of the mount. This should be done to see how the vehicle mount actual interaction with the real environment, as all simulated test only give a partial truth of the reality. A trial period is an excellent way to see what problems that might not be foreseen that exist and fixing them before implementing the vehicle mount on a big scale.

The last recommendation relates to the use of the vehicle mount, more precisely the emergency use. It could be a good idea to test how the interaction between the user the vehicle mounts functions in an actual emergency situation. This means making some usability test in a scenario that is more like an emergency and not conducted in a calm way in a workshop. This is a good idea to make sure that the vehicle mount is used in a safe way that does not endanger the user when in an emergency situation.

6.2.2. No implementation

There is a chance that Boliden decides that the vehicle mount used today is a better option than the new vehicle mount that is presented and developed in this thesis. If that would be the case are there still some recommendations to be presented. The first one being a review and inquiry of the current oversight of the fire extinguisher and mounts on the vehicles in their mines. This is due to some problems that became apparent during the context phase of the process, the first one being a lack of instructions on searching and determining if the fire extinguisher and vehicle mount were damaged before the vehicle was put in use. Another problem that surfaced was that the inspections of the fire extinguisher before use was often left undone or poorly so.

These two problems could be a big cause for the damage that is found on the fire extinguishers as they only get damaged when the vehicle mount has malfunctioned which should be discovered in these inspections.

That is why an investigation into the reason why the inspection is done so poorly and rarely should be done as well as make inclusion of checking the straps on the vehicle mount into the inspection routine, as the damage will occur when they are not tight enough.

The second recommendation is the same as one of the recommendations if the vehicle mount presented in this thesis is implemented and that is to implement vibration dampers at the attachment point. This is for the same reason but maybe more important here as the vehicle mounts used today are known for braking due to vibrations and lack of damping for the vehicle mount.
7. Conclusions
7. Conclusions

In this chapter will conclusions be drawn at the same time as a result is used to discuss the result in context with the objectives and aims of the project. First will a short recap of the objectives and aims be presented before a short discussion surrounding them is done with help from the research questions.

7.1. Recap

The objectives of this project were, in the beginning, set out to be the identification of the main problem concerning the vehicle mounts that are used today. The objective also consisted of solving the current problems that were identified. This solution could be in the form of a redesign of the current vehicle mount or a brand new design.

The project aimed to reduce the number of fire extinguishers that Boliden discards and replaces. A decrease in the percentage of damaged fire extinguishers will ultimately result in a safer work environment, as the risk of an accident will go down as well. Another added bonus is also the economic gain for Boliden.

Figure 65: Wear on straps.

7.2. Research questions

Below are a short discussion surrounding the two research questions used to make it easier to both guide the work but also make sure that the aims and objectives were fulfilled. Before the discussion can start must the research questions, of course, be presented again, and they are as following:

- What is the main problem with the vehicle mounts used today?
- Can a vehicle mount for fire extinguisher be adapted for both emergency use and use in mines as well as have resistance against vibrations?

The first question focused on pinpointing the cause of the problem to help solve it later. The main problem with the vehicle mounts used today was determined to be that the environment that the vehicle mount is used in is very vibration heavy. This exposure to a large number of vibrations gives many follow up problems that all can be derived back to vibrations. The biggest problem that the vibration caused was that the vehicle mounts got damaged. More precisely did the straps that suspended the fire extinguisher brake, see Figure 65. This caused the fire extinguisher not to be adequately secured and therefore get damaged in the process. The reason for the vehicle mount to brake is vibrations and...
a lack of vibration damping between the mount and the vehicle it is suspended on. An easy way of solving this is by placing vibration dampers at the attachment points which reduces the amount of vibrational energy that is transferred between the mount and vehicle.

The identification of the problem leads us directly to the second research question which is connected with the design of a new vehicle mount that is better than the ones used today. One of the most significant obstacles with the current vehicle mounts is that they brake one way changing that is by making the mount more durable and suited for vibrations.

This is precisely what the vehicle mount presented at the end of this thesis does, as it is made of a material that is more suited for the environment by being vibration damping as well as non-corrosive, it is also more durable than the straps used today. The construction of the mount also moves the wear from the fire extinguisher to the vehicle mount itself, which means that the fire extinguisher will not sustain fatigue damage anymore. This will, in the long run, mean that the number of fire extinguishers that Boliden needs to replace hopefully will reduce, which happens to be the aim of this project.

The vehicle mount is also adapted for emergency situations in a significant way as the action affordance, and functional affordance is the same, which is essential for proper use in emergencies. It is also a simple design that is designed in order to identify easily is supposed to be done and to attract more attention in the user, which also is an essential aspect in emergency use. This means that the vehicle mount presented in this thesis is also adapted for emergencies situations. The objective and aim of this project have been fulfilled as both research questions have been answered and fulfilled.
8. References
8. References


• Presto (n.d.) Hur fungerar en brandsläckare?. Available at: http://www.presto.se/produkter/brandslackare/hur-fungerar-en-brandslackare/ (2018-03-05)


• SveMin (2005) Vibrationer i gruvindustrin. Luleå: Luleå tekniska universitet


Questionnaire for safety workers

This appendix deals with the questionnaire sent out to safety workers in Bolidens mines during the Context phase of this thesis project. In the first section can the layout and questions used in the questionnaire be found, in the second section can the summary of the result for these questions be found. In the last section are the questions used for the telephone interview that were conducted with one of the respondents of the questionnaire.

Section A: questionnaire

Below is first a layout of the questions found, as some answers would lead to some questions not needing to be answered. After that is the questions asked listed in order.

Introduction
- Are you a safety worker in one of Bolidens mines?
  Answer options:
  Yes
  No

- What mine do you work in?
  Answer options:
  Free text

- Would you be interested in doing a phone interview?
  Answer options:
  Yes
  No

- Contact information (optional question only presented when the previously answer was yes)

Oversight of fire extinguishers
- Is handheld fire extinguisher something that is actively checked?
  Answer options:
  Yes
  No
  Do not know

- Should hand held fire extinguisher be actively checked according to you?
  Answer options:
  Yes
  No

- Why do you have that opinion?
  Answer options:
  Free text

- Are there guidelines in place for checking hand held fire extinguisher?
  Answer options:
  Yes
  No
  Do not know

- How often should hand held fire extinguisher be checked according to these guidelines? (optional question only presented when the previously answer was yes)
  Answer options:
  Free text

Damages on fire extinguishers
- How many hand held fire extinguishers have been replaced due to damages in your mine over the past year?
  Answer options:
  Free text

- How many of the hand held fire extinguisher was replaced due to damages caused by the suspension?
  Answer options:
  Free text

- How are damaged fire extinguishers identified?
  Answer options:
  Free text

- Are there guidelines in place that explains what should be examined in order to identify some damages easier?
  Answer options:
  Yes
  No
  Do not know
• What does these guidelines say? (optional question only presented when the previously answer was yes)
  Answer options:
  Free text

Usage of fire extinguishers
• Do you consider the suspension for fire extinguisher to be easy to use in general?
  Answer options:
  A 6 staged scale between “very easy” to “very hard”

• Do you consider the fire extinguisher being easy to release from the suspension?
  Answer options:
  A 6 staged scale between “very easy” to “very hard”

• Do you consider the suspensions used being well adapted for emergencies?
  Answer options:
  A 6 staged scale between “very well adapted” to “very badly adapted”

• Do you consider the fire extinguishers to be placed at a good positions on the vehicles?
  Answer options:
  A 6 staged scale between “very well positioned” to “very poorly positioned”

• Have there been any reported problems with the suspensions when the fire extinguisher has been needed?
  Answer options:
  Yes
  No
  Do not know

• What problem was reported? (optional question only presented when the previously answer was yes)
  Answer options:
  Free text

• Where the consequences severe? (optional question only presented when the previously answer was yes)
  Answer options:
  Free text

Section B - Results
Below is the relevant result from the questionnaire listed.

Is handheld fire extinguisher something that is actively checked?

![Chart showing 50% Yes, 50% No]

Should hand held fire extinguisher be actively checked according to you?

![Chart showing 100% Yes]
Are there guidelines in place for checking hand held fire extinguisher?

Yes: 100%
No: 0%

Are there guidelines in place for checking hand held fire extinguisher?

Yes: 75%
No: 25%

Do you consider the suspension for fire extinguisher to be easy to use in general?

1 (25%) 1 (25%) 2 (50%)

Do you consider the fire extinguisher being easy to release from the suspension?

2 (50%) 1 (25%) 1 (25%)
Do you consider the suspensions used being well adapted for emergencies?

Do you consider the fire extinguishers to be placed at a good positions on the vehicles?
Field study in Skellefteå

In this appendix can the material that was prepared before the field study at Skelefteå. This material consists of areas of investigation as well as questions that should be answered in order for the field study to be a success. These questions are mixed, some were asked directly towards people of experience and some were used in order to observe.

**General questions**

- Where are the fire extinguishers placed?
- How often is service performed on the fire extinguisher?
- What fire extinguishers are used?
- What kinds of suspension is used?
- What suspension are used for certain fire extinguisher?
- What type of suspension is used for what vehicles?
- What manufacturer of the fire extinguisher and suspension is used?
- Does the fire extinguisher and suspension go together or are they separate?
- What is best, protective box or not?
- How many boxes are used?
- Why are/ are not boxes used?
- How does the selection of fire extinguisher and suspension work?
- Is it adapted for vehicle type or not?

**Protocol**

- Are there any protocols about the inspections of the fire extinguishers?
- What do they consist of?
- Where does the protocols come from?
- What are the general opinion of the protocols?
- Can the protocols be clearer?

**Suspension - general**

- Vilka hållare används mest?
- What suspension is used the most?
- How often are suspensions replaced or fixed?
- What suspension is the best?
- What suspension is easiest to maintain?
- What suspension is easiest to use?
- What test are the suspension submitted to before installation or implementation?
- Are there any usability test done?

**Specifics for every suspension used**

- How are the suspension attached?
- How does id suspend the fire extinguisher?
- What are the biggest issues?
- What usually breaks?
- Why does it break?
- What manufacturer is there?
- What fire extinguisher can it suspend?

**General - fire extinguisher**

- What fire extinguisher are used the most?
- What types of damages occur and where?
- What are the cause of the damage?

**Specifics for every fire extinguisher used**

- Weight?
- Size?
- Type?
- Common damages- how do they look? Where are they located?
- Area of use?
Position

• Vart är de placerade?

• Where are they placed?

• Is there a reason for that?

• Does the position vary a lot?

• What height are the fire extinguisher placed at?
Vibration measurements

vibration measurements done in the Garpenberg mine. In the first section is the instructions given to the person performing the measurements and in the second section are the vehicles used listed.

Section A: Instructions

Preparations before testing:
• Before the testing begins make sure the data logger is fully loaded, plug it in in the computer using the USB-cable. The lamp will turn green if it is fully loaded, any other light combination means it needs to be loaded some more.

• Put tape over the USB-outlet on the data logger to prevent dirt and water from entering later.

• Tie a string in the loop in the lower right corner of the data logger, this will act as a safety line later if it gets loose.

• Adhere the data logger to the fire extinguisher using the double sided tape in the box. Place the data logger in the middle of the fire extinguisher, see figure. Make sure the x-axis of the small coordinate system on the front of the data logger is parallel with the edge of the fire extinguisher, see figure again.

• Press firmly when attaching the data logger to the fire extinguisher.

• Test if the data logger is adhered enough by giggling it slightly. If it is not secure it some more using duct tape.

• Fasten the other end of the safety line two the vehicle.

• Take the following pictures of the test set up:
  • Strength ahead
  • From the side
  • A perspective views
  • One was the vehicle is shown.

• Drive the vehicle as normal

During testing

• Press the button with the big C on it, the light will turn green if it is fully loaded or else it will turn green and red.

• Drive the vehicle as normal

After testing

• Remove the data logger from the fire extinguisher.

• Plug in the data logger to the computer using the USB-cord

• Go to my computer and the unit named SlamStickC. Make sure there is a folder named “DATA”, this means that the data logger has recorded.
Section B: Test set

The test was performed in the Garpenberg mine on three different vehicles, and six separate test were done, which are shown in the table below.

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Brand</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Ore truck</td>
<td>12-04-2018</td>
<td>19:30-21:00</td>
</tr>
<tr>
<td>Test 2</td>
<td>Ore truck</td>
<td>12-04-2018</td>
<td>23:30-01:00</td>
</tr>
<tr>
<td>Test 4</td>
<td>Loader</td>
<td>13-04-2018</td>
<td>23:00-00:30</td>
</tr>
<tr>
<td>Test 5</td>
<td>Minetruck</td>
<td>15-04-2018</td>
<td>19:15-20:45</td>
</tr>
<tr>
<td>Test 6</td>
<td>Minetruck</td>
<td>15-04-2018</td>
<td>23:15-00:45</td>
</tr>
</tbody>
</table>

Test 1 and 2
Test 3 and 4
Test 5 and 6
Fault tree analysis- FTA

Below is the fault tree analysis made of the data collected in the Context immersion phase. First is a simplified version of the FTA presented, before two more detailed are shown. Unfortunately is the FTA’s in Swedish, hopefully is this not to inconvenient.
Ideation

In this appendix will the result from the workshop as well as the morphological matrix be presented in full.

Section A: Workshop

Below are the ideas generated listed with a short explanation.

**Smart straps** - That the straps should have some kind of mechanism that keeps it tight even when it is starting to break or that the strap could sense that it was about to break and fix it self.

**Plastic** - a change of material to a reinforced plastic keeping the design pretty much the same. This would eliminate the sharp edges that wear on the straps as well as making the material connected to the fire extinguisher softer, prolonging its life before fatigue occurs.

**Quick release** - A quick release feature that moves the fatigue damage from the fire extinguisher to the attachment instead.

**Conveyor belts** - Using conveyor belts instead of the straps used today, as they are a lot stronger.

**Straps casted into the suspension** - In order to eliminate the attachment points between the suspension and the straps an idea was to cast them into the plastic, this is an idea that is based on the plastic version of the suspension.

**Dampers in the attachment points** - using some sort of dampers in the attachment points between the suspension and the vehicle.

**Utilizing the grapple on the fire extinguisher** - This idea is based on the bottom of the fire extinguisher being held in place in a similar way as it is done in type one except the top is held in place by a hook to the grapple. This hook is then supposed to be retractable making the release of the fire extinguisher easier.

**Air pillow** - using an inflatable pillow to suspend the fire extinguisher within a hard case. It should then be easy to deflate when removing the fire extinguisher.

**Plastic arms** - This idea is that instead of using straps should plastic arms that hug the fire extinguisher keep it in place. It would be fastened with the same clasp as now.

**Burdock** - Using a very strong burdock instead of straps and clasp.

**Clamping** - This idea is based on the design of the first suspension except it is in plastic giving it some flexibility and that it is open at the bottom so the fire extinguisher should be able to be drawn out of the suspension fast.

**Spring and screw** - This idea is based on putting the fire extinguisher in a cylinder with springs at the bottom and putting some tension on them, so that when released the fire extinguisher is pushed upward and out. The thought is also that the springs should give some dampening to the fire extinguisher.
Section B: Morphological matrix

Below is first the matrix with ideas shown and then are the ideas generated listed.

Number 1: Toolholder toolflex with casted straps
Number 2: Quick release with spring with angled cylinder
Number 3: Casted straps med solid cylinder
Number 4: Hook with rotation
Number 5: Quick release with spring with toolholder toolflex
Number 6: Casted straps with angled cylinder
Number 7: Retractable hook with solid cylinder
Number 8: Arms with toolholder toolflex

Number 9: Arms with solid cylinder
Number 10: Arms with cylinder with open front
Number 11: Retractable hook with solid cylinder med vickning
Number 12: Retractable hook with angled cylinder
Number 13: Arms with angled cylinder
Number 14: Quick release with spring with cylinder with open front
Evaluation

In this appendix will the evaluation steps taken be shown in full in chronological order, starting with the first screening done and all its steps and ending with the relative decision matrix.

Section A: First evaluation

Concepts after morphological matrix

Number 1: Toolholder toolflex with casted straps
Number 2: Quick release with spring with angled cylinder
Number 3: Casted straps med solid cylinder
Number 4: Hook with rotation
Number 5: Quick release with spring with toolholder toolflex
Number 6: Casted straps with angled cylinder
Number 7: Retractable hook with solid cylinder
Number 8: Arms with toolholder toolflex
Number 9: Arms with solid cylinder
Number 10: Arms with cylinder with open front
Number 11: Retractable hook with solid cylinder med vickning
Number 12: Retractable hook with angled cylinder
Number 13: Arms with angled cylinder
Number 14: Quick release with spring with cylinder with open front
Number 15: Material and shape change

Screening demand used:
Different option contradicts each other and are not compatible.

Concept after first screening

Number 1: Toolholder toolflex with casted straps
Number 3: Casted straps med solid cylinder
Number 4: Hook with rotation
Number 5: Quick release with spring with toolholder toolflex
Number 6: Casted straps with angled cylinder
Number 8: Arms with toolholder toolflex
Number 10: Arms with cylinder with open front
Number 11: Retractable hook with solid cylinder med vickning
Number 13: Arms with angled cylinder
Number 14: Quick release with spring with cylinder with open front
Number 15: Material and shape change

Screening demands used (taken from the product specification):
Should work for different brands
Fire extinguisher should be removable
Fire extinguisher should not be accidently released when vehicles is in use
Should be adapted for emergencies
Instructions should be visible
Be able to suspend a fire extinguisher
Concept after second screening

Number 1: Toolholder toolflex with casted straps
Number 5: Quick release with spring with toolholder toolflex
Number 8: Arms with toolholder toolflex
Number 10: Arms with cylinder with open front
Number 14: Quick release with spring with cylinder with open front
Number 15: Material and shape change

Screening demands used:
Risk of patent infringement

Concept before stakeholder evaluation

Number 10: Arms with cylinder with open front
Number 14: Quick release with spring with cylinder with open front
Number 15: Material and shape change

Final concepts

Number 10: Arms with cylinder with open front
Number 14: Quick release with spring with cylinder with open front
### Section B: Relative decision matrix

Below is the relative decision matrix presented with scores and criteria used.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Reference</th>
<th>Concept 1</th>
<th>Concept 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hold a fire extinguisher with the diameter of 150mm</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Instructions should be visable</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Is suitable to be mounted on different vehicles</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Not have a shape that makes it easy to be exposed to corrosion</td>
<td>(+)</td>
<td>(-)</td>
<td></td>
</tr>
<tr>
<td>Be constructed in a way that does not cause wear on fire extinguisher</td>
<td>(+)</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Have damping inside the suspension</td>
<td>-</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Be constructed in a way that failure of the fire extinguisher does not cause damage to the fire extinguisher</td>
<td>(+)</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Fire extinguisher is removable</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Fire extinguisher cannot be removed when the machine is operational</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Is adapted for emergency situations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visible handle/loch to release fire extinguisher</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>The release mechanism is natural aka the action affordance is equal the functional affordance</td>
<td>-</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Handle is easy to remove</td>
<td>(+)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>The fire extinguisher is easy to remove</td>
<td>(+)</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>There should be no fatal errors</td>
<td>(+)</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Should be able to hold different brands of fire extinguishers</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Concept 1</th>
<th>Concept 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+)</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>0</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>
Vibration analysis

In this appendix is the graphs from the vibration analysis presented.

Test 1
Test 2
Test 3
Test 4

FFT: Acceleration X (DC) (1200.0000s to 1500.0000s)

FFT: Acceleration X (DC) (3300.0000s to 3400.0000s)

FFT: Acceleration Y (DC) (1200.0000s to 1500.0000s)

FFT: Acceleration Y (DC) (3300.0000s to 3400.0000s)
Appendix 7

Test 5

- FFT: Acceleration Z (DC) (3300.0000s to 3400.0000s)
- FFT: Acceleration Z (DC) (1200.0000s to 1500.0000s)
- FFT: Acceleration X (DC) (2500.0000s to 2800.0000s)
- FFT: Acceleration X (DC) (4800.0000s to 4900.0000s)
Appendix 7

Test 6
Vibration analysis in NX12

In this appendix will the are every mode from the female and male half presented alongside their natural frequency.

Section A: Female half

Mode 1: 2365.25 Hz

Mode 2: 216.99 Hz
Appendix 8

Mode 3: 618.08 Hz

Mode 4: 3863.85 Hz

Mode 5: 4303.19 Hz
Appendix 8

Mode 6: 4628.55 Hz

Mode 7: 5510.19 Hz

Mode 8: 5586.06 Hz
Appendix 8

Mode 9: 5811.58 Hz

Mode 10: 6091.84 Hz
Section B: Male half

Mode 1: 2557.48 Hz

Mode 2: 3007.71 Hz

Mode 3: 3626.89 Hz
Appendix 8

Mode 7: 6585.22 Hz

Mode 8: 6619.47 Hz

Mode 9: 6886.87 Hz
Appendix 8

Mode 10: 7827.04 Hz