3D printing as a production method to improve operationality in the training/preparation phase of units

Bachelor thesis

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Abstract

The Royal Netherlands Army (RNLA) encounters problems, regarding the availability of their systems during the training phase. The focus of this thesis will be to improve system availability during the training phase of units.

One of the causes that reduces system availability are disruptions in part supply. Parts that suffer a disruption are not available via the normal supply chain. This can cause systems to be non-operational as they miss a part. Additive manufacturing (AM), in other words 3D printing, is seen as a solution that can contribute to reduce the magnitude of this problem.

In the first chapters of this thesis, the current policies and the current problems with regards to system management are described.

I will end this thesis by investigating the possibilities and cost-efficiency of AM, for some military parts of the RNLA.

This thesis aims to answer the question how AM can contribute to the training phase of units.

Management Summary

In this thesis, I have investigated how AM can contribute to the training phase of units. The following research question will be answered in this thesis:

How can AM of spare parts contribute in the training phase of units?

AM is famously known as 3D printing. AM is an upcoming manufacturing technology that could improve system availability, as the technology may offer an alternative supply source.

Disruption in supply

Within the RNLA, a system triangle existing out of a normsteller (system manager), a maintenance engineer and a system user, deals with a threat to part availability. This threat to part availability is caused by a disruption in supply. The system triangle considers several alternatives, to work around this disruption (Figure I). AM gives the system triangle an additional alternative to cope with a disruption of part supply, as additively manufactured parts can be used as replacement parts.

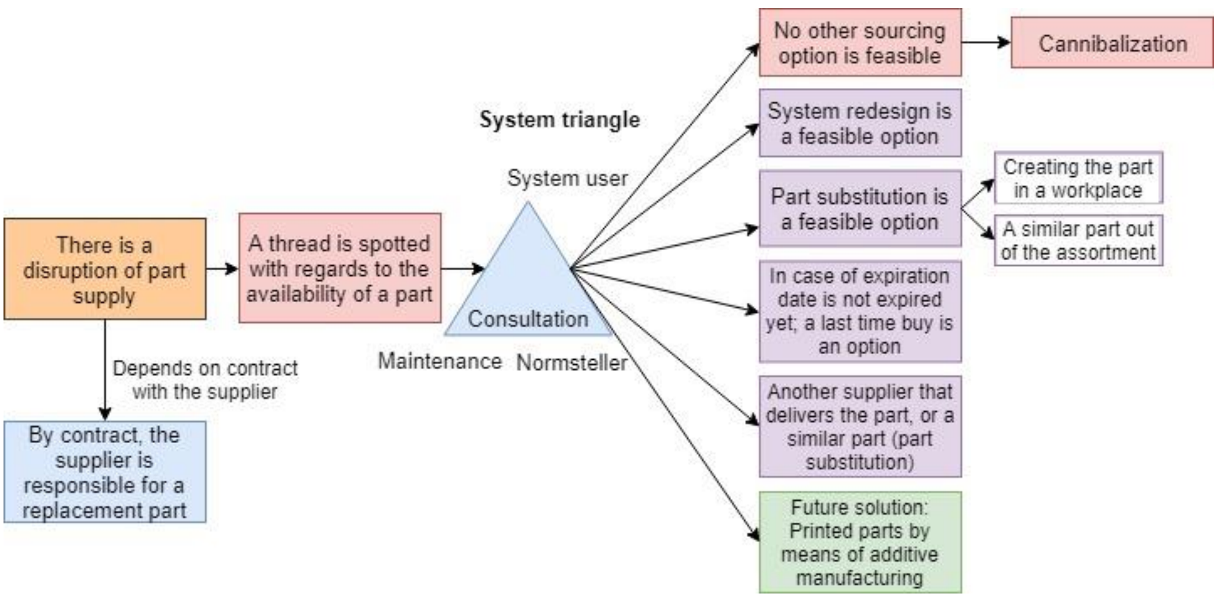

Figure I: AM; an extra alternative to safe systems

Systems that disturb the training phase

Next, I have investigated how AM can contribute to improve the availability of parts that suffer a disruption in supply. I decided that it would be most interesting to do this for systems that overlap the two sets in Figure II, as these systems disturb that training phase the most.

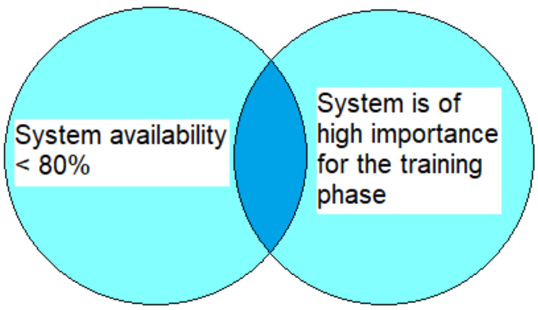

Figure II: Overlapping set of systems

The systems that were present in both sets are the Fennek, Boxer and Combat Vehicle 9035NL.

Investigating the possibilities of AM as a substitution method

Out of a set of components of the Fennek, Boxer and CV 9035NL, I made a selection based on the attributes criticality of an article and technical feasibility for AM (Table I). Also, I only considered components were supply was disrupted, since these components were identified as most critical to increase the system availability in the first place.

Together with two experts, I assessed the technological feasibility to print these parts (Table I).

Part	**Printed version can successfully be used a spare part?**
Protection plate	Yes
U – Profile	Yes
Spring brake cylinder	No, although a number of SRU's deserve consideration
Master cylinder	No
Distribution box	No, although a number of SRU's deserve consideration

Table I: Selection of parts and whether or not they AM can be applied to manufacture these parts.

Comparing AM with other alternative supply options

AM can be regarded as an alternative supply option, as well as part substitution (divided in creating the part in a workplace and using a similar part of the assortment), system redesign, having an external supplier delivering the part and a last time buy (see Figure I). These alternatives can be used to solve disruptions in part supply.
For the long term, finding another supplier or solving the disruption with a similar item that is already in the assortment is the best alternative. For the short term, this would be to take a similar part out of the assortment.
However, either of these options might not be feasible. For the short term, creating the part in a workplace would then be the best solution. If this option is not feasible, additive manufacturing must be considered.

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Preface

This research is conducted at the Royal Netherlands Army. The Royal Netherlands Army is part of the Ministry of Defence (Figure 1). This thesis was conducted as my final assignment of the Bachelor program Industrial Engineering and Management, which I followed at the University Twente. This Bachelor thesis is part of the 'Sustainability Impact of New Technology on After-sales service Supply Chains' (SINTAS) project. Within the SINTAS project, the impact of AM on spare part supply chains for advanced capital goods is studied.

Captain Jelmar den Boer and Hannah Wildenborg, my external supervisors, were active at the barracks in Soesterberg, at a logistical knowledge centre (OTCLog). At the knowledge centre, research is conducted about logistical chains within the Royal Netherlands Army.

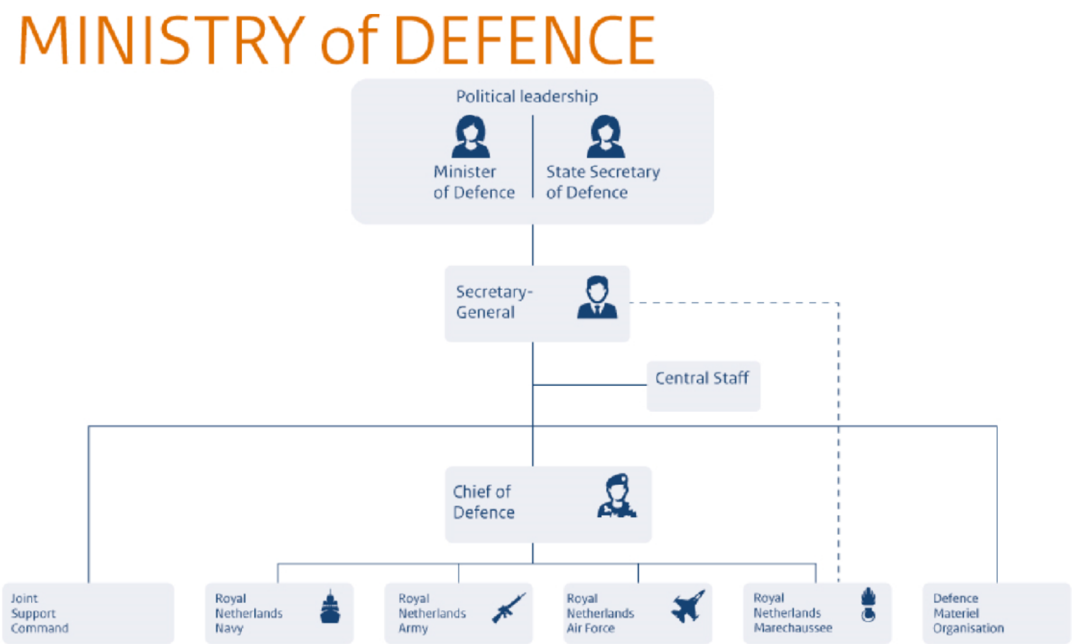

Figure III: Ministry of Defence as an organization (www.defensie.nl)

Acknowledgement

My journey throughout the RNLA allowed me to get an impression of the structure of the organization and to get to know people that work within the RNLA, which was one of my desires.

Employees of the RNLA were not always able to help me further when I had a question, because they did not have the right expertise to give me the information I needed. Still, it was really convenient that everybody with whom I got into contact was willing to help me. Either they helped me by giving me information or by putting me into contact with other people, that were in a better position to help.

It was good to have two external supervisors in Jelmar den Boer and Hannah Wittenburg that where available in case I needed some help. They have not only helped me to shape my

Bachelor assignment and to give me some contacts within the RNLA, but also they have also helped me with the more “trivial”, but important, stuff. I want to thank them for that.

I also want to thank internal supervisor, Nils Knofius. Nils was able to look at certain parts from an “outsiders perspective”. His advice made me aware of things I did not really think about. Those additions make this Bachelor thesis more complete. Also, the feedback that he gave me was always clear, which helped to process the feedback and come up with improvements. At last, my thanks go out to everybody within the RNLA that helped me throughout my time at the RNLA. I have had quite some mail contact and phone conversations with numerous of people about various subjects. As I already said, the willingness to help stood out.

1. Introduction

The Royal Netherlands Army contributes to peace, freedom and safety in and outside the Netherlands.
The Royal Netherlands Army has three duties inside the Netherlands (www.defensie.nl):

- The land force defends Dutch territory
- The land force supports bodies of the government
- The land force supports social organizations

The most important tasks abroad, are the following:

- Defending the territory of NATO allies
- Keeping peace or enforcing peace
- Offering humanitarian assistance
- Protecting citizens and supporting civil organizations

For a number of missions, the Royal Netherlands Army cooperates with other foreign army units.
To accomplish the mission goal, military equipment and trained soldiers are vital. For RNLA units it is important to have military systems available to train with, in order to become mission ready.

The perceived problem of the RNLA was that the level of availability of their equipment in the training phase is too low, in order to prepare soldiers sufficiently for a mission. The training phase is the period of time in which soldiers of the RNLA prepare for a mission. Military preparation could be defined as "the actions taken to plan, organize, equip, train, and exercise to build and sustain the capabilities necessary to prevent, protect against, mitigate the effects of, respond to, and recover from threats to national security interests." (www.dhs.gov) The goal of training soldiers is to build and sustain their capabilities.

Currently, the RNLA is considering various new technologies that may help in optimizing the technological readiness during missions and preparation phase. AM, popularly known as 3D printing, is one of the technologies that is considered interesting.
AM is thought of as a technique that should be useful for the manufacturing of single products (or very small quantities), customer-specific, on demand and on location. The RNLA encounters such products often in after-sales service supply chains, the supply chains of spare parts needed for maintenance & servicing of advanced capital goods like military equipment. With regards to the problem that the RNLA has encountered; AM could be used to improve system availability. In case a part is unavailable, a printed version of the part could be as (temporary) substitute part to keep a complete system operational.

1.1.1 AM technology

J.C Johnson and A. Sasson (2016) define AM as a process where solid objects are made from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created layer by layer until the entire object is created. Each of these layers can be seen as a thinly sliced horizontal cross-section of the eventual object.
There are different ways of manufacturing that fall under the term AM. Table 1 shows the different ways of AM and their properties. The properties of a printed object can differ in the type of material, complexity, size, (surface) quality and accuracy. (Ngo et al. 2018)

Methods	Materials	Benefits	Drawbacks
Fused deposition modelling	Thermoplastic polymers, fibre reinforced polymers	Low cost, high speed, simplicity	Weak mechanical properties, limited materials
Powder bed fusion	Metals, alloys, polymers*, ceramic	Fine resolution, relatively high quality	Slow printing, expensive, high porosity in binder method
Inkjet printing and contour crafting	Concentrated dispersion of particles in a liquid, ceramic	Ability to print large structures, quick	Coarse resolution, lack of adhesion between layers
Stereolithography	Resin with photo-active monomers, hybrid polymer-ceramics	Fine resolution, relatively high quality	Limited materials, slow manufacturing process, expensive
Direct energy deposition	Metals and alloys (in form of powder or wire), ceramics, polymers	Reduced manufacturing time and cost, good mechanical properties	Low accuracy, low surface quality, limitations in printing complex shapes
Laminated object manufacturing	Polymer composites, ceramics, paper, metal	Reduced tooling and manufacturing time, high range of materials, low cost, possibilities to manufacture larger structures	Low surface quality, limitations in manufacturing of complex shapes

Table 1.1: Different ways of AM and their properties (Ngo et al, 2018)

1.1.2 AM at the RNLA

The RNLA has a proactive approach towards printing. Part of this proactive approach is the establishment of the AM centre. At the AM centre, knowledge about AM is collected. The AM centre will also act as a point of contact.

To embed AM in the organization, a roadmap has been made that outlines the implementation process within the RNLA. The roadmap is divided in three parts:

- Phase 1 (approximate length: 2 years): This is the current phase in which Defence finds itself. Defence is still experimenting during this phase. The goal of this phase is to gather more knowledge about AM and to let people become acquainted with AM.
  In this phase, investigation on which parts are interesting to be produced by means of AM is executed. Key aspects as quality of a part and life cycle costs are analysed.
  Because the mechanical properties of printed items differ from conventionally manufactured parts, the RNLA considers only non-critical parts to experiment with.
  For now, this policy ensures that when someone mistakenly puts trust into a printed part, the consequences of failure are mediocre.
  A recent experiment of the RNLA was that fifteen Fennek (vehicle) parts were printed. These parts where printed by a plastic printer by of the RNLA themselves and by a metal printer of a service provider. The RNLA investigates what the quality of these parts is and how they differ from conventionally manufactured parts.

3D printing has also been used in Mali during a mission, where the technique was able to fulfil some small desires of soldiers. For example, a weapon holder and a small part of a pair of glasses were successfully printed and used in the mission area. (www.defensie.nl)

- Phase 2 (approximate length: 3 years): In this phase, the RNLA uses knowledge that is gained in Phase 1. In Phase 2, AM is wider applied within Defence. The experimentation time is over as AM gets imbedded into the logistical chain.

- Phase 3 (The future after the first two phases): In this phase, AM is completely embedded in the organization. AM is used for different purposes, for which the usage is optimized.

1.2 Research design

1.2.1 Problem Identification

The RNLA possesses systems that cannot be used for training purposes, because of missing replacement parts and no alternative supply options.
Figure 1 depicts what the consequences of a disruption in part supply during training are. Eventually, the disruption of parts will disturb the training phase as training systems are unavailable due to lack of parts. This causes the units that are in training to be less qualified to perform in a mission context.
From the problem cluster in figure 1.1, I derive the following core problem:

Core problem: Certain systems cannot be used in the preparation phase for a mission, since they lack parts that are not available because of a supply disruption.

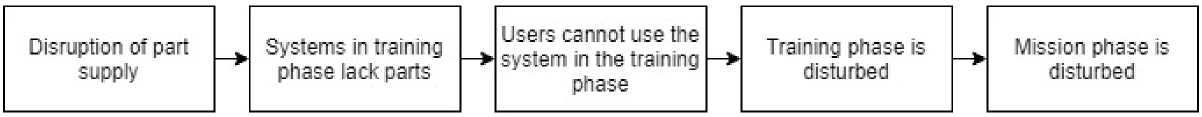

Figure 1.1: Problem cluster

Within the RNLA, AM is seen as a (future) solution to produce unavailable parts that can be used to overcome this problem and therefore to keep systems operational.

Cannibalization

The only purpose of non-operational systems is the option to harvest spare parts for other systems. This phenomenon is also reffered to as cannibalization.
According to Jingyu Sheng and Darren Prescott (2017), the definition of cannibalization is the following: "*cannibalization is a maintenance activity that involves removing serviceable parts from one platform to replace failed parts in other platforms when the required spares are unavailable.*"

1.3 System of research questions

The core problem reveals that there is a need to consider alternative supply sources to obtain unavailable parts, in order to improve system availability in the training phase.
By answering the following main research question, I want to find out how AM may make a difference in increasing system availability within the RNLA during the training phase.

Main research question: How can AM of spare parts contribute in the training phase of units?

In order to answer the research question I will answer the research questions mentioned below.

1. How is the current process of dealing with disruptions in supply within the RNLA?

The first research question will describe how the RNLA currently deals with disruptions in part supply.
Employees of the RNLA, including me, have access to the RNLA's internal network, the intranet. I have used the intranet to find information to answer this research question. Obtaining information by talking to people that are active within the RNLA has also helped me to answer this research question.

2. What is AM?

To answer the second research question, I will use various literature sources to explain what AM is and why it is considered interesting to manufacture parts by means of AM.

3. How is the training phase structured?

In the third research question I will answer how the training phase is structured and what the consequences can be of insufficient training. Again, I will answer this question by using the information that I got from the Intranet and interview sources.

4. Which military systems have an availability that is deemed too low?

Fourth, I will investigate the system availability of forty military systems. In order to assess whether the system availability of a certain system is inappropriate, I need to find out what the RNLA's norm is with regards to system availability. Again, I will answer this question by using the information that I got from Intranet and interview sources.

5. Which military systems have a high importance for training?

In the fifth research question I will investigate which systems are most important for the training phase. I will assess what the most important system is by calculating which systems have the biggest contribution to soldiers becoming qualified.

6. How can potentially attractive parts (with a disruption in supply) for AM be identified for the identified systems?

The system set that is identified in Research Question 4 and the system set that is identified in Research Question 5, will be used to answer Research Question 6. The overlapping systems of the two system sets indicate for which systems further investigations appears most valuable. By assessing the attributes of the parts I will thin the group of parts out. The small selection of parts that remains will be used for further investigation with an AM expert.

7. How does AM compare with alternative sources of supply?

With the help of normsteller (system manager), I get insight in the supply alternatives that can be considered for the selected of Chapter 6. Eventually, I will compare AM with other supply alternatives that are used to solve a supply disruption.

1.4. Outline

Table 1.2 below aims to give an outline of which content each chapter covers and which research question is answered in a certain chapter.

Chapter	**Content**	**Research Question**
Chapter 2	I will describe the current process within the RNLA, with regards to dealing with a supply disruption	1
Chapter 3	I will use literature to extensively explain what AM is	2
Chapter 4	I will give the reader information about the structure and the meaning of training for the RNLA units	3
Chapter 5	I will determine which system disturbs the training phase the most	4 and 5
Chapter 6	I will select parts of the in Chapter 5 identified systems and assess their possibilities to be manufactured by means of AM	6
Chapter 7	I will compare AM with other supply alternatives for the selected parts of Chapter 6	7
Chapter 8	I will give a conclusion, recommendations and discuss the possibilities for further research	8

Table 1.2: Outline of this thesis

2. How the RNLA deals with a threat to system availability

In order to describe the processes within the RNLA, I have made use of sources (experts and documents) within the RNLA.
Figure 2.1 depicts how a supply disruption of spare parts is recognized within the RNLA and how the RNLA deals with it. The process basically consists of two steps.
The first step of the process is to recognize a threat to system availability, which is caused by a supply disruption. This means that the supplier is not able to deliver the part anymore.
Supply disruptions can either be expected and unexpected. It would be expected when the long-term contract with a supplier, to secure spare parts, expires. It is challenging to keep a military system operational after the contract has expired, as military parts are customized for military. There are also cases in which the supplier unexpectedly has problems to deliver the part.
For most systems, the RNLA has contracts in which is documented that the supplier is responsible to find another supplier in case of a disruption in part supply.

After the thread to system availability is recognized, the system triangle consults with each other about possible sourcing alternatives that may solve the problem. In some cases, the RNLA needs to look for an external supplier themselves. As said, this depends on the contract that the RNLA has with the original supplier.
However, an external supplier may not be found or the lead time may be unacceptable. The system triangle also considers three other supply alternatives: System redesign, part substitution and a last time buy.

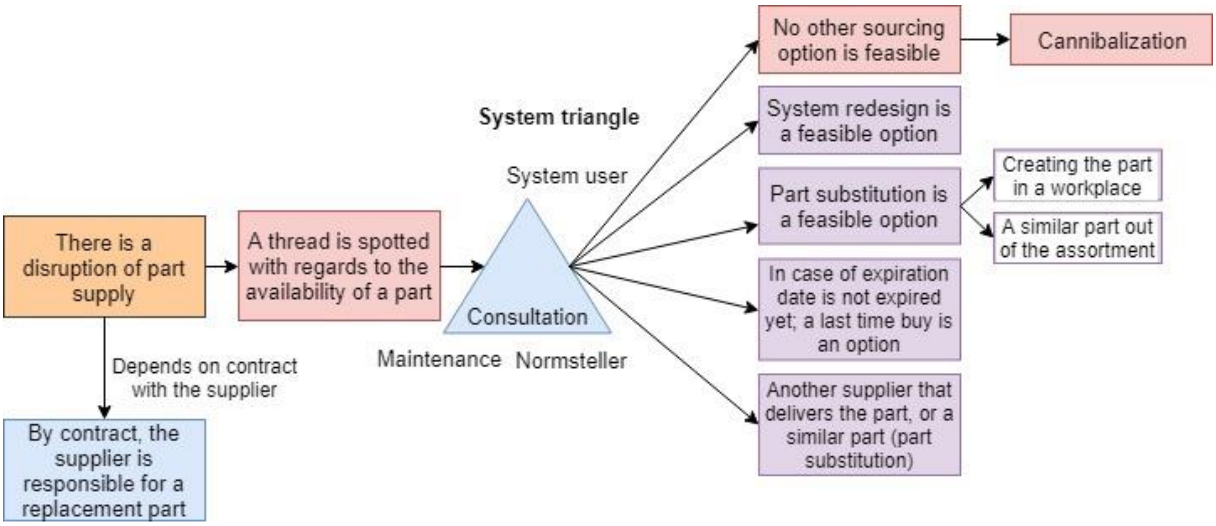

Figure 2.1: Process of dealing with a threat to part supply, when the part is not available anymore

In Section 2.1 of this chapter, I will discuss what the system triangle is and what it wants to achieve. I will follow this up in Section 2.2, as I extensively discuss which roles each party plays within a consultation of the system triangle.
In Section 2.3, I will explain what the different supply alternatives are when there is disruption in part supply.

2.1 System triangle

The system triangle is composed of three actors, namely the normsteller ("someone who states

requirements for a system", see Section 2.2.1 for a more extended definition), a maintenance engineer and a system user.
The purpose of the system triangle is to achieve a pre-defined level of system availability, against the lowest possible life cycle cost.

2.1.1 The system triangle's way of working

The consultation of the system triangle results in a system analysis (Figure 2.2). Based on the system analysis, decisions are made with regards to system upkeep.

In short, the participants of the consultation are responsible for:

- Striving for a system availability that is above the norm
- Getting insight in the current and future usage profile
- Getting insight in the needed financial budgets
- Getting insight in the needed maintenance capacity in the short and long term

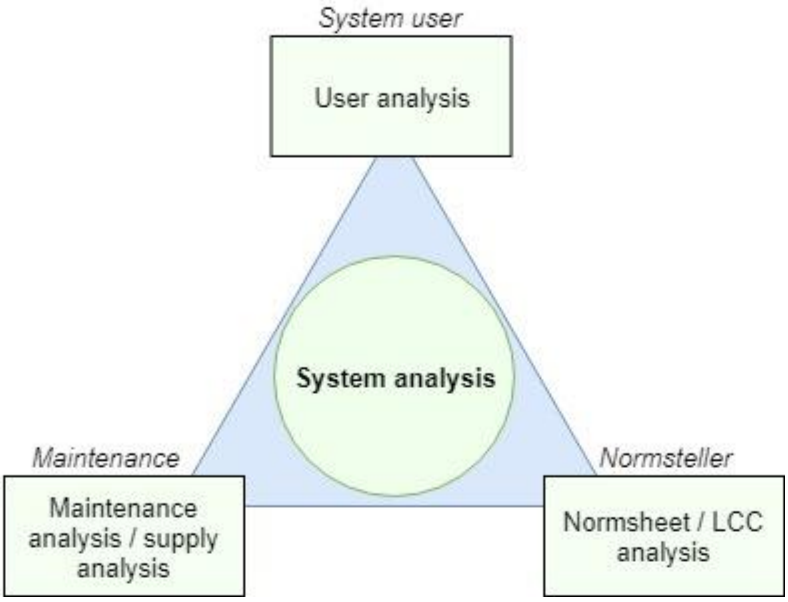

Figure 2.2: The different perspectives that each member of the system triangle brings to the table for the consultation

2.2 Parties involved in the system triangle

In this section, I will explain the role and perspective of each party that is part of the system triangle in further detail.

2.2.1 Normsteller

A normsteller is a representative of DMO, the defence materiel organization. A normsteller has the competence to set requirements that apply for (weapon) systems and/or installations. The normsteller monitors standards related to reliability, availability, maintainability, safety and value retention. Also, the normsteller keeps track of system performance indicators and projects the life cycle costs. The normsteller monitors the life cycle costs by doing a LCC analysis. In this analysis, the investment costs, exploitations costs, maintenance costs and release costs of a system are determined. These costs are further divided into smaller, more detailed costs.

2.2.2 System user

The system user formulates desires with regards to availability of the system. He also evaluates functional demands with regards to the way of using a system.
The system user brings an user analysis to the consultation. The user analysis verifies whether the current user profile is representative for the actual usage. The goal of an user analysis is to increase the system effectiveness. The outcome of the analysis could lead to possible changes in the user profile.

2.2.3 Maintenance

MATLOGCO (Materiel Logistics Command) who is usually responsible for the system maintenance, shares information about relevant maintenance and supply contracts. Furthermore, the maintenance representative also share insights about spare parts supply and maintenance.
There are two analyses that are brought to the consultation by the maintenance representative, namely a (part) supply analysis and a maintenance analysis. The supply analysis is carried out continuously.
The goal of the supply analysis is to find out whether the right amount of parts are present in stock and to check whether the supply chain configuration requires improvements. The maintenance analysis considers several maintenance aspects that are relevant for the system. The recommendations that result from the analysis aim to ensure that the required system availability will be achieved in the future, against the lowest costs.

2.2.4 Chairman

The chairman leads the consultation between the three parties that are involved. The chairman has to report the outcomes of the consultation between the three parties. He also coordinates the integral decision making process with regards to future system usage and system upkeep.

2.3 Sourcing options that are considered in case of supply disruption

As elaborated earlier, the system triangle considers the following sourcing options when the availability of a system is in danger: a different supplier (external supplier), system redesign, part substitution and a last time buy. When these four options are not feasible, the system is deemed to stay non-operational. In this case, the non-operational system will be cannibalized, which is explained in Section 1.2.1.
All the options that are mentioned are further explained in the next sections.

2.3.1 Finding another supplier

In case of a supply disruption, the preferred option for the long term is to find another supplier offering the same part. It could also be a very similar part that could act as a replacement for the unavailable part. This would be part substitution, which is explained in Section 2.3.3

2.3.2 System redesign

System redesign avoids the need for a specific part (Behfard et al., 2013). The system is redesigned in such a way, that the missing part is not needed anymore to make the system operational. This alternative is in general expensive and takes a lot of time (Hekimoglu, 2015). System redesign is often regarded as the least desired solution in case of a supply disruption. In this Bachelor thesis, part redesign falls also under system redesign. After all, a part redesign leads to a redesign of the system, which is a collection of parts.

2.3.3 Part substitution

When part substitution is applied, a missing part is replaced by a different part that is available. In this Bachelor thesis, part substitution is divided in two options:

- Taking a similar part out of the assortment
- Creating the part in a workplace

Note it is also part substitution when a part that is manufactured by means of additive manufacturing is used for substitution.
With additive manufacturing technology, objects can be created. To make use of this technology, a 3D printer and resource material is needed. A 3D printer has the ability to convert a computer made CAD-file into a physical 3D object.
The industry and the RNLA have recognized additive manufacturing as a new method to manufacture replace parts. The idea is that a printed part can replace a failed part of a system, to make the system operational again.
In Chapter 3, additive manufacturing is extensively explained.

2.3.4 Last time buy

Behfard et al. (2013) explain the last time buy option as follows: "Placing a large final order (before contract with OEM expires), a so-called Last Time Buy (LTB), is common in industry. Often, the LTB quantity is very large to attain a high service level, which also yields high obsolescence levels at the end of the service period."
According to Behfard et al. (2018), the key causes of uncertainty in making a last time buy decision are:

- The size of the installed base and its evolvement
- The parts failure rate over time, which may be affected by usage patterns and wear-out.

The uncertainties that are tied to a last time buy make it an option for which the order quantity needs some consideration.
Some military spare parts also need maintenance in stock. In these particular cases, ordering a large quantity as a last time buy, means that there are also maintenance costs included in the inventory cost of a part.
Furthermore, the quantity that is ordered will take up space, which leads to inventory costs next to cost of capital.

2.4 Conclusion

The system triangle, which exist out of a normsteller, a maintenance engineer and a system user, is responsible to handle threats to system availability.
The system triangle considers four different options to conserve a system, when there is a supply disruption of parts: Looking for another supplier, system redesign, part substitution and a last time buy. When these options are not feasible, the system is used for part cannibalization. In the next chapter I will discuss the possibilities that AM brings and what its impact could be on system availability.

3. AM: the future

In this section, I will explain what AM is and why it is considered interesting by the RNLA as possible alternative to deal with supply disruptions.
Further, I will discuss the future perspective of AM and which obstacles AM needs to overcome to become a major manufacturing technology.
Note that I have stated which different AM methods there are in Section 1.1.1, followed up by the RNLA's future plan for AM in Section 1.1.2.

3.1 AM technology

Conventional manufacturing methods involve a piece of material that is being shaped into the desired object. AM is the opposite; structures are made layer by layer by a 3D printer. The addition of minuscule layers eventually forms a solid object. (www.spilasers.com)
Typically, production lead time to print spare parts is short. In some cases, it may even possible to produce a 3D printed part within one day. Altogether this renders AM as a fast manufacturing method, that minimizes system downtime.
The idea to manufacture parts by means of AM and use them to improve system availability, is not new to the world. Li et al. (2015) and Khajavi et al. (2014) are examples of literature sources that propose AM as a sourcing alternative for spare parts. Also, printed spare parts have already been successfully applied at the RNLA and US Navy.

3.2 Advantages of AM

The following advantages can be recognized for AM, as opposed to conventional manufacturing methods cf. Zanardini et al. (2016), Knofius, Van der Heijden, Zijm (2016) and Gibson et al. (2010).

1. The supply chain can be shortened by cutting unnecessary actors and processes.
2. It is possible to manufacture customized, different designs embedded with personal preferences with rapid changeovers.
3. Safety stock costs can be avoided while response times are kept short by printing on demand.
4. It is likely for low-volume parts that the production costs can be reduced because of lower setup and tooling costs.

AM shortens the supply chain as part suppliers are not necessary as well as that it reduces the need for inventory and material handling.
The layer-by-layer technology of AM allows users to manufacture complex shapes, that could not have been created by means of conventional manufacturing.
For low-volume production, AM can be cost-efficient since tooling and setup costs are usually less than for conventional production processes.

3.3 The obstacles that AM needs to overcome

Although AM has clear potential, there are obstacles that it needs to overcome to become an established manufacturing technology. Some key obstacles are the quality of the manufactured parts, costs, piracy, print prices

3.3.1 Quality of additively manufactured parts

The mechanical properties like hardness, toughness, abrasion resistance and surface quality of a printed part differ from a conventionally manufactured part. It should be noted that the mechanical properties of printed parts also differ per AM method.
According to Ngo et al. (2018), the biggest quality problems that are encountered in additively manufactured objects are the following:

- A challenge that printed objects have to deal with is anisotropic behaviour. According to Kalpakjian and Schmid (2014), anisotropic behaviour means that an object exhibits different properties when tested in different direction.
- Another issue that printed objects have is void formation between subsequent layers of materials. This causes additional porosity during the manufacturing process. As a consequence, the mechanical performance of the object is reduced as the bonding between the two layers deteriorates.

3.3.2 Costs

The costs of AM are high, but as said in Section 3.4.2, AM may be cost-efficient for low volumes.
However, AM faces the following issues with regards to costs according to Murmura and Bravi, 2018.

- Due to patents and less competitive market structures the raw material cost for AM can be quite high compared to conventional manufacturing.
- The implementation phase of a new technology needs time, as the organization needs to get familiar with the technology. These costs are part of the typically high investment costs for AM.
- The printing equipment itself is rather expensive. Next to the general novelty of commercial printing processes, short equipment development cycles increase the threat of technological obsolescence.

The department of technology, where the AM centre of the RNLA will be located, is already experimenting with printing parts. In cooperation with DiManEx, an industrial partner of the RNLA, metal parts of the Fennek were manufactured. One of these experiments was a locking pin.
In a comparative case study (see Appendix X17), I have compared three methods to obtain a part, based on costs: Printing, creating the part in a workplace and ordering the part from a supplier.
The conclusion of the case study was that metal printing with post-processing is clearly more expensive than ordering and creating the part in a workplace.

3.3.3 Intellectual property

Because of the digital nature of additive manufacturing, its application causes an additional threat to cybersecurity. Also, it is perceivable that designs or intellectual property gets stolen or corrupted by a cyberattack.

According to Erica L. Neely (2015), there are two other ways to recreate using a 3D printer: "First, if you have a copy of the relevant CAD file, you can simply print it out using your own equipment. This is something companies can address by protecting their files; if a person has an illicit copy of the file, then that can be treated as theft, just like for any other file. Unfortunately, there is another method of reproduction that avoids this sort of obvious theft. Using a 3D scanner, a person can scan an object and create their own plan for how to print it. This file can then be saved and used to reproduce the original object."

3.4 The potential of AM

AM has a lot of hype and already has been implemented by various industries. Still, further advancements are necessary to see a more frequent application of AM in industry. Table 3.1 and Figure 3.3 show that (literature) sources expect AM to grow and technologically advance, which justifies the RNLA's interest in AM.

"In the case of a technology like AM, it is assumable that the technology will keep on developing and become more efficient"	Khajavi, Partanen & Holmström (2014)
"AM (AM) is poised to bring about a revolution in the way products are designed, manufactured, and distributed to end users."	Gao et al. (2015)
- *Printing speed will increase* - *New combinations of 3D printing materials will come up* - *Improvements to existing materials will be made* - *There will be an emphasis in metals that is likely to grow over the next three years (metal printing)*	UPS and the CTA. (2015)
"Recent advancements in speed, printing technology and material capabilities are now aligned, and together they will push the entire industry forward." *"Direct-metal printing is getting faster and more capable, and many new technologies are now coming into play. The number of metal alloys that can be 3-D printed is on the rise, and they have exceptional performance characteristics."* *"For decades, 3-D printing has been capable in terms of geometric precision and accuracy, but printing speeds remained very slow. But this too is changing."*	Avi Reichental (2018)

Table 3.1: Positive perspectives of AM, according to literature

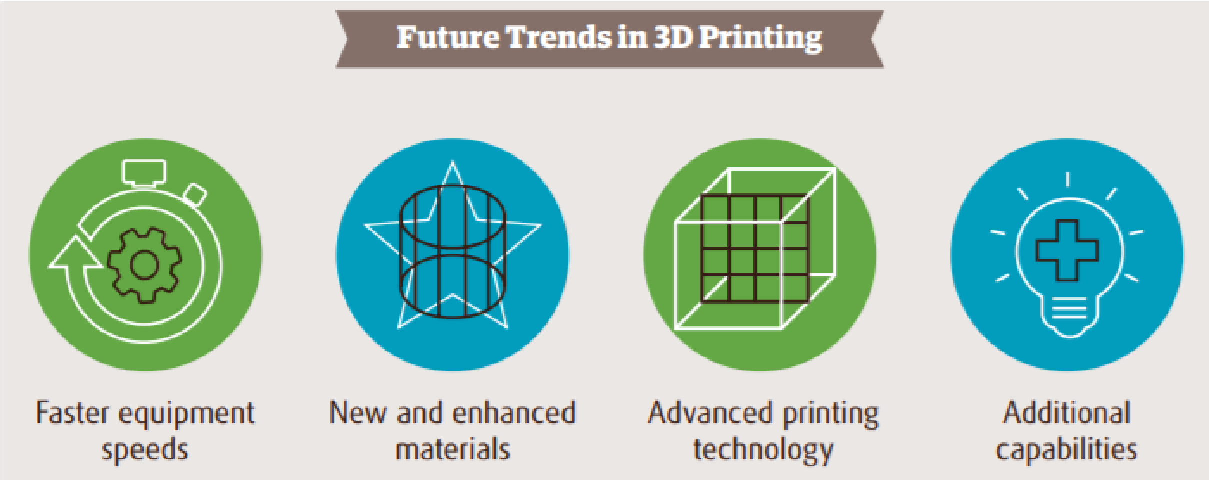

Figure 3.1: Future of AM by UPS and the CTA. (2015)

3.5 Conclusion

The upcoming manufacturing technique, AM, presents an extra option to re-establish the supply continuity and therefore improve the availability of equipment in the training (Figure 3.3). Spare parts can be printed by means of AM and be used to substitute the failed parts.
In the future, the RNLA wants to use additive manufacturing for all kinds of purposes, to quickly obtain parts. Although there are still obstacles to overcome, AM is growing quickly and it is believed that it might replace conventional manufacturing methods in some domains. Therefore, it is justifiable that the RNLA has started experimenting with AM to become acquainted with the technology.

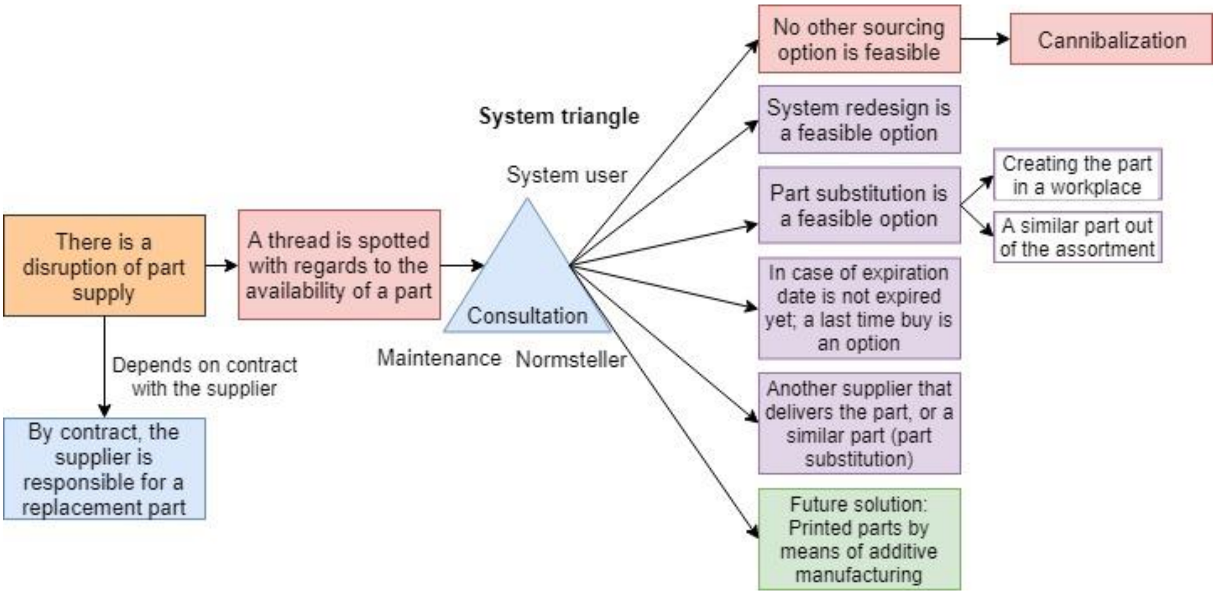

Figure 3.2: The new process that considers AM as a way to obtain spare parts

4. Military preparation and military training

4.1 Training as part of the preparation phase

The key focus of the RNLA is to have enough systems available to work with, on the actual mission itself. After all, the "real work" is done on a mission. Because of its importance, improving the availability of systems in missions has always got more attention than improving the availability in the training phase.
The goal of training soldiers is to build and sustain soldier's capabilities. Training can be seen as a smaller part of mission preparation (Figure 4.1). Soldiers of the RNLA train/prepare inside the Netherlands, but also abroad. The key advantages of training abroad are that there is more space to train and the circumstances may be more representative for the actual mission.

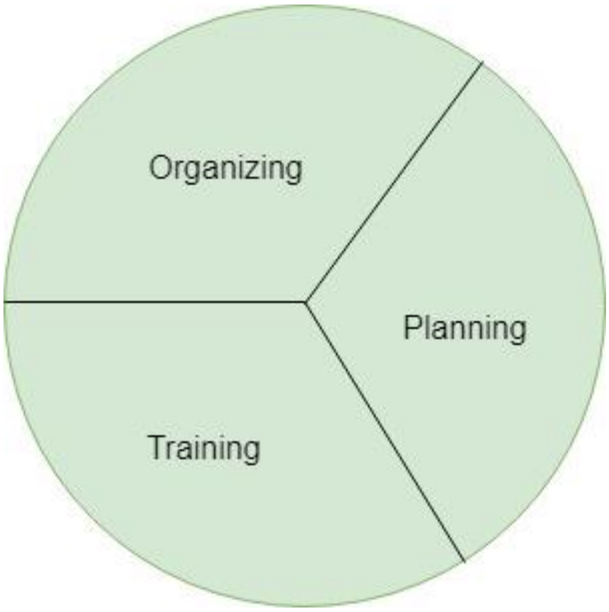

Figure 4.1: Mission preparation

4.1.1 Operational readiness

The operational readiness of units depends on the following three factors: personal preparation, material preparation and practice.

1. **Personal preparation** is concerned with the physical and mental fitness of soldiers to execute military activities.
2. **Material preparation** is concerned with the extent to which systems are available to perform military tasks.
3. **Practice** is concerned with the extent to which a unit has practiced certain activities, to reach the desired level of acquaintance and fluency. In this thesis, I will try to improve this factor.

4.2 System availability in the training phase

The availability of systems/parts has been an issue for quite some time within the RNLA. Also the media and politics have discussed this problem. (www.digibron.nl) Not only supply

disruptions of parts caused this problem, but also other factors played a role, such as incorrect demand forecasts and quality of personnel. Probably though, the most important cause is the lack of budget that the RNLA had (www.nos.nl).
The problems with system availability are documented by the most recent system readiness reports (Gereedheidsrapportages), where commanders report about operational reality.

4.2.1 Current level of system availability

During the period of time from 21-01-2016 to 13-06-2018, military units have carried out the following measurement every week: The units have measured the system availability of every system type that they possessed. In total, 194881 measurements were carried out during this period of time. Table 4.1 presents the results.

Number of measurements above or under 60% system availability		**Number of measurements above or under 80% system availability**	
Above 60%	153712 (78,88%)	Above 80%	135720 (69,64%)
Under 60%	41169 (21,12%)	Under 80%	59161 (30,36%)
Total	194881	Total	194881

Table 4.1: Measurement carried out every week during period of time from 21-01-2016 to 13-06-2018: System availability per system type (per unit). In total 194881 measurements were carried out. (internal source)

4.2.2 Consequences of a low level of system availability during training

There are numerous consequences of a disturbed training phase. In this section, I sum up the consequences that are encountered when system availability is too low to train conveniently.

4.2.2.1 Inability to perform in a mission context

Within the RNLA, a guiding principle for practice is “train as you fight”. The reasoning behind this principle is that training has the most added value when it approaches operational reality. Training and repetitions should lead to a unit or an individual being able to recognize a situation and act on auto-pilot. The combination of too little training and having to perform in the stressful mission context, can have as a consequence that a soldier makes the wrong decisions, which could have devastating consequences.

4.2.2.2 Wrong usage of systems

When a soldier does not use a system correctly, this could lead to unwanted consequences:

- The system can get damaged, because the system usage was reckless.

It is important for system users to practice system usage in different environments since the environment may influence how a system should be operated. Damage originating from improper use of the equipment causes systems downtime and leads to unnecessary maintenance costs.

- The system is not used to its fullest potential.

Most systems of the RNLA are equipped with advanced equipment. In order to get to know how the equipment can be used and what the possibilities of the equipment are, (excessive) training is required. Otherwise, full mission potential will not be reached.
There might also be more trivial things as driving fuel-friendly, that improve as there is more training interaction with the system by the training units.

4.2.2.3 Lower mission effectiveness

The effectiveness of the mission and the overall fluency of the operations is affected by the training. Basically, success of a mission largely depends on the skill of the soldiers, which are obtained during the training phase.

4.2.2.4 Low military morale

The military morale of a unit is largely based on the fidelity to a cause, attitude toward duty and the confidence level of that unit (James A. Ulio, 1941).
A level of system availability that is perceived as low by a unit, has a negative effect on the motivation of that unit. Having a shortage of training materials does not allow units to train as much as they would like to. Resulting that units have a low confidence level, as they feel that they are not prepared properly. It may make them feel that they are not taken seriously, which has an effect on their military morale.

4.2.2.5 Value of a better training

The previous sections show that the system availability during training is related to safety and costs during the mission. But, it is difficult to relate an improved availability in the training phase to safety and costs during mission.
However, it is possible to measure the cost effectiveness of training. Certain performance measurements should be made and be checked during the mission. For example, a variable as *number of accidents per total time spent in battlefield* could be used as performance measure during a mission. This variable should be linked to a variable as *the total costs of training,* in order to put it into perspective.

4.3 Conclusion

Training is part of military preparation. There are many system types for which less than 80% is available for the units to train with. This has the following consequences:
- Soldiers may be unable to perform in a mission context.
- System users are not able to use a system correctly which may lead to system damage.
- System users cannot use the system to its fullest potential.
- The mission effectiveness is lower.
- Military morale is low.

5. Systems that disturb the training phase

In this chapter, I will investigate which military systems disturb the training phase the most. The set of systems which will be identified will be used for further investigation in Chapter 6, where I will examine the attractiveness of AM for parts that belong to these systems. For a system to belong to this set, I have set two requirements (Figure 5.1)

1. The system availability is lower than 80%.

2. The system is of high importance for the training phase.

Further explanation and motivation for these requirements will be given in the next sections.

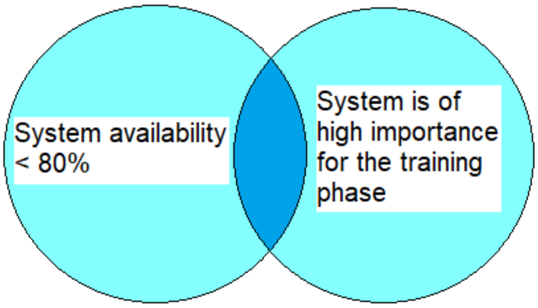

Figure 5.1: The overlap between the two sets gives which systems disturb the training phase

5.1 System availability

System availability is an indicator, which gives the percentage of operational systems. System availability is calculated with the following formula:

$$System\ availability = \frac{Number\ of\ available\ systems}{Total\ number\ of\ systems} * 100\%$$

The 80% norm is widely used within the RNLA, in order to say something about the availability of a system. If a system has a system availability higher than 80%, the availability of that system is in general “acceptable”. In case a system has a system availability lower than 80%, this is perceived as an alarming situation.
Table 5.1 shows the set of systems that have a system availability lower than 80%. Appendix X1 shows all the military systems and their system availability. Note that the system availability is calculated per system type.

System	System Availability
Mobiele telescoopkranen	0.79
Leopard 1	0.79
CBRN Verkenningssystemen	0.78
Bouwmachines	0.78
YBZ 3300 en YWL 3300	0.75
Graafdozer	0.75
Vrachtauto 12kN Vector	0.75
Fuchs (EOV)	0.75
UAV Scan eagle	0.72
Fennek	0.72
Patriot	0.70
Army Ground Bases Air Defense System (AGBADS)	0.69
Y 2300 alle types	0.68
EODD	0.67
Tactische satellietsystemen	0.67
Mobiele voedselbehandelingsystemen	0.66
Bushmaster	0.65
Leopard 2	0.63
BOXER	0.61
Raven	0.44
QUAD	0.44
Mobiele Waterbehandelingsystemen	0.40
Combat Vehicle 9035NL (CV90)	0.36
PzH 2000 NL	0.30
MOGOS ? MGC containers	0.17

Table 5.1: Systems with an availability under the 80%

5.2 System importance for the training phase

It is difficult to just order systems based on their "importance for training". Every military system needs interaction with humans in order to be installed or perform in a mission context. Therefore, the capabilities to install a system or to perform with a system need to be trained by the units that go on mission. However, it is unclear which systems deserve the most attention during training.

In the next sections, I will approximate the importance of military systems for the training phase. Therefore, I will assess what the most important system is by calculating which systems have the biggest contribution to soldiers becoming qualified.

5.2.1 Way of working

I will use a document called the "Trainingscompendium" to find out which systems are of high importance for the training phase. This document is used within the RNLA to provide information about to what extent a certain military activity should be mastered by a certain unit. It is basically a document that holds qualifications, that can be obtained by the units by means of training.
Because I also have information about the total amount of systems that are in use at the different units, I will connect system usage to the qualifications that are obtainable. By finding out which

qualifications require systems usage the most, I can conclude which systems are of high importance for the training phase.

5.2.2 The RNLA's configuration

In order to quantify which set of systems are of high importance for the training of units, it is necessary to provide the reader with some additional knowledge about the RNLA. The RNLA is divided into nine main units (Appendix X2). These main units are further divided into smaller units that practice "dienstvakken" and "wapens". For example: bevoorrading en transport (supply and transport) is a "dienstvak" and infanterie (infantry) is "wapen". For sake of simplicity, I will only use the word "dienstvak" to refer to a unit's practice.

5.2.3 The Trainingscompendium

The Trainingscompendium (Tc) is a document that holds which qualifications, or abilities, units should achieve in order to be qualified for certain tasks.
The Tc is divided in different chapters (specializations). The Tc gives qualifications for the following specializations:

- Infanterie (Infantry)
- Verkenning (Reconnaissance)
- Vuursteun (Fire support)
- Genie (Military engineering)
- Grondgebonden luchtverdediging (Ground-based air defense)
- Verbindingsdienst (Connection service)
- Bevoorrading en Transport (Supply and transport)
- Technische dienst (Technical service)
- Militaire gezondheidszorg (Military healthcare)
- EOD (Explosives clearance service)
- Nationale Reserve (National Reserve)
- Inlichtingen (Information)

There are different "Niveau's" on which units can train military activities (Table 5.2). The Trainingscompendium gives qualifications for units acting in Niveau II, Niveau III and for some specializations also Niveau IV and Niveau V.

Niveau I (individual)	Individueel – 1 person
Niveau II (group)	Groep ~ 6 persons
Niveau III (peloton)	Peloton ~ 30 persons
Niveau IV (company)	Compagnie/Batterij/Eskadron ~ 120 persons
Niveau V (battalion)	Bataljon ~ 500 persons
Niveau VI (brigade)	Brigade ~ 4000 persons

Table 5.2: The different training "Niveau's" within the RNLA

The Trainingscompendium states whether a unit should train a military activity and on which level the unit should be able to execute the military activity: High, Medium or Low.

High: The activity can be executed all kinds of complicated environments. To reach this level the activity is practiced multiple times, whereby the level of complexity is varied. The level of

complexity can be altered by changing variables as terrain, the thread, available time to plan, available time for execution and executing the activity simultaneously with other military activities.
Medium: The activity can be executed in the most likely (complicated) environment. In general, it is enough to practice an activity one or two times to reach the medium level.
Low: The unit needs procedural knowledge about the activity. Normally, it is enough to theoretically study this activity to reach this level.

In Appendix X3, I have added two examples of the content of the Trainingscompendium with an additional explanation.

5.2.4 Top-down explanation about determining system importance

The aim of Section 5.3 is to determine which system is of the highest importance for the training phase.
The number of systems that are used to train a specialization relates to the number qualifications that are obtainable for that specialization and the number of people that train that specialization. However, there are most likely differences in the return (in the form of qualifications) of a system and per specialization. The system which usage yields the highest return, has the highest importance for the training phase.

5.2.5 Quantifying the importance of a system for training

Before I explain the details of the method, I will first give an overview of the steps I will execute to quantify the importance of system for training. In the following sections, the details of these steps are discussed and the method is also applied.

1. Calculate the average number of High, Medium and Low qualifications per “Niveau”.
2. Determine which Trainingscompendium specialization is trained by which units of the RNLA.
3. Estimate how many people train a certain Trainingcompendium specialization.
4. Quantify which Trainingscompendium specialization needs the most training effort, based on the number of people that train a certain Tc specialization and the average number of qualifications that can be obtained for that specialization.
5. Determine which and how many systems are used per Trainingscompendium specialization.
6. Determine, based on the calculation of Step 4 and the information of Step 5, which training system is important for soldiers in order to obtain qualifications.

5.2.6 Calculating the average number of qualifications

Qualification scores (High, Medium or Low) are given for all the units that fall under a certain “Niveau” and specialization.
The first step would be to count the number of High qualifications, the number of Medium qualifications and the number of Low qualifications per specialization and per “Niveau”. The next step would be to divide the total number of High, Medium and Low qualifications by

the number of units that need to train these qualifications. This will give an average number of qualifications per specialization on a certain “Niveau” for one unit.
Appendix X4 shows the outcomes of this calculation.

Assumption 1

I have made the assumption that every qualification is mentioned in the Trainingscompendium. This is probably incorrect. For example, according to Appendix X4, units that train Grondgebonden luchtverdediging qualifications and Fire Support qualifications on Niveau II only need to get two or less qualifications on average. It seems like these qualifications are either not specifically formulated or that there are qualifications missing. However, I feel like this is the only way to quantify system importance.

5.2.7 Which Tc specializations are trained by the RNLA units

The RNLA is divided in the following units that practice a “dienstvak”:

- Infantry units
- Reconnaissance units
- Fire support units
- Military engineering units
- Ground-based air defence units
- Connection service units
- Supply and transport units
- Technical service units
- Military healthcare units
- Explosives clearance service units
- National Reserve units
- Information units

Appendix X5 shows which units I match with the Tc specializations.
Note that the staff units, all the MATLOGCO units and the most of the OTCO units (of Appendix X2) are not matched to a Trainingscompendium specialization.

Assumption 2

It is not entirely correct that there is a one on one relationship between units that practice a “dienstvak”, and the Trainingscompendium specialization for which they need to obtain qualifications.
In general, every unit possesses some people that are specialized in another field. Also, not only infantry soldiers practice infantry skills, but for example also the ground-based air defense units.
However, it was for me not possible to obtain and process all the exceptions on the one on one relationship. Therefore, for sake of simplicity, I assume that there is a one on one relationship between a “dienstvak” and a Trainingscompendium specialization.

5.2.8 Estimation of how many people train a Trainingscompendium specialization

In order to determine how many people practice a Trainingscompendium specialization, I have

searched in the military data base out of how many “Compagnieën” each unit exists. The “staf compagnieën” (leading companies) were not included in the calculations. Every main unit of Appendix X2 is divided in “dienstvakken”, including a leading company. These leading companies need to be able to act as an independent unit. However, I was not able to determine the associated Trainingscompendium specialization.
A “compagnie” exists out of approximately 120 people. A compagnie is of the same size as a batterij or eskadron.
For units that are “Commando’s”, I have looked into the military database to find out of how many people they exist.
Appendix X6 presents the calculations.

5.2.9 Estimating which Trainingscompendium specialization needs the most training effort

Based on the number of people that train a certain Tc specialization and the average number of qualifications that can be obtained for that specialization, I have come up with the following formula:

$$E_i = N_i * (3 * H_i + 1 * M_i)$$

Where:
N_i: Number of people that train a specialization i
H_i: Average number of High qualifications per specialization i on “Niveau II”
M_i: Average number of Medium qualification per specialization i on “Niveau II”
E_i: Score that shows how much training effort is needed to get specialization i fully qualified within the RNLA on “Niveau II”

Motivation

This formula aims to quantify which amount of training effort needs to be carried out for a specialization. The formula is built up in two parts: (N_i) and ($3*H_i+1*M_i$).
The first part of the formula (N_i) tells how many people train a specialization. The second part of the formula ($3*H_i+1*M_i$) tells how much training needs to be carried out by the people that train the specialization. The average number of High and Medium qualifications for units that practice a specializations has influence on the training effort of units to obtain qualifications. Because obtaining High qualifications deserves more training effort than Medium qualification, I multiply the number of High qualifications 3 times in the formula. The number of Medium qualifications has a weight of 1 in the formula and it is trained 1 to 2 = 1.5 times in the most likely environment. High qualifications are trained multiple times (I assume 3 to 4 = 3.5 times) and also the complexity is varied. I assume that the added complexity accounts for one extra time in training, which brings the total training time on 4.5 times. The time and therefore training effort that is needed for 1 High qualification can therefore be used to obtain three Medium qualifications.
Low qualifications do not need to be trained, but only to be studied. Therefore, these are not included into the formula.

I choose to use only the qualification numbers of Niveau II for the analysis. I have no information about Niveau I qualifications. I do have information about Niveau II, III, and for some specializations also Niveau IV and V. Niveau III, Niveau IV and Niveau V originate from the qualifications on Niveau II and therefore the qualifications on the Higher "Niveau's" overlap with the "Niveau II" qualifications. Table 5.3 shows an example of this overlap.

Niveau	**Qualification/Activity**
Genie II	Building and repairing underwater constructions
Genie III	Building and repairing underwater constructions
Genie IV	Genie diving combat support
Genie V	Underwater engineering

Table 5.3: Example of qualifications that overlap each other

Table 5.4 depicts the Training Effort scores (E_i) for each specialization i.

Specialization	E_i: Amount of training that needs to be carried out to get specialization i qualified within the RNLA *Calculations are done for Niveau II
Infanterie (Infantry)	$E_{infanterie}$ = 3360*(3*9,44+1*8) = 122035,20
Verkenning (Reconnaissance)	$E_{verkenning}$ = 360*(3*16.2+1*5.2) = 96350,40
Nationale Reserve (National Reserve)	$E_{nationale\_reserve}$ = 2040*(3*12+1*0) = 73440
Militaire gezondheidszorg (Military healthcare)	$E_{militaire\_gezondheidszorg}$ = 720*(3*10,5+1*3) = 24840
Bevoorrading en Transport (Supply and transport)	$E_{bevoorrading\_en\_transport}$ = 1080*(3*5,4+1*1,4) = 19008
Genie (Military engineering)	E_{genie} = 720*(3*6,72+1*3,72) = 17193,60
Technische dienst (Technical service)	$E_{technische\_dienst}$ = 360*(3*10.5+1*3) = 12420
Inlichtingen (Information)	$E_{inlichtingen}$ = 600*(3*4,6+1*0) = 8280
EOD (Explosives clearance service)	E_{EOD} = 240*(3*5+1*0) = 3600
Vuursteun (Fire support)	$E_{vuursteun}$ = 360*(3*1,63+1*0,27) = 1857,60
Verbindingsdienst (Connection service)	$E_{verbindingsdienst}$ = 360*(3*1+1*0) = 1080
Grondgebonden luchtverdediging (Ground-based air defense)	-----

Table 5.4: Training Effort (E_i) that is needed for the different specializations

Assumption 3 and Assumption 4

I have assumed that each High qualification takes as much time to train as another High qualification, regardless of the different specializations there are. Same counts for each Medium qualification.
Even though I have motivated that each High qualification accounts for 3 Medium qualifications, this is still an assumption.

5.2.10 Amount of systems used per Trainingscompendium specialization

It is well known inside the RNLA which and how many systems are in use at the RNLA units of Appendix X1. I have used this information to determine which systems are used to train a certain specialization. I have already matched the RNLA units to the Trainingscompendium

specializations they train, therefore I can also state which and how many systems are in use to obtain qualifications for a certain Trainingscompendium specialization.
Table 5.5 shows the number of systems per specialization.

Confidential

Table 5.5: The number of systems in use to obtain qualifications for the Trainingscompendium specializations

5.2.11 Training systems that are important to obtain qualifications

The goal of training is to become qualified for a mission. For a unit to prove that it is qualified, it needs to obtain qualifications by training. The units make use of their systems, to obtain these qualifications. This is the basis of the analysis.
Therefore, you would expect that the training effort (E_i) is related to the number of systems that are in use at each specialization. This means that the amount of systems that are in use at each specialization should be in proportion with the training effort for a specialization.
In Table 5.6, I have examined this relationship by dividing E_i with the total number of systems in use at a specialization:

$$\frac{E_i}{total\ number\ of\ systems\ in\ use\ at\ specialization} = Relationship\ (R)$$

Relationship (R) aims to find out to which extent the systems are of importance for a specialization, in order to obtain qualifications and therefore are of importance for training. The higher the value of Relationship (R) is, the higher the importance of system usage is to obtain qualifications for the specialization.

Specialization	**E_i (Training effort per specialization i)**	**Total number of systems in use**	**E_i/(Total number of systems in use)**
Infanterie (Infantry)	122035.2	728	167.63
Verkenning (Reconnaissance)	96350.4	100	963.50
Nationale Reserve (National Reserve)	73440	126	582.86
Militaire gezondheidszorg (Military healthcare)	24840	336	73.93
Bevoorrading en Transport (Supply and transport)	19008	899	21.14
Genie (Military engineering)	17193.6	699	24.60
Technische dienst (Technical service)	12420	258	48.14
Inlichtingen (Information)	8280	231	35.84
EOD (Explosives clearance service)	3600	99	36.36
Vuursteun (Fire support)	1857.6	180	10.32
Verbindingsdienst (Connection service)	1080	234	4.62

Grondgebonden luchtverdediging (Ground-based air defense)	-----	431	-

Table 5.6: Link between training effort and system usage

It stands out that to master the specialization reconnaissance, not many systems are needed to train with. Still, there is a lot of training effort needed to obtain the reconnaissance qualifications. This gives reconnaissance the highest Relationship score with a score of 963.50. Other specializations with a high Relationship-score are the National Reserve, Infantry and Military Healthcare.
I will use the specializations with highest relationship score, to determine which systems are important for the training phase. Appendix X7 shows the percentages that each system has of the total amount of systems per specialization. I have highlighted six military systems that have a percentage above 10% for one of the specializations.
This gives the following set of systems that are of high importance for the training phase: Fennek, Boxer, Amarok, Combat Vehicle 9035NL, YA-4442; alle types and MB 290 GD; alle types.

Assumption 5

Note that in Section 5.2.11, I do not differentiate between the different kinds of systems that are in use to obtain qualifications for a certain qualification, but take the total number of systems that are in use.

5.3 Conclusion

In the first part of this section, I identified which systems had a system availability of under 80%. This gave the following set of systems:

- AGBADS
- Bouwmachines
- Boxer
- Bushmaster
- CBRN Verkenningsystemen
- Combat Vehicle 9035NL
- EODD
- Fennek
- Fuchs (EOV)
- Graafdozer
- Leopard 1
- Leopard 2
- Mobiele telescoopkranen
- Mobiele voedselbehandelingsystemen
- Mobiele Waterbehandelingsystemen
- MOGOS ? MGC containers
- Patriot
- PzH 2000NL
- QUAD
- Raven
- Tactische satellietsystemen
- UAV Scan eagle
- Vrachtwagen 12kN Vector
- Y 2300 alle types
- YBZ 3300 en YWL 3300

In the second part of this chapter, I identified the systems that were of high importance for training:

- Amarok
- Boxer
- Combat Vehicle 9035NL
- Fennek
- MB 290 GD; alle types
- YA-4442; alle types

The Fennek, Boxer and Combat Vehicle 9035NL are the three systems that are present in both sets. Therefore I conclude that the Fennek, Boxer and Combat Vehicle 9035NL disturb the training phase the most.

6. Selecting parts that are interesting for AM

In Chapter 5, I concluded that the Fennek, Boxer and Combat Vehicle 9035NL disturbed the training phase the most. Therefore, it would be most interesting to select parts of these systems and check whether additive manufacturing could be applied to manufacture these parts.

6.1 Parts that suffer a supply disruption

In order to select parts that connect to the identified problem of Chapter 1, I will only select parts that suffered a supply disruption during 2018.
Appendix X11 gives a full list of the orders that coped with a disruption in supply during 2018. Note that some articles are mentioned more than one time.
The fourth column states whether the article is critical. The criticality concept will be discussed in further detail in the next section, but in general it indicates the importance of an article for a safe and successful military operation.
The fifth column states the number of articles which belong to open orders.
Table 1 provides an overview of the items that suffered a supply disruption during 2018.

Confidential
Table 6.1: Items that suffered a supply disruption

6.2 Technical feasibility and criticality

Out of the group of articles that cope with a disruption in supply, I will select articles that are both technologically feasible to print and critical for military operations.
Rooijakkers (2017) developed a framework for the RNLA based on Knofius et al. (2016), to identify promising (temporary) spare parts for on-location AM.
Rooijakkers' framework aims to identify which spare parts are interesting for AM in a mission context. My Bachelor thesis does not have this focus, as it focusses to improve system availability during training. Also, as opposed to Rooijakkers (2017) I want to identify which parts should be selected out of a set of parts that have one thing in common: all the articles suffer a supply disruption. Because the focus of my thesis differs most attributes of Rooijakkers' framework are not relevant.
However, Rooijakkers uses the attributes technical feasibility for AM and criticality of a part. I want to use these elements to classify which articles that are in the set of articles that suffer a supply disruption, are most interesting for further investigation.
The distinction that I will make will give me a new selection of parts. This selection of articles will be used for further investigation. In this further investigation, I will study the blueprint of the part together with two experts, to determine whether the part is interesting for AM. It is convenient to work with a smaller selection of articles, as it is quite time consuming to find information about the articles from the RNLA's SAP system.

6.2.1 Technical feasibility with regards to AM

Together with an expert, I decided based on the description of an article, whether the article should be considered for further investigation. As you can imagine, a rev counter (TOERENTALMETER) or an article that consist a sensor (SENSORKOP BAA VWRN), is not interesting for AM, as these articles contain electronics. There are more articles like this. We aimed to exclude articles like this.

6.2.2 Criticality

The articles that are not critical, are not selected for further investigation. Table 6.1 depicts which articles are critical.
When an article is critical, this means that a defect of this article seriously disturbs the military operation or a that the defect could have dangerous consequences. The value of this parameter for an article is determined by the RNLA.
The parts that are both technically feasible (based on description) and critical are depicted in Table 6.2.

System	Article	Description
Fennek	10000196264	BESCHERMPLAAT
Fennek	10000161212	U-PROFIEL, NIET METAAL
Fennek	10000088309	VEERREMCILINDER
Fennek	10000138668	HOOFDREMCILINDER
CV9035NL	10000209174	[VERVANGEN] DISTRIBUTION BOX

Table 6.2: Both technically feasible (based on description) and critical articles

6.2 Investigating the possibilities of AM for the selected parts

In this section, I will discuss the possibilities of AM for each of the five selected parts. I have used the knowledge of two experts to obtain information.
Lindemann (2015) has developed a trade-off methodology (TOM) matrix, which purpose is to screen parts and to assess whether parts are interesting to be produced by means of AM. The TOM matrix exists out of two segments.
The first segment aims to reduce the number of parts that could be interesting for AM, by assessing the following number of attributes:

1. Size limitations: The size of a part can be a constraint in whether a part can be printed or not, as 3D printers need to be able to manufacture parts of that size.
2. Part classification: The attribute part classification aims to classify whether the part is complex. Complexity can be an advantage for AM, as the technique offers freedom of design. However, an article might be too complex if it consists electronics.
3. Suppression of assemblies: An advantage of AM is that is it offers the functionality to manufacture single piece assemblies (Gibson et al., 2010).
4. Post-processing: AM parts can only achieve certain mechanical properties and functional properties. Post-processing could be done, to improve the properties of AM parts.
5. Applicability of already used AM material for aerospace parts: This attributes aims to find appropriate material. Lindemann (2015) states that one should focus on materials that are already used in the industry. The Aerospace industry represents the domain where AM is implemented the most, that is why it is mentioned in this attribute.
6. Compliment of specific geometric conditions for AM: This attribute identifies which parts should be manufactured, based on geometric conditions. Some parts have geometric properties that are not interesting for AM.
7. Property improvement of part by design optimization: This attributes aims to identify possible improvements, with regards to the design of the part.
8. Material consumption: The freedom of design that AM offers, can reduce the material consumption.

9. Processing time: This attribute aims to identify how AM relates to traditional manufacturing methods with regards to the processing time.

The second segment of Lindemann (2015)'s TOM matrix contains the following attributes.

10. Material change: This attribute identifies if the produced part has the required mechanical properties. It also identifies the post-processing steps that need to be taken.
11. Material consumption: This attribute compares the material consumption of AM with the material consumption of traditional manufacturing methods.
12. Processing time: This attribute compares the processing time of AM with the processing time of traditional manufacturing methods.
13. Economic aspects: This attribute compares part costs for AM and traditional manufacturing methods.

In the next sections, I will assess what the possibilities of AM are for the selected articles. I will consider the first ten attributes of Lindemann (2015) for the assessments of these articles. I will not make a comparison with traditional manufacturing methods. However, I will say something about printing costs compared to the new price of the article. This will help to put the manufacturing cost of AM into perspective.
Note that my aim is to use Lindemann's attributes to give a complete assessment of each article. As opposed to Lindemann (2015), I will not use the attributes to make a comparison of the attractiveness of AM for the articles.
With the help of two experts, I was able to obtain information about the attributes of an article.

6.3.1 BESCHERMPLAAT (protection plate)

Appendix X12 depicts the protection plate. The protection plate is used in the Fennek as a part of the shutter on top of the Fennek, which can be opened and closed. Most likely, this part is made out of foam or rubber. The article needs to be soft as users should be able to bump their head against it in a safe manner.

Both the experts agreed that a printed version of this article could successfully be used as a substitute part, or in other words, as a spare part. They proposed the possibility to print this article with stereolithography (SLA). In SLA, an object is created by selectively curing a resin of polymers, layer by layer, with a ultraviolet (UV) laser beam (www.3dhubs.com). Therefore, the material out of which the printed object will exist are thermoplastic elastomers.

The experts I talked to agreed that the part would be strong, especially if post-processing with UV light is applied. In this process, the SLA printed part is placed in a box under intense UV light. This post-processing process creates cross-links between the polymers. This improves the hardness and temperature resistance of the printed object. A disadvantage is that it makes the printed part more brittle (www.3dhubs.com).
The SLA printed part will have isotropic properties (www.3dhubs.com). Isotropic means that the object is equally strong in all directions (Kalpakjian and Schmid, 2014).

The protection plate is with dimensions of 670X440X50 MM quite large for AM, although the industry is able to print these kinds of sizes. The volume of the protection plate is 14.740.000 mm^3, which equals 14,74 liter. According to an expert, the price for a liter of material is around €230,- for private individuals. This might be less for the industry, but it is assumable that the price per liter will still be well over €100,-. This gives at least 14,74*€100,- = €1474,- as a price

for just the materials. Compared to the new price of €12,50, this is a high amount. Because this part is quite big in size the printing process may take longer than a week.
However, an advantage of AM is that it gives freedom of design. By creating a triangle structure between the top and the bottom layer of the protection plate as depicted in figure 6.1, a flexible structure with less volume can be created.

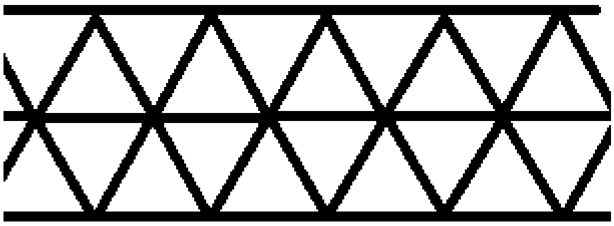

Figure 6.1: Triangle structure between the top and bottom layer of the protection plate

Application of Lindemann (2015)

1. Size limitations: No
2. Part classification: Not complex
3. Suppression of assemblies: -
4. Post-processing: Necessary to make the part stronger
5. Applicability of already used AM material for aerospace parts: Appropriate material is available
6. Compliment of specific geometric conditions for AM: The article has the required geometric properties
7. Property improvement of part by design optimization: Possibility to improve design
8. Material consumption: Possibility to reduce consumption
9. Processing time: Longer than a week
10. Material change: The article has the required mechanical properties

Conclusion: The protection plate can be manufactured by means of AM and can also be used as a spare part. The manufacturing process should be carried out by a service provider, as the RNLA does not have the printers to manufacture articles of this size. AM will be expensive for this part and the manufacturing process will take around a week of time.

6.3.2 U-profiel (U-profile)

Appendix X13 depicts the U-profile article. The U-profile is a protection edge, that envelops a shielding plate.
According to the RNLA's SAP system, the U-profile article has the dimensions 10000x1x1 MM. It turned out that this article was ordered at 10 meters length before the disruption in supply and cut to the desired length. In case of this U-profile depicted in Appendix X13, that length would be equal to 460 MM. According to a system analyst, the 1MM sizes of the U-profile are also incorrect. Therefore, we assumed that the right size is 10MM. This gives this U-profile a size of 460x10x10 MM. The 460MM makes this article quite lengthy, but the industry is able to print these sizes.

Both the experts that I talked to agreed that a printed version of this article could successfully be used as a spare part. A fitting AM method to manufacture this article would be selective laser sintering (SLS). The SLS printing process is a Powder Bed Fusion process. In SLS, a laser

selectively sinters the particles of a polymer powder which fuses them together (www.3dhubs.com). The part is build up layer-by-layer. This part will be made out of nylon, if it would be printed.
SLS is able to print parts with excellent bond strength between the layers. This gives SLS printed parts almost isotropic properties (www.3dhubs.com).
SLS printed object have excellent tensile strength. However, a possible disadvantage of a SLS printed part is its internal porosity. The porosity of the printed SLS object gives it the ability to absorb water. Also, the porosity gives the parts a grainy surface (www.3dhubs.com).
The surface quality of SLS printed parts can be improved with post-processing processes as sanding and filling. However, this will not be necessary for the application that the U-profile has.

SLS is an expensive method, as an expert estimates the production cost to be around €100,- for this U-profile. If this article would have been available, it would have had a price of only €2,54. The printing process will be quite fast.

Application of Lindemann (2015)

1. Size limitations: No
2. Part classification: Not complex
3. Suppression of assemblies: -
4. Post-processing: Not necessary
5. Applicability of already used AM material for aerospace parts: Appropriate material is available
6. Compliment of specific geometric conditions for AM: The article has the required geometric properties
7. Property improvement of part by design optimization: No
8. Material consumption: No possibility to reduce consumption
9. Processing time: Fast
10. Material change: The article has the required mechanical properties

Conclusion: The U-profile can be manufactured by means of AM. The part can also be used as a spare part. The manufacturing process should be carried out by a service provider, as the RNLA does not have the printers to manufacture articles with these dimensions. Printing this article will be expensive. The manufacturing process can be executed in one day.

6.3.3 VEERREMCILINDER (Spring brake cylinder)

The spring brake cylinder, with dimensions of 245X170X160 (Appendix X14), exists out of many smaller parts (SRU's). Metal printing the parts of the spring brake cylinder is possible, but the mechanical and geometric properties of most printed parts will not allow a sufficient performance of the complete assembly. The same counts for printing this article as a single piece assembly. Also, metal printing is expensive and a lot of post-processing will be needed.
Still, there are a couple of parts that at least deserve consideration for metal printing. These parts have a green circle around it, as can be seen in Appendix X14. There is post-processing needed to finish these parts.

Metal printed parts have higher strength and hardness than parts manufactured using a traditional method. An issue is that metal printed parts are prone to fatigue (www.3dhubs.com). This is the reason why metal printed versions of the parts highlighted in Appendix X14, most

likely cannot function within the spring brake cylinder. The parts have to be able to withstand forces. A failure of the parts can have bad consequences.
However, to be sure whether or not the metal printed parts could successfully act as a spare part, calculations need to be done.

Application of Lindemann (2015)

1. Size limitations: No
2. Part classification: Too complex
3. Suppression of assemblies: Not feasible
4. Post-processing: -
5. Applicability of already used AM material for aerospace parts: Could be printed out of metal
6. Compliment of specific geometric conditions for AM: The article will not have the required geometric properties
7. Property improvement of part by design optimization: -
8. Material consumption: -
9. Processing time: -
10. Material change: Article will not have the required mechanical properties

Conclusion: The part cannot be manufactured as a single-piece assembly. It is easily determined by an expert that most parts of the assembly should also not be manufactured by means of AM. Some parts however deserve some consideration/calculation (Appendix X14, with a green circle around it).

6.3.4 HOOFDREMCILINDER (Master cylinder)

It is possible to print this article (metal printing), but it will most likely not have the desired functionality. As this article is part of the brake system of the Fennek, it should be reliable. Most likely, a printed version of this article cannot give this reliability.
As with the spring brake cylinder, printing this article will be very expensive and there is also post-processing needed.

Application of Lindemann (2015)

1. Size limitations: -
2. Part classification: Too complex
3. Suppression of assemblies: -
4. Post-processing: -
5. Applicability of already used AM material for aerospace parts: Could be printed out of metal
6. Compliment of specific geometric conditions for AM: The article will not have the required geometric properties
7. Property improvement of part by design optimization: -
8. Material consumption: -
9. Processing time: -
10. Material change: Article will not have the required mechanical properties

Conclusion: This article should not be manufactured by means of AM.

6.3.5 DISTRIBUTION BOX

The distribution box contains electronical equipment. Although there is some experimenting going on where electronics are printed, this is not a viable option today.
It is possible to print the box that surrounds the electronics. The best way to do this would not be to print all the plates of the box separately, but to print the whole box at once. This way, the possibilities of AM, namely freedom of design, are maximally utilised.

Application of Lindemann (2015)

1. Size limitations: No
2. Part classification: Too complex
3. Suppression of assemblies: No, not for the complete article
4. Post-processing: -
5. Applicability of already used AM material for aerospace parts: No
6. Compliment of specific geometric conditions for AM: -
7. Property improvement of part by design optimization: -
8. Material consumption: -
9. Processing time: -
10. Material change: -

Conclusion: This article should not be manufactured by means of AM. However, it is possible to print the box of this assembly.

6.4 Conclusion

Table 6.3 shows which of the selected parts can be printed and used successfully as a spare part.

Part	**Printed version can successfully be used as a spare part?**
Protection plate	Yes
U – Profile	Yes
Spring brake cylinder	No, although a number of SRU's deserve consideration
Master cylinder	No
Distribution box	No, although a number of SRU's deserve consideration

Table 6.3: Printed versions used as spare part

The protection plate can be printed by means of stereolithography (SLA). It should be noted that this an expensive method. The printing process may take more than a week.

The U-profile can be printed by means of selective laser sintering (SLS). Compared to the new price of the U-profile, this is also an expensive method. The printing process is quite fast.

The spring brake cylinder, master cylinder and the distribution box should not be printed. However, some SRU's of the spring brake cylinder and distribution box deserve consideration with regards to AM. It is expected that the considered SRU's of the spring brake cylinder can not be successfully used as a spare part, because the part needs to be reliable. The box that surrounds the electronics of the distribution box can be printed.

7. Alternative sources of supply

In the previous section, I have determined that it is possible to print the protection plate and the U-profile. Therefore, AM can be used to solve the supply disruption.
However, there are different alternatives that are considered in case of a disruption of supply, namely:

- Searching for an external supplier
- Part substitution
- System redesign
- Last time buy

In the chapter, I will examine whether these alternatives can be used for either the protection plate and the U-profile.

7.1 External supplier

The following rules of thumbs apply within the RNLA, with regards to the possibility to get a part of an external supplier.

- The younger the part, the easier it is to find a replacement on the market

The amount of parts on the market depends strongly on the age of the system to which the part belongs. Especially, this applies for military systems. As the system gets older and reaches its ELOT (end life of type), the amount of parts offered on the market decreases.

- The less the part is specifically customized for military, the easier it is to find a replacement on the market

When a part is also used for other applications, the amount of replacements offered on the market is higher.

The protection plate and the U-profile are both Fennek parts. The RNLA has a contract with the OEM of Fennek parts, Krauss-Maffei Wegmann GmbH & Co (KMW). KMW has the responsibility to deliver spare parts. When there are problems at KMW, which could cause a disruption in part supply, it is contractually documented that the KMW needs to look for alternatives to solve the issue. Typically, the OEM has a bigger network then the RNLA which makes it easier to get replacement parts from external suppliers.

7.1.1 Protection plate

The protection plate is customized for the Fennek, that why it is difficult to get this part from an external supplier.
I do not know whether KMW is close to finding an external supplier or not. As of now, a replacement part has not been implemented in the RNLA's SAP system.

7.1.2 U-profile

For the U-profile, KMW has found a replacement part from an external supplier. As of now, this part is already implemented in the RNLA's SAP system. The replacement part is similar to the old part. Most likely, this replacement part was not too expensive, as the new price of the old part was €2,54 per meter. It is assumable that the price of the new part is somewhere in that region.
The original lead time for this part was 58 days. It is expected that the replacement part has a similar lead time, which is somewhere around 58 days.

7.2 Part substitution (AM excluded)

In this section, I will examine whether part substitution is possible for either the protection plate and the U-profile. I will only consider replacements by a different part out of the supplier/RNLA's assortment or a part that is made in the workplace that could be used for part substitution.

7.2.1 Part substitution by a different part out of the supplier/RNLA assortment

7.2.1.1 Protection plate

It is expected that there is not a similar article that could be used as a protection plate. The protection plate has quite unique characteristics, with regards to its outline and form.

7.2.1.2 U-profile

The U-profile is a simple, common article that could be used in all kinds of settings. There might be a similar article that is used for another military system of the RNLA. However, I do not have the insights to verify this.

7.2.2 Part substitution by creating this article in a workplace

7.2.2.1 Protection plate

Although the workplaces of the RNLA are more focussed on metalworking, it should be possible to create this protection plate in-house in a workplace.
If a plate of rubber/foam with the right dimensions can be obtained on the market, this part can be carved out by either cutting or with more precise laser cutting. This depends on the requirements of the part. It is expected that the Royal Netherlands Navy has this laser technology. Manufacturing the part should not be expensive.
It is difficult to say exactly in which time frame the protection plate can be cut out and delivered at the place where it is needed. This depends on the communication between the RNLA and the Royal Netherland Navy and on the importance that is attached to the delivery. However, it is expected that this alternative can be executed quite fast, which gives the RNLA quick access to the part.

7.2.2.2 U-profile

A part like this is typically made in mass production. The RNLA and service providers cannot manufacture this part in a workplace setting.

7.3 System Redesign

When system redesign is applied, the need for the specific part is avoided by changing the design of the system. Note that in this Bachelor thesis, part redesign falls under system redesign.

7.3.1 Protection plate

It is difficult to say whether there are possibilities for system redesign, to avoid the use of the protection plate within the Fennek. In case a system redesign is technically feasible, it is assumable that this is a very expensive option which makes it not interesting.

7.3.2 U-profile

It is possible to redesign the plate that is enveloped by the U-profile, to a single piece metal plate that already possesses the upstanding edges. However, it should be questioned whether this design has the right functionalities, for example to provide waterproofness.
A redesign is an expensive solution which makes it uninteresting for the RNLA. There are a lot of things that need to happen, to implement a redesign into an organization. A new design needs to be made, it needs to be tested and it needs to be implemented in the organization's system.

7.4 Last Time Buy

The last time buy option does not apply for these two cases. In both cases there was an unexpected disruption of part supply. Therefore, this option cannot be seen as an alternative.

7.5 Comparing alternative sources of supply with AM to solve a supply disruption

In Chapter 6, I have assessed what the possibilities of AM are, for the protection plate and the U-profile. I will compare the information I have obtained in Chapter 6 with the findings of the current chapter, in order to determine what the implications are to solve the supply disruption with AM.

7.5.1 Protection plate

For the protection plate, the following alternative sources of supply are possible: Additive manufacturing and creating the part in a workplace.

Additive manufacturing: Because the protection plate is relatively large with regards to its dimensions, a service provider needs to print this part. The sizes of the part make it also expensive and time-consuming to print the part; the material cost of AM will be > €1000,- and the printing process may take approximately one week. The time frame in which the part can be obtained is expected to be short.

Creating the part in a workplace: A plate of foam/rubber with the right dimensions needs to be bought on the market. This should not be time consuming. This plate needs to be cut out either by laser technology or by a traditional cutting device, depending on the required precision, which is unknown.

Laser cutting needs to happen at a specific place, namely at either the Royal Netherlands Navy or at a service provider. Traditional cutting would propose less logistical difficulties, as it is a process that can be done at every workplace.
It is expected that this supply alternative can be executed in a short time frame and it is compared to additive manufacturing very cheap.

Conclusion for the protection

It is contractually documented that the OEM needs to find a replacement part. If the OEM succeeds, it will be in the RNLA's best interest to go with this solution. The lead time can be quite long though.
If the protection plate is needed as soon as possible, creating the part in the workplace would be the best supply option. It is most likely a faster alternative than AM and certainly a cheaper alternative.

7.5.2 U-profile

For the U profile, the following alternative sources of supply are possible: Additive manufacturing, finding an external supplier and system redesign.

Additive manufacturing: AM offers the opportunity to obtain this part in a relatively short time frame, although the production needs to be sourced out. The part will be very expensive (at least €100,-) compared to the new price of the old model.

External supplier: KMW has already found an external supplier that offers the part, to solve the supply disruption. The new price of the replacement part will be around €2,50/meter, which is cheap compared to AM.
However, the lead time of a replacement part can take quite some time. Because this is a common uncomplicated article, it is not expected to have a lead time of more than six months. But, a lead time of 40+ days is certainly not unthinkable. The lead time of the old U-profile was 58 days, it is assumable that the lead time of the replacement part is somewhere in that region.

System Redesign: It is possible to come up with a redesign, although it should be questioned whether this new design has the right functionalities. It will also take a lot of time to implement this redesign, which makes it an expensive alternative. Most likely way more expensive than AM. Altogether, this option is not interesting for the RNLA.

Conclusion for the U-profile

AM is way more expensive than getting a replacement part via an external supplier. However, it is expected to have a shorter lead time than waiting until the part has been delivered by the supplier. If the part is needed in a short time frame, AM might be worth its price tag.

Table 7.1 provides an overview of all the alternative supply sources that are considered for the protection plate and the U-profile.

	Protection plate	U-profile
Additive manufacturing	Technically feasible, but material cost will already be > €1000,-.	Technically feasible, but material cost will ≈ €100,-.

	Manufacturing must be done by a service provider. It is expected that the part can be obtained in a relatively short time frame.	Manufacturing must be done by a service provider. It is expected that the part can be obtained in a relatively short time frame.
External supplier	No external supplier has been found yet. This may be difficult as this part is customized for this particular application. The lead time of this alternative may be longer than other alternatives.	The OEM (KMW) has found an external supplier which can deliver a replacement part. The lead time of replacement part can easily be 40+ days.
Part substitution out assortment	No substitution part found	No substitution part found
Part substitution – creating the part in a workplace	This is possible and could be done quite easily. A plate of foam/rubber needs to be found on the market. This plate needs to be cut out either by laser technology or by a traditional cutting device, depending on the required precision. This alternative is relatively fast and cheap.	Typically, these kind of parts are not interesting to be made in a workplace.
System redesign	Either from a technical perspective as from an economical perspective, it is assumable that system redesign is not a feasible option.	There are possibilities. However, it should be questioned of the redesign meets the required functionalities. Also, a redesign would be very expensive and take a lot of time to implement.
Last time buy	Does not apply	Does not apply

Table 7.1: Overview of how the sources of supply relate to each other

8. Conclusion

In this last chapter of my thesis, I will answer the research question based on the findings in this thesis. I will also suggest some recommendations based on this thesis and what I encountered during my time at the RNLA. In the end, I will discuss which opportunities there are for future research.

8.1 Conclusion

In this conclusion I will answer the main research question: How can AM of spare parts contribute in the training phase of units?

AM can be seen as an additional option to keep systems operational in case there is a disruption of part supply. The other options to keep systems operational are system redesign, part substitution by creating the part in a workplace, part substitution by a similar part out of the existing assortment, to look for another supplier and to ask for a last time buy (in case of a supplier contract almost expiring). Note that additively manufacturing parts are used as substitute parts. Therefore, AM actually falls under parts substitution.
Because AM is growing fast, it is seen as a future manufacturing method that could challenge traditional manufacturing methods. By some literature sources, it is believed that AM might change the manufacturing landscape.

Disruptions in part supply contribute to lower levels of system availability. In Chapters 4 and 5, it can be seen that the system availability is inappropriate (under 80%) for a decent amount of systems that is used for the training of units. This leads to a disturbed training phase.

I developed a method that measures which systems are the most valuable for training, based on the qualifications that have to be obtained with training (according to the Trainingscompendium docuemnt). Out of the analysis, I conclude that the Fennek, Boxer, Amarok, Combat Vehicle 9035NL, YA-4442 and MB 290 GD are most important for the training phase.
The systems that both suffer a low system availability and have a high importance for training are the Fennek, Boxer and Combat Vehicle 9035NL.

Together with two experts I have examined the possibilities of AM for five parts of these systems. It is certainly possible to manufacture most of the selected articles, but the difference in mechanical properties will not always allow the printed parts to perform as desired.
The examined protection plate and U-profile are the most interesting to be produced by means of AM. I conclude that AM can be used as an alternative supply option to solve a disruption in part supply for one of these parts.

Other alternative supply options that can be used for the protection plate and the U-profile are the following:
For the protection plate: Creating the part in a workplace
For the U-profile: Finding an external supplier and system redesign

Finding an external supplier is the best alternative for the long term, as it is the cheapest alternative. In the time that an external supplier has not been found or the part has not been delivered yet, other options can be considered for the short term: AM and creating the part in a

workplace. As you can imagine, if obtaining the part fast implies that systems are saved from being non-operational, this should certainly be considered.
Creating parts in a workplace is relatively fast and cheap. Additive manufacturing is also relatively fast, but expensive. If the part is needed in a short time frame, it would be best to first consider whether the part can be created in a workplace setting, as it is relatively fast and cheaper than AM. If this is not an option, AM should be considered.

8.2 Recommendations

For now, AM can be seen as an alternative option to obtain parts, though it is outperformed by conventional manufacturing techniques for most parts.
According to the literature, the future perspective of AM is promising. Therefore, I would recommend that the current proactive and enthusiastic approach of the RNLA with regards to AM should be proceeded further.

In my analysis in Section 5.2, I used a document called the Trainingscompendium. It is fair to say that the document is still a bit incomplete, as some specializations have an unrealistically low number of qualifications that they should obtain. Therefore I would recommend to make the document more realistic, so it provides more clarity for the active units.

An advantage of additive manufacturing is that it offers more freedom of design, compared to traditional manufacturing methods (Figure 8.1). I would recommend to make use of this advantage, from early on. The designs of the articles within the RNLA are based on traditional manufacturing methods. Because additive manufacturing offers freedom of design, the original designs of the RNLA articles should only serve as orientation.
Additive manufacturing can produce parts that have a high complexity. The parts can be lighter, more versatile and they might also have improved mechanical properties.

AM can certainly contribute to the training phase of units, in case the part is needed in a relatively short time period. Though, creating the part in a workplace will be cheaper in most cases. This can be done by the RNLA themselves or a service provider. However, not every part can be created in a workplace setting, especially plastic parts. For these cases, I would recommend AM as a very interesting alternative.

Figure 8.1: Improved design by means of AM (Siemens) (www.aviationweek.com)

8.3 Limitations and future research

8.3.1 Limitations

To conduct my research I assumed that there is a clear link between system availability and disruptions in part supply. This is only partly true. Complex systems need more extensive maintenance checks which also causes them to have more downtime than less complex systems. Basically, every system has a different time frame in which a maintenance check is done. To this end, future research may further refine the link between system availability and supply disruptions.
The method that I applied in Section 5.2 is based on many assumptions. Therefore, the conclusion that the Fennek, Boxer and Combat Vehicle 9035NL are the systems that disturb the training phase the most, has to be further investigated.

8.3.2 Quality based research

Whether AM can compete with traditional manufacturing methods also depends on the quality of the printed parts. I have mentioned this aspect in my thesis, but I have not handled this in depth. Therefore, future research should put further emphasis on the achievable quality of printed parts at the RNLA. It would be valuable to examine how the differences in quality of conventionally manufactured parts and additively manufactured parts can be quantified.

8.3.3 Print price

In my case study of Appendix X17, I stated that the printed prices of the locking pin with post-processing costs included is equal to, €500. This print price is an estimation made by the Department of Technology. The accuracy of this estimation is uncertain.
In the case study, I also used literature to find out which cost factors matter in printing an object. For future research, it would be interesting to see how high the cost factors of a printed object are.

Appendix

Appendix X1 - System availability

Confidential

Appendix X2 – Configuration of RNLA units

11LMB - 17028 - 11LUCHTMOBIELE BRIGADE
11LMB - 18105 - 11LMB/STSTCIE
11LMB - 18370 - 11HERSTELCOMPAGNIE AMB
11LMB - 18411 - 11BEVOORRADINGSCOMPAGNIE AMB
11LMB - 18282 - 11GENIECOMPAGNIE AMB
11LMB - 18423 - 11GENEESKUNDIGE COMPAGNIE AMB
11LMB - 17029 - 11INFANTERIEBATALJON AMB GGJ
11LMB - 17030 - 12INFANTERIEBATALJON AMB RVH
11LMB - 17031 - 13INFANTERIEBATALJON AMB RSPB
11LMB - 17074 - 20NATIONALE RESERVEBATALJON
11LMB - 18195 - 11BRIGADEVERKENNINGSESKADRON
13LTBRIG - 17034 - 13LICHTE BRIGADE
13LTBRIG - 18106 - 13LTBRIG/STSTCIE
13LTBRIG - 17038 - 13HERSTELCOMPAGNIE
13LTBRIG - 18416 - 13GENEESKUNDIGE COMPAGNIE
13LTBRIG - 17035 - 17PANTSERINFANTERIEBATALJON
13LTBRIG - 17041 - 42PANTSERINFANTERIEBATALJON
13LTBRIG - 18196 - 42BRIGADEVERKENNINGSESKADRON
13LTBRIG - 47060 - 41PANTSERGENIEBATALJON
13LTBRIG - 17076 - 30NATIONALE RESERVEBATALJON
1GNC - 17024 - 1(GE/NL)CORPS
1GNC - 18129 - 1GNC/ST
1GNC - 17026 - CISBN 1GNC
43MECHBRIG - 17045 - 43GEMECHANISEERDE BRIGADE
43MECHBRIG - 18108 - 43MECHBRIG/STSTCIE
43MECHBRIG - 17049 - 43HERSTELCOMPAGNIE
43MECHBRIG - 17050 - 43GENEESKUNDIGE COMPAGNIE

43MECHBRIG - 17046 - 44PANTSERINFANTERIEBATALJON
43MECHBRIG - 44978 - 45PANTSERINFANTERIEBATALJON
43MECHBRIG - 18197 - 43BRIGADEVERKENNINGSESKADRON
43MECHBRIG - 17054 - 11PANTSERGENIEBATALJON
43MECHBRIG - 17068 - 10NATIONALE RESERVEBATALJON
DGLC - 18192 – DGLC
DGLC - 64414 - DGLC/STAF
DGLC - 49268 - 13LUCHTVERDEDIGINGSBATTERIJ
DGLC - 62647 - 800SQUADRON
DGLC - 62648 - 802PATRIOTSQUADRON
DGLC - 43287 - OTC GLRV
KCT - 17066 - KORPS COMMANDOTROEPEN
KCT - 25965 - KCT/SSVCIE
KCT - 49796 - KCT/OTCSO
KCT - 49623 - 103COMMANDOTROEPENCOMPAGNIE
KCT - 18155 - 104COMMANDOTROEPENCOMPAGNIE
KCT - 18156 - 105COMMANDOTROEPENCOMPAGNIE
KCT - 18154 - 108COMMANDOTROEPENCOMPAGNIE
MATLOGCO - 66505 - MATERIEEL LOGISTIEK COMMANDO
MATLOGCO - 66509 - MATLOGCO/AFD S&A
MATLOGCO - 66510 - MATLOGCO/AFD TECH
MATLOGCO - 66511 - MATLOGCO/AFD LOG
MATLOGCO - 68380 - MATLOGCO/300MATLOGCIE
OOCL - 58035 – OOCL
OOCL - 58038 - OOCL/HQ
OOCL - 17052 - JOINT ISTAR COMMANDO
OOCL - 17055 - 101GENIEBATALJON
OOCL - 17057 - 101CISBATALJON
OOCL - 17060 - BEVO&TRANSPORT COMMANDO
OOCL - 17065 - 400GENEESKUNDIG BATALJON
OOCL - 51747 - 1CMICO
OOCL - 58974 – EODD
OOCL - 67750 - VUURSTEUNCOMMANDO
OOCL - 77124 - DEFENSIE CYBER COMMANDO
OTCO - 17080 - KONINKLIJKE MILITAIRE SCHOOL
OTCO - 17086 – OTCMAN
OTCO - 17088 - OTCGENIE
OTCO - 17089 - OTCLOG

OTCO - 17090 – OTCRIJ
OTCO - 73473 - LAND WARFARE CENTRE
OTCO - 40003574 - LAND TRAINING CENTRE

Appendix X3 – The Trainingscompendium

Column 2 holds the military activities.
Row 2 holds the names of the units that should train these activities.
The blocks that are filled with H, L and M or are still white, represent the level on which the unit should be able to perform the activity.

TAKENLIJST GENIE NIVEAU II

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Number	**Tactical Activity/ Task**	**Remarks**	**Pagngp**	**Brk**	**Gntk**	**Pabm**	**AST**	**Verk**	**GnAaslt**	**AST Aaslt**	**Duikverk**	**BMLmbl**	**BM**	**Constr**	**Adv Constr**	**Kranen**	**Mattenleg**	**GWW 105**	**Kranen105**	**Mattenleggp105**	**waterbouw**	**Waterboor**	**DuikConstr**	**Ontsmet**	**Dimgp**	**A&ATeams**	**Verk&Detect**
	COMMAND & CONTROL / TECHNICAL ADVISOR																										
2.gn.000	Optreden/Advies als Gn (Plv)Gpc		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	OST AAN INLICHTINGEN																										
2.gn.001	Uitv van verkenningen van fysieke militaire aspecten (Mil Eng)		M	L	L	L	L	H	M	L	H	L	L	M	H	M	L					H	H	H	M	H	H
	GAP CROSSING																										
2.gn.002	Inzet fascine		L		H																						
2.gn.003	Inzet mechanische brug		L	H																							
2.gn.004	Bouwen MGB EV		H			M							M	M	M						L			-			
2.gn.005	Bouwen systeembruggen Bouwen MGB (TV)												M			H		H			M						
2.gn.006	Bouwen MGB MACH												M			H		H			M						
2.gn.007	Bouwen pijler tbv paneelbruggen													-		L		M			H		M				
2.gn.010	Inzet veer																				H						
2.gn.012	Versterken overgangen		M	M	M	M							M					M		M	H						
2.gn.013	Herstel overgangen																				M						
2.gn.014	Landhoofden												M	-	-			M			M		M				
2.gn.015	Inzet standaard boten		M						H		H										H		H				
2.gn.016	Inzet geïmproviseerde vlotten / drijvers		L						H														L				
2.gn.017	Inrichten doorwaadbare plek (plaats)		L			L			L		L	L	L					L		L	L		L				
2.gn.018	Funderingen pijlers												M	-	-			M			M		H				
	BREACHING																										
2.gn.019	Doorbreken explosieve hindernissen		H		H			L	H		L																
2.gn.020	Doorbreken niet-explosieve hindernissen		H	L	H			M	H		H												L				

TAKENLIJST GENIE NIVEAU III

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Number	**Tactical Activity/ Task**	**Remarks**	**ArmdEngr**	**ArmdSpt**	**EARS Armd**	**Aaslt Engr**	**EARSAaslt**	**Constr**	**AdvConstr**	**Plant**	**Spt Constr**	**Logconstr**	**WaterConstr**	**WaterConstrSpt**	**Logwaterconstr**	**UW Constr**	**CBRNRecce**	**CBRNDeco**	**CBRNResponse**	**Water Drill**	**GNW: Milconstr**	**GNW: Logost**
	COMMAND & CONTROL / TECHNICAL ADVISOR																					
3.gn.000	Optreden/Advies als Gn (O)PC		H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	OST AAN INLICHTINGEN																					
3.gn.001	Ost met inlichtingen van de fysieke operationele aspecten (MilEng)		H	M	H	H	H	M	M	M	M	L	H	M	L	H	H	M	H	M	H	M
	GAP CROSSING																					
3.gn.002	Adviseren brugherstel		M										H								H	
3.gn.003	Inzetten systeembruggen		M	M				M	L	M	H		M	H								
3.gn.004	Inzetten paneelbruggen		L	L				H	L	H	L		H	L								
3.gn.005	Inzetten vouwbrug												H									
3.gn.006	Inzetten niet standaard overgangen							L	L	L			H									
3.gn.007	Inzet fascine			H																		
3.gn.008	Inzetten gecombineerde overgangen		L	L																		
3.gn.009	Inzetten boten / vlotten		M			H							H									
3.gn.010	Inrichten doorwaadbare plek (plaats)		L	L		L				L	L		L	L		L						
3.gn.011	Ondersteunen Amfibische oversteek					L										L						
3.gn.012	Ontwerpen gecombineerde overgangen												H									
3.gn.013	Plannen mechanische brugslagsystemen		H	H		L																
	BREACHING																					
3.gn.019	Doorbreken complexe hindernissen		H	H		H																
	DEMOLITION																					
3.gn.024	Uitvoeren complexe vernielingen		H	H		H																

Appendix X4 – Number of qualifications per specialization niveau

Group	Average High	Average medium	Average low
Infantry II	9.444444444	8	4.333333333
Infantry III	9.428571429	8.285714286	4.857142857
Infantry IV	8	6.833333333	8.166666667
Reconnaisance II	16.2	5.2	1.6
Reconnaisance III	14.4	5.8	1.6
Reconnaisance IV	13	6.5	3.5
Fire Support II	1.636363636	0.272727273	0.363636364
Fire Support III	1	0.125	1
Fire Support IV	1.75	0	3
Fire Support V	2	1	0
Genie II	6.72	3.72	4.16
Genie III	6.35	2.35	3
Genie IV	8.166666667	4.833333333	6.5
Genie V	4.5	1.5	9.5
Grondgebonden Luchtverdediging II	2	0	0
Grondgebonden Luchtverdediging III	1	0	0.5
Grondgebonden Luchtverdediging IV	2	0	0
Verbindingsdienst II	1	0	0
Verbindingsdienst III	1	0.25	0
Bevoorrading en Transport II	5.4	1.4	2.4
Bevoorrading en Transport III	3.2	3.2	4.2
Bevoorrading en Transport IV	1.2	2	1.6
Bevoorrading en Transport V	0	1	2
Technische Dienst II	10.5	3	1.5
Technische Dienst III	5	1	1
Technische Dienst IV	2	4.5	1
Military Healthcare II	4.6	0.2	3.8
Military Healthcare III	1.333333333	0	0
Military Healthcare IV	1	0	0
EOD II	5	0	0
EOD III	1	0	0
Nationale Reserve II	12	0	0
Nationale Reserve III	3	0	4
Nationale Reserve IV	4	0	4
Inlichtingen II	4.6	0	0.2
Inlichtingen III	3.4	0.2	0.4
Inlichtingen IV	3.5	0	0.5

Appendix X5 – Which units train a specialization

Specilizations in Tc	Practiced by the following units
Infanterie (Infantry)	+ 11LMB - 17029 - 11INFANTERIEBATALJON AMB GGJ + 1LMB - 17030 - 12INFANTERIEBATALJON AMB RVH + 11LMB - 17031 - 13INFANTERIEBATALJON AMB RSPB + 13LTBRIG - 17035 - 17PANTSERINFANTERIEBATALJON + 13LTBRIG - 17041 - 42PANTSERINFANTERIEBATALJON + 43MECHBRIG - 17046 - 44PANTSERINFANTERIEBATALJON + 43MECHBRIG - 44978 - 45PANTSERINFANTERIEBATALJON
Verkenning (Reconnaissance)	+ 11LMB - 18195 - 11BRIGADEVERKENNINGSESKADRON + 13LTBRIG - 18196 - 42BRIGADEVERKENNINGSESKADRON + 43MECHBRIG - 18197 - 43BRIGADEVERKENNINGSESKADRON
Vuursteun (Fire support)	+ OOCL - 67750 – VUURSTEUNCOMMANDO (3 Batterijen)
Genie (Military engineering)	+ 11LMB - 18282 - 11GENIECOMPAGNIE AMB + 13LTBRIG - 47060 - 41PANTSERGENIEBATALJON
Grondgebonden luchtverdediging (Ground-based air defense)	+ DGLC - 49268 - 13LUCHTVERDEDIGINGSBATTERIJ + DGLC - 62647 - 800SQUADRON + DGLC - 62648 - 802PATRIOTSQUADRON + DGLC - 43287 - OTC GLRV
Verbindingsdienst (Connection service)	+ OOCL - 17057 - 101CISBATALJON
Bevoorrading en Transport (Supply and transport)	+ 11LMB - 18411 - 11BEVOORRADINGSCOMPAGNIE AMB + OOCL - 17060 - BEVO&TRANSPORT COMMANDO
Militaire gezondheidszorg (Military healthcare)	+ 11LMB - 18423 - 11GENEESKUNDIGE COMPAGNIE AMB + 13LTBRIG - 18416 - 13GENEESKUNDIGE COMPAGNIE + 43MECHBRIG - 17050 - 43GENEESKUNDIGE COMPAGNIE + OOCL - 17065 - 400GENEESKUNDIG BATALJON
EODD (Explosives clearance service)	+ OOCL - 58974 – EODD
Nationale Reserve (National Reserve)	+ 11LMB - 17074 - 20NATIONALE RESERVEBATALJON + 13LTBRIG - 17076 - 30NATIONALE RESERVEBATALJON + 43MECHBRIG - 17068 - 10NATIONALE R ESERVEBATALJON

Inlichtingen (Information)	+ OOCL - 17052 - JOINT ISTAR COMMANDO

Appendix X6 – Number of people training a specialization

Units that practice a certain specialization	**Exist out of (staff units excluded) (These are all rough estimations)**
+ 11LMB - 17029 - 11INFANTERIEBATALJON AMB GGJ + 1LMB - 17030 - 12INFANTERIEBATALJON AMB RVH + 11LMB - 17031 - 13INFANTERIEBATALJON AMB RSPB + 13LTBRIG - 17035 - 17PANTSERINFANTERIEBATALJON + 13LTBRIG - 17041 - 42PANTSERINFANTERIEBATALJON + 43MECHBRIG - 17046 - 44PANTSERINFANTERIEBATALJON + 43MECHBRIG - 44978 - 45PANTSERINFANTERIEBATALJON	Infanterie (Infantry) ≈ 28 compagnies ≈ 3360 people
+ 11LMB - 18195 - 11BRIGADEVERKENNINGSESKADRON + 13LTBRIG - 18196 - 42BRIGADEVERKENNINGSESKADRON + 43MECHBRIG - 18197 - 43BRIGADEVERKENNINGSESKADRON	Verkenning (Reconnaissance) ≈ 3 eskadron's ≈ 360 people
+ OOCL - 67750 – VUURSTEUNCOMMANDO (3 Batterijen)	Vuursteun (Fire support) ≈ 3 batteries ≈ 360 people
+ 11LMB - 18282 - 11GENIECOMPAGNIE AMB + 13LTBRIG - 47060 - 41PANTSERGENIEBATALJON	Genie (Military engineering) ≈ 6 companies ≈ 720 people
+ DGLC - 49268 - 13LUCHTVERDEDIGINGSBATTERIJ + DGLC - 62647 - 800SQUADRON + DGLC - 62648 - 802PATRIOTSQUADRON + DGLC - 43287 - OTC GLRV	-
+ OOCL - 17057 - 101CISBATALJON	Verbindingsdienst (Connection service) ≈ 3 companies ≈ 360 people
+ 11LMB - 18411 - 11BEVOORRADINGSCOMPAGNIE AMB + OOCL - 17060 - BEVO&TRANSPORT COMMANDO	Bevoorrading en Transport (Supply and transport) ≈ 11 companies ≈ 1080 people
+ 11LMB - 18423 - 11GENEESKUNDIGE COMPAGNIE AMB + 13LTBRIG - 18416 - 13GENEESKUNDIGE COMPAGNIE + 43MECHBRIG - 17050 - 43GENEESKUNDIGE COMPAGNIE	Militaire gezondheidszorg (Military healthcare) ≈ 7 companies ≈ 720 people

+ OOCL - 17065 - 400GENEESKUNDIG BATALJON	
+ OOCL - 58974 - EODD	EODD (Explosives clearance service) ≈ 2 companies ≈ 240 people
+ 11LMB - 17074 - 20NATIONALE RESERVEBATALJON + 13LTBRIG - 17076 - 30NATIONALE RESERVEBATALJON + 43MECHBRIG - 17068 - 10NATIONALE R ESERVEBATALJON	Nationale Reserve (National Reserve) ≈ 17 companies ≈ 2040 people
+ OOCL - 17052 - JOINT ISTAR COMMANDO	Inlichtingen (Information) ≈ 1 companies, 3x eskadron, 1 battery ≈ 600 people

Appendix X7 - Percentage that each system has of the total amount of systems per specialization

Systeem	Verkenning	Nationale Reserve	Infantery	Military healthcare
Graafdozer	0	0	0	0
Mobiele telescoopkranen	0	0	0	0
Bouwmachines	0	0	0	0
Trilwals	0	0	0	0
Wegenmattenlegger MLC-70	0	0	0	0
MOGOS ? MGC containers	0	0	0.0055	0.006
Leopard 1	0	0	0	0
Leopard 2	0	0	0.0137	0
M577 (Zodiac)	0	0	0	0
PzH 2000 NL	0	0	0	0
CBRN Verkenningssystemen	0	0	0	0
BOXER	**0**	**0**	**0.0797**	**0.125**
Bushmaster	0	0	0.0151	0
Fuchs (EOV)	0	0	0	0
Combat Vehicle 9035NL (CV90)	**0**	**0**	**0.1016**	**0**
LSV	0	0	0.0302	0.0506
Fennek	**0.63**	**0**	**0.1841**	**0**
YPR-765 en 806	0	0	0.022	0.003
Army Ground Bases Air Defense System (AGBADS)	0	0	0	0
Gevechtsveldcontroleradar	0	0	0	0
Motorfietsen	0	0	0.0453	0.0119
MB 290 GD; alle types	**0.17**	**0**	**0.2953**	**0.3304**
DAF tropco 400 en 600 kN	0	0	0	0
Oplegger Met Werkruimte (OMW)	0	0	0	0
Scania WLS	0	0	0	0
Y 2300 alle types	0	0	0.0055	0.0536
YA-4442 alle types	**0.16**	**0.1746**	**0.1346**	**0.2679**
YBZ 3300 en YWL 3300	0.03	0	0.0165	0.0149
QUAD	0	0	0	0
Mortieren	0	0	0	0
Brandstofopvoer en -distributiesysteem (BODS)	0	0	0	0
EODD	0	0	0	0
Mobiele voedselbehandelingsystemen	0	0	0	0
Mobiele Waterbehandelingsystemen	0	0	0	0
Vrachtauto 12kN Vector	0	0	0	0
Amarok	**0.01**	**0.8254**	**0.0508**	**0.1369**
Patriot	0	0	0	0
Raven	0	0	0	0
UAV Scan eagle	0	0	0	0
Tactische satellietsystemen	0	0	0	0

Appendix X8 – Seven Fennek types

Reconnaissance vehicle: The reconnaissance vehicle is low and the engine is silent. The exhaust gases are scattered in such a way that these are not clearly visible on heat images. This makes it a difficult vehicle to trace for the enemy.

The vehicle has a special observe equipment, a BAA module. This viewer can be pushed up 1,5 meters above the roof of the Fennek. The BAA head exists out of a laser distance measurement tool, a digital camera and a heat image observer. This special observe equipment allows the crew to look kilometres ahead, even in the dark.

The forward observer: This Fennek type acts as the eyes of the fire support units. The forward observer gathers information with which targets can be recognized.

Tactical aircontrol party: This Fennek type is equipped with observation tools for air support.

Fenneks that are used for general service: This Fennek type does not have the special BAA module. It is used for "general" purposes. It is particularly used as a transportation vehicle.

Mortar Fennek: This Fennek type transport an 81mm-mortar that is used as fire support.

Medium range anti-tank Fennek: This Fennek type transports a launching system for anti-tank missiles.

Stinger weapon platform Fennek: This is an Air Defense type of the Fennek, with an integrated stinger launching system.

Appendix X9 – Blueprint of locking pin

Confindential

Appendix X10 - Diameters in which material is available

Diameter mm	Toleranties ISO	Kg/m	Prijs €/kg	Prijs €/m
25	h10	3,85	3,34	12,86
30	h10	5,55	3,34	18,54
35	h10	7,55	3,34	25,22
40	h10	9,86	3,20	31,55
45	h10	12,48	3,20	39,94
50	h10	15,41	3,09	47,62
55	h10	18,65	3,20	59,68
60	h10	22,20	3,09	68,60
65	h10	26,05	3,31	86,23
70	h10	30,21	3,09	93,35
75	h10	34,68	3,20	110,98
80	h10	39,46	3,00	118,38
90	h10	49,94	3,11	172,39
95	h10	55,64	3,11	193,80
100	h10	61,65	3,11	207,07
110	h10	74,60	3,11	231,63
120	h11	88,78	3,11	275,67
125	h12	96,33	3,11	299,10

Appendix X11 – Supply disruptions during 2018

Confidential

Appendix X12 – Protection plate

Confidential

Appendix X13 - U - profile

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Appendix X14 – Spring brake cylinder

Confidential

Appendix X15 – Master cylinder

Confidential

Appendix X16 – Distribution box

Confidential

Appendix X17 – Case study

The department of technology, where the AM centre of the RNLA will be located, is already experimenting with printing parts. In cooperation with DiManEx, an industrial partner of the RNLA, metal parts of the Fennek were manufactured.

The Fennek

The Fennek (Figure X1) is a light reconnaissance vehicle that is also used for reconnaissance and surveillance purposes. The vehicle is primarily used by reconnaissance units. The Fennek is able to perform in different kinds of environments.
The traits of the Fennek are that it is silent, discrete and sharply observing. (Landmacht app)

Figure X1: The Fennek

Specifications of the Fennek

Length: 5,58 meters
Width: 2,55 meters
Height: 2,29 meters
Weight: 10400 kilos (battle ready)
Engine: 6-cilinder diesel, 177 kW
Crew size: 3 persons
Arsenal: Heavy 12,7mm-mitrailleur (.50) (Source: Landmacht app)

Fennek types

The RNLA possesses seven types of Fenneks. The total amount of Fenneks within the RNLA is 365. (Landmacht app)

- 144 reconnaissance vehicles
- 45 forward observers
- 8 tactical aircontrol party Fenneks
- 63 Fenneks that are used for general service
- 39 mortar Fenneks
- 48 medium range anti-tank Fenneks
- 18 stinger weapon platform Fenneks

Appendix X8 explains the differences between these seven Fennek types.

The chosen part

The RNLA has a cooperation going with service provider DiManEx. Recently, the RNLA and DiManEx have selected fifteen part that were deemed appropriate for experimenting with AM. These parts have already been printed by now.

The part that I have selected for this case study is a locking pin (In dutch: een blokkeerpen), Figure X2 shows a comparison of the original locking pin (left) and the printed locking pin (right). The part is used in the Fennek. Its main function is to lock a part in place, which provides safety.

Figure X2: The original locking pin (left) and the printed locking pin (right)

7.3 Comparison of different methods to obtain the part

There were always two methods known within the RNLA, to obtain a part like this. One way would be ordering the conventionally manufactured part from a supplier. The other way would be to let their own workers create the part in the workplace, by means conventional manufacturing methods.
AM is coming up as a new option to manufacture parts. It is regarded by many as an interesting option.
In this case study, I will compare the three different methods on costs. I will also discuss the differences in mechanical properties between a printed part and a part that is produced by means of conventional manufacturing methods.

Ordering the part

The standard price of ordering the part of a supplier is €192,12. Of course the part has a lead time and therefore it is not immediately available in case there is no stock. However, the lead time is unknown.

Conventionally manufacturing the part in a workplace

In order to create the part in a workspace, different conventional processes need to be executed. With the help of a work preparator, I was able to map out the two different processes that need to executed in order to create the locking pin in the workplace: a build job preparation and the conventional processes.

Build job preparation

It takes the work preparator about 90 minutes to order and select the right materials needed. Hereby, the work preparator prepares for the conventional processes.

Conventional processes

Table X1 depicts all the conventional processes that are needed to make the locking pin.

Conventional processes		Time
7	Sawing short	à 15min
8	Turning to nominal measurement values	à 60min
9	Post processing (tolerances)	à 45min
10	Adding radius R23	à 30min
11	Adding the borehole + countersinking	à 30min
12	Adding screw threat	à 30min
13	Adding coating (External process)	à 60min to source this process out

Table X1: Conventional process needed to create one locking pin

These conventional processes can be carried out by using a CNC lathe, a conventional mill and a bore. There is only one person needed to execute these processes. The total time of the first six processes will take 2,5 hour man hour (not 3,5), as some processes can be combined. The last process, adding coating, has to be carried out externally. This will take about an hour. This gives a total of 4,5 man hours to create one locking pin.

Series production

In a series production of 10 pieces, the process time per part would be shorter, than when only a single part is manufactured. In this case study, I will only consider the production of one part.

Cost of in-house conventional manufacturing

There is 1,5 hour of preparation time needed and 4,5 hours to carry out the conventional processes, in order to create the part. As the preparation and the conventional processes can be carried out by one person, this means that creating one locking pin costs 6 man hours. For this cost calculation, I assume that on average the person who executes this job is a Korporaal with salary number 15. This person earns € 2.371,23 a month, which equals to €27.854,76 a year (www.werkenbijdefensie.nl). €27.854,76/52 gives €535,67 per week. €535,67/40 gives a labour cost per hour of €13,39.
This gives the following sum to calculate the labour costs to manufacture the locking pin: 6 * €13,39 = €80,35.
There are also material costs that should be taken into account. According to the part specifications, the part is made out of alloyed steel that is round, hot-rolled and tempered. Appendix X10 shows the diameters in which this steel is available. In case of this part, a

diameter of Ø25mm will be fine. A length of approximately 200mm Ø25mm steel will be fine; the part is 113,9 mm long, but there is also extra material needed for clamping. The price of the alloyed steel is €12,86 per meter. The price of 0,2 meter is: 0,2 * €12,86 = €2,57. This gives a material cost of €2,57.
There should also be machine costs and coating costs be included in the cost price. It was for this case not possible to determine the machine costs. According to an expert, €50,- to €75,- is a realistic indication to take for the coating costs. I take an average (50+75)/2=€62,50 as the coating cost.
All of the above gives a total cost of: €145,42

Printing the part, with post-processing

Costabile et al (2016), a literature review, has provided me with an overview of all the established cost models of printing parts. I have used these cost models to determine for myself which cost factors play a role in printing the locking pin.

Lindemann et al. (2012)

Lindemann recognizes four cost process that are relevant in additively manufacturing a part:

- Building job preparation: Basically, everything that needs to be done before the actual production process can be started.
- Building job production: In this process the part is build.
- Sample parts and support manually removing: Removing the object from the printer and its support material.
- Post processing: Finishing the 3D print, as certain object properties cannot be created by printing.

Rickenbacher (2013)

Rickenbacher (2013) calculates the total manufacturing costs, $C_{tot}(P_i)$, by summing up all the costs that play a role in the manufacturing process from start to finish. Figure X depicts Rickenbacher's cost model, where P_i stands for a part with geometry i.
The cost model exists respectively out of:
- Preparation costs
- Costs for build job assembly
- Machine set up costs
- Costs for the process that builds the part up
- Costs for removing the part from the machine
- Costs to separate the part from the print plate
- Post processing costs

$$C_{tot}(P_i) = C_{Prep}(P_i) + C_{Buildjob}(P_i) + C_{Setup}(P_i) + C_{Build}(P_i) + C_{Removal}(P_i) + C_{Substrate}(P_i) + C_{Postp}(P_i)$$

Figure X3: Cost model of Rickenbacher (2013)

Cost of printing the locking pin

The Lindemann (2012) cost model gives me which relevant cost processes play a role in AM. Rickenbacher (2013) is more specific as it splits the total manufacturing cost up in seven cost factors.

The locking pin is printed by service provider DiManEx. Via my contact at the Department of Technology (Afdeling Techniek) of the RNLA, I have obtained an estimated print price of €500,-. This includes the costs that are mentioned in Rickenbacher's cost model. AM is not able to print screw threat and print the right tolerances. Therefore the locking pin does not match the all the properties that it should have according to the blueprint. The post-processing processes need to be carried out, in order to finalize the part:
- Turning
- Milling
- Adding screw threat
- Coating

Comparison between the three manufacturing methods

A comparison between the manufacturing methods can be made based on costs, but will not tell the whole story. Therefore, there will also be a comparison between the conventionally manufactured and the additively manufactured parts based on mechanical properties.

Comparison based on costs

Table X2 shows the calculated costs for the three different methods to obtain the part.

Order the part from the supplier	€192,12
Creating the part in the workplace	€145,42
Printing with post-processing	€500

Table X2: Comparison of the three different methods

Printing with post-processing is clearly more expensive than the traditional methods to obtain the part, ordering and creating the part in a workplace.
Printing the locking pin was part of an experiment, with as main goal for the people of the RNLA to become more acquainted with AM. Literature and current developments suggest that AM will develop and become more cost-efficient. Therefore, printing has the potential to replace conventional manufacturing methods.

Comparison based on mechanical properties

A printed part is build up out of layers. A conventional part is created out of a bigger block of material, which is with the use of conventional process reduced to the part itself. As said in Section 6.3, the mechanical properties of a metal printed part differ from a part that is produced by means of traditional manufacturing methods. The strength, hardness and flexibility of metal printed parts are typically higher. However, metal printed parts are also more prone to fatigue (www.3dhubs.com).
Currently, the RNLA and DiManEx are researching the state of the mechanical properties of the printed parts that were part of the experiment.

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