UiO : University of Oslo

Fast-tracking development of military high technology

A study of the Norwegian Triaxial Model

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Master's thesis in "Technology, innovation and knowledge"
60 credits
at

TIK Centre for Technology, Innovation and Culture
Faculty of Social Sciences

October 2019

Abstract

Norwegian authorities want to make sure the Norwegian Armed Forces get access to the best possible technological solutions catering to their operational requirements, maintain and advance Norwegian industrial capabilities in important technological areas, and keep Norwegian defence industry internationally competitive. To support these ambitions, they have developed the Norwegian Triaxial Model, a framework for innovation cooperation between the Armed Forces, the Norwegian Defence Research Establishment and industry actors.

This study researches how the Norwegian Triaxial Model performs in practice, when new defence systems are developed based on available high technology.

The theoretical framework belongs to the technological innovation systems approach, where central processes, or *functions*, within the system are analysed in order to understand exactly what goes on within the system and how well each function is currently fulfilling its role in supporting innovative activity.

The method applied is qualitative case study, using interviews as the primary tool for data collection, and the research questions are:

- How do the actors "play their part"; what are the different actors' roles and contributions to innovation in this version of the Norwegian Triaxial Model?
- Which drivers positively contribute to innovation and which barriers hamper progress for innovation in this version of the Norwegian Triaxial Model?
- What can be done to improve this version of the Norwegian Triaxial Model?

The theoretical and empirical findings in this study contribute to a better understanding of actors, roles and processes in the current version of the Norwegian Triaxial Model, and its contribution to innovation in the military domain. The conclusion also presents central drivers that promote innovation in the system, central barriers that can hamper innovation, and suggest some measures that could possibly be beneficial for improved performance of the Norwegian Triaxial Model in the future.

Acknowledgements

While many hours have been spent alone stooped over the keyboard, writing this master's thesis was not entirely a solo project. There are a few I wish to extend my sincere gratitude to.

My supervisor Arne Martin Fevolden (NIFU) has been of great assistance. With deep knowledge of innovation studies and of the defence sector, his constructive critique has guided me through my entire process, from the very beginning to the very end. Thank you, Arne.

The Norwegian Defence Research Establishment (FFI) has helped facilitate my research trough providing me with an office space and direct access to both research reports and the researchers who wrote them, for which I am very grateful. A special thanks to Hanne Bjørk, head of the Innovation and Industrial Development division at FFI, who made this possible.

I promised confidentiality to all my informants, which means that I cannot publicly thank them for their contributions. They nevertheless deserve credit for their contributions to this study. Without the rich empirical data from all those interviews, my project would have been much less interesting, and the result much less worth. Thank you all.

And last but not least, I owe thanks to my wife, Beate. Your support was tremendously valuable!

Simen Pedersen

October 2019

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1. Introduction

«Innovation […] demands feedback, and effective innovation demands rapid, accurate feedback with appropriate follow-on actions. Radical, or revolutionary, innovation prospers best when provided with multiple sources of informational input. Ordinary, or evolutionary, innovation requires iterative fitting and trimming of the many necessary criteria and desiderata. In either case, feedbacks and trials are essential.» (Kline & Rosenberg, 1986, p. 286)

The international market for defence materiel is a particularly challenging one, characterised by strong political control, protectionism and limited access for foreign competitors. A number of policies, mechanisms and agreements influence competitiveness, such as offset requirements and discriminatory procurement practices, adding to the complexity that is already inherent in all innovation processes (Castellacci & Fevolden, 2015, p. 17; Ministry of Defence, 2015, p. 5).

The Norwegian government has stated that maintaining industrial capability in important technological areas is a crucial factor in making sure that our defence sector can access the right materiel and competence at the right time. This increases the ability to safeguard national security in areas where conditions unique for Norway require special competences. Norway is a small country, at least in terms of population, and the home market is too small to sustain a broad range of high technology military industry. This makes it a strategic ambition to ensure that the Norwegian defence industry is internationally competitive (Ministry of Defence, 2015, p. 5).

In order to serve these needs, the Norwegian government has implemented policies that are designed to help reduce uncertainty and increase the rate of success for Norwegian industry actors, and to contribute to the Norwegian Armed Forces getting access to the best technological solutions suited for their needs. These policies form a framework for cooperation between Norwegian defence industry actors, the Norwegian Defence Research Establishment (FFI) and the Norwegian Armed Forces, in a user-industry-research collaboration that is called the Norwegian Triaxial Model.

This type of collaboration has been done for decades, contributing to a number of products that have provided Norwegian Armed Forces with advanced products as well as resulting in international commercial successes, such as NASAMS (Norwegian Advances Surface-to-Air Missile System), NSM (Naval Strike Missile), and Protector (Remote Weapon Station). In the Norwegian Triaxial Model each actor contribute with their special competencies; the Armed Forces (the Ministry of Defence (MoD) and its subordinate units) make up the *user side*, defining needs and specifying what capabilities are needed; the industry is the *producer*, knowing what is currently possible and the NDRE contributes with *science*, in terms of both in-house knowledge development and a large professional network.

The current version of the Norwegian Triaxial Model can be divided into three different main categories of development and procurement:

- Long term development of high-tech defence systems on the basis of basic science development
- Development of new defence systems based on available commercial technology
- Early involvement of the defence industry in development and/or procurement projects.

The development of new defence systems based on existing technology is, in the context of the Norwegian Triaxial Model, a fast-track for military innovation. Even though development can still take years, it carries with it a particular set of challenges, for instance: the fact that most military procurement is planned many years ahead, since the Armed Forces traditionally typically wants equipment and systems with a very long life span, means that a large percentage of money are tied up in long term projects and little money is available for purchasing «off the shelf» materiel or investing in emerging new technologies. Another challenge is finding ways to make new equipment fit as seamlessly as possible with existing capabilities and ways to operate, making concept development an important part of the innovation process.

In the spring of 2017, a discussion on how to further evolve the current innovation model and three-way cooperation in the defence sector was initiated in a forum for strategic dialogue concerning the defence sector and the defence industry in Norway.[1] A work group was tasked with presenting suggestions for how to further develop the Norwegian Triaxial Model,

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[1] This forum is called «høynivågruppen» (translates into «high level forum»). It is a forum for dialogue on a strategic level between MoD, other government agencies in the sector, and industry leaders, and members are appointed by the MoD. It is chaired by the MoD's National Armaments Director (NAD), and consists of representatives from the MoD, top level managers from selected defence industry firms, the Norwegian Defence and Security Industries Association, and central government agencies in the defence sector (Ministry of Defence, 2017).

framework conditions, policy instruments and the procurement process in light of current national and international development trends. Published in November 2018, the report "Videreutvikling av forsvarssektorens innovasjonsmodell – trekantmodellen versjon 2.0" summarises experiences with the model so far, highlighting important success criteria, benefits, and long-term effects from national development and procurement. Acknowledging national and international trends, the report states that in order to ensure continued relevance and effectiveness, the Norwegian Triaxial Model must be developed further. Of particular importance is to assess challenges and possible solutions for speeding up the processes of development and implementation of materiel and technologies that the Armed Forces need, among them the possibility of using available commercial technology and competence (Bjørk et al., 2018, p. 7).

Speed in innovation and product development has "always been of interest", but with the report on how to further develop the Norwegian Triaxial Model, the need for a fast-track version was formalised.

1.1. Research questions

The aim for the Norwegian Triaxial Model is to make sure the Norwegian Armed Forces get access to the best possible technological solutions catering to their operational requirements, to maintain and advance Norwegian industrial capabilities in important technological areas, and at the same time ensure that Norwegian defence industry is internationally competitive.

The three different tracks, or categories, within the Norwegian Triaxial Model carries with them different sets of challenges. The fast-track version seems to be getting extra attention from the highest levels of the involved parties, and FFI accordingly appear to pay special attention to it at present. This makes it stand out as especially relevant and timely as a focus for academic research.

This thesis will therefore examine how the Norwegian Triaxial Model functions for those innovation projects that fall into the fast-track category. The aim is to achieve a functional analysis of how this mode of innovation performs, in order to identify possible barriers that act as constraints for progress, and to identify what contributes to progress, driving the process forwards. In order to do this, I will seek the answers to the following research questions:

- How do the actors "play their part"; what are the different actors' roles and contributions to innovation in this version of the Norwegian Triaxial Model?

- Which drivers positively contribute to innovation and which barriers hamper progress for innovation in this version of the Norwegian Triaxial Model?
- What can be done to improve this version of the Norwegian Triaxial Model?

1.2. Structure of the thesis

Chapter 2 presents the theoretical framework I have used to study the research topic. The broader family of theories on systems approach to innovation studies will be presented briefly, before a more detailed discussion of theory on Technological Innovation Systems and relevant concepts and literature will explain and justify the framework I have developed for my analysis.

Chapter 3 explains the methodological choices and delineations for the study. A qualitative approach, primarily through interviews but also document studies, has been used to gather data to research the questions.

Based on the empirical findings, chapter 4 will be used to define the TIS with its structural components. This will form a basis for the following analysis of the innovation processes.

Chapter 5 presents the empirical findings and seeks to answer the research questions through analysing the performance of the seven functions explained in the theoretical framework (chapter 3).

Chapter 6 is the conclusion, where I will sum up the main findings from the analysis and present answers to the research questions.

Chapter 7 will present some topics for further research that could help increase knowledge on how the Norwegian Triaxial Model functions and performs.

2. Theory

2.1. Introduction

This chapter will present literature and concepts that inform the analytical framework of the thesis. When studying interaction between industry, user and research institutions in innovation, several perspectives are available to be used as focal lenses. The triple helix of university – industry – government relations, as described by Etzkowitz and Leydesdorff (2000), focuses on the fluidity of relations and networks and how they impact the continuous reshaping of institutional arrangements in knowledge and technology intensive fields, with particular emphasis on the potential for universities to play an enhanced role in innovation.

The aim for this thesis is to study processes in what is de facto a formally established model for innovation, and within that model I will focus on a mode of innovation where the industry actor is more likely to be the primary driving force. I therefore find using a technological innovation systems (TIS) approach to be more suitable than, for instance, the triple helix perspective. TIS belongs to a wide family of theories, and in the following I will present a brief introduction to that family and explain why I regard TIS to be appropriate for this thesis, before I explain the TIS framework in greater detail and how I plan to make use of it in this thesis.

2.2. The systemic nature of innovation - TIS in a wider context

Organisations seldom innovate in isolation; successful innovation often depends on making use of resources and expertise that cannot be found inside the organisation, but could be available from customers, suppliers, competitors and various other private and public actors. To access these external units, organisations have to form relationships with them and find ways to cooperate and exchange knowledge and other resources. Those interactions are influenced by institutional frameworks, in the form of norms, rules, regulations and so on. In sum these elements can be described as a system, and when such a system functions in some way to produce innovations; an *innovation system*. A general definition of systems of innovation is that they encompass «all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovations» (Edquist, 2006, p. 182).

Edquist's general definition shows that innovation systems are made up of a set of components and the relationship between them. While generically true, this definition might need clarification or elaboration depending on what phenomenon one wants to study. The phrase "innovation system" can give the impression of a well organised set of actors, behaving in a coordinated manner, towards a common goal. This is not necessarily the case; the components of any given innovation system might have different objectives and contribute in very varying degrees. "This implies that the system in focus does not have to exist in reality as fully-fledged. Instead, it may be emerging with very weak interaction between components" (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 408). Therefore, the systems perspective is not a theory as such, it is an analytical framework constructed not to predict future events but nevertheless well suited to explain why things are the way they are – in the specified innovation system that is studied.

Johnson (1992, p. 26) defines institutions as "sets of habits, routines, rules, norms and laws, which regulate the relations between people and shape human interaction. By reducing uncertainty and, thus, the amount of information needed for individual and collective action, institutions are fundamental building blocks in all societies". He includes banks, government agencies, and other entities we call institutions in everyday speech in this definition. A bank, for instance, is organised to carry out the already institutionalised acts of borrowing and lending. Institutions influence how people relate to one another, including how knowledge is transferred. According to Lundvall (1998, p. 409), the institutional setting to a great extent determines how economic agents behave in an economy that is characterised by on-going innovation and fundamental uncertainty. In the context of this study institutions are framework factors that regulate how the actors behave in relation to each other.

Innovation processes involve various actors, with different roles and agendas, the interplay between them, and different rules that regulate behaviour. Innovation can thus be regarded as taking place in a systematic manner. Nevertheless, this *system* is not necessarily explicitly defined. Scholarly research of innovation from a systemic perspective can take different form, depending on what level of aggregation or what the focus of the research is.

2.3. Different systemic perspectives on innovation

Several different types of innovation systems have been conceptualised in innovation studies. One perspective is to focus on National Systems of Innovation (NSI). Classical economical perspectives tend to focus on problems concerning allocation, and these perspectives call for organising economic systems based on normative conclusions drawn from analysis of actors with *"given preferences and sets of information, including a given stock of publicly shared* *technical knowledge, make rational choices among well-defined alternatives"* (Lundvall, 1998, p. 408). Lundvall claims that a better understanding of economic development has to take the process of innovation into account, since a focus on allocation of existing resources without improving production methods or introducing new products would lead to stagnation. He argues that for economic development, innovation is more important than allocation, and that learning capability is more important than what body of knowledge is available to an actor at a given time. *"One basic intention behind the concept of national systems of innovation is thus to change the analytical perspective away from allocation to innovation, and from making choices to learning"* (Lundvall, 1998, p. 408). According to Nelson (1992, p. 347), NSI is suitable for comparing similarities and differences in different countries and discussing how nations perform with regard to innovation. Cooke et al. (1997, p. 475) point out that especially smaller nations, with few large corporations and with economical limitations that prevent public funding of a wide range of technological research, need to be acutely aware of their innovative strengths, and can benefit from knowledge produced through application of the NSI perspective.

"The view of interactive learning as a fundamental aspect of the innovation process provides the ground for an interactive innovation model, which is greatly facilitated by geographical proximity and territorial agglomeration" (Asheim & Isaksen, 1997, p. 325). Building on this type of notion, some scholars have found that it can be advantageous to reduce some of the vast complexities and diversities of national systems of innovation by introducing another, sub-national perspective: Regional Innovation Systems.

Cooke et al. (1997, p. 476) note that *"although a key impulse for NSI research was the question of whether globalisation was eroding national hegemony in respect of the organisation of innovation, the equally valid question of whether the organisation of innovation within nations was evolving in new ways was scarcely mentioned".* They further point out that innovation occurs, with substantial variation, in subnational clusters effectively untouched by NSI, and propose that systemic innovation should be studied not only on a national level, but also on a sub-national level. The subnational level has previously been studied through the lens of *sectoral innovation systems*, but Cooke et al. suggest that the sectoral approach might be too narrow, and propose that the way firms in different sectors and clusters interact with each other, influenced by both regional policies and support structures in addition to national factors, is better studied through the lens of *regional innovation systems* (Cooke et al., 1997, p. 476). Like Lundvall, Cooke et al. (1997, p. 490) emphasise the importance of learning in any innovation process, and that learning has "important specific and local characteristics and that it can be improved through certain institutional changes and properly oriented active policies".

The technological innovation system (TIS) perspective introduces a fourth approach to studying innovation as a systemic phenomenon. The TIS approach is often used to explain the nature and rate of technological change. The TIS approach is applicable on several different levels of analysis, spanning from studying technology in the sense of an entire field of knowledge, such as the development and diffusion of sustainable energy technologies, to focusing on how one specific product has made the journey from research/development to diffusion.

A central concept within TIS is that the system is defined more in terms of knowledge and competence flows, rather than the flow of ordinary goods and services. This puts an emphasis on knowledge and competence networks within the system, and focuses the analysis towards the dynamics of these networks. (Carlsson & Stankiewicz, 1991, p. 111)

Some critique has been leveraged against the systemic perspective on innovation, such as lack of clarity or unity in concepts and definitions; what is an «institution», and delineation; what should be included as part of and what should be excluded from any given innovation system analysis. Comparing results between different studies become difficult unless the components and relationships studied are more or less similar, which makes it difficult to build theory in the classical sense of a model that can explain how similar input should produce similar results when repeated over time.

I have chosen to study innovation in the Norwegian Triaxial Model through the perspective of a technological innovation system (TIS). Using this perspective, I will start by defining the TIS at hand and identify the structural components in the system. When the structure of the TIS is mapped out, I will focus on functions, that is I will describe what actually goes on in the system by studying 7 key processes, or functions, each representing different aspects of research, development, production and diffusion of new technologies.

The aim for this thesis is not primarily to contribute to the theoretical understanding of the concept of TIS, but to build on an established analytical framework to study performance and identify drivers and barriers in a politically defined innovation system. By properly defining the TIS to be studied, and all its actors, institutions and networks, this analytical framework is likely to produce useful results for this purpose.

The Norwegian Triaxial Model is a formal framework for a three-part collaboration. Two of the actors, the FFI and the Armed Forces are always part of the triangle, independent of which technology is currently being developed. The third participant, the industry actor, is the one actually producing the technology in question, and who this is changes from project to project. This degree of consistency in the setup of the actors allows for studying different projects in the Norwegian Triaxial Model using the same analytical framework and enables a comparison between different cases that can shed light on core processes and thus inform stakeholders on how to further develop the model for future use. This TIS approach provides a way to study what goes on in the innovation system through analysing how the different functions in the system are performing. This is why I deem the TIS approach the best way forward for this thesis, and the next section will explain my analytical framework in detail.

2.4. Technological Innovation Systems

An early definition explains that a TIS «may be defined as a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology» (Carlsson & Stankiewicz, 1991, p. 111). Studies of technological innovation systems focus on the performance of the innovation system surrounding a particular technology, and with that technology as the starting point establishes a framework for analyses (Bergek et al., 2015, p. 51). This can lead the analysis to see across the geographical and sectorial boundaries of the national, regional and sectoral perspectives on innovation. In reality, a TIS will not be entirely independent of these boundaries but will be entangled in what can be defined as national, regional or sectoral systems.

«As a technology-centred framework, there has always been a focus on technology-specific factors in TIS research. However, since it is a systems approach analysts have from its inception tried to find ways to take into account interactions with other types of systems encompassing or transcending the TIS, such as sectoral and national systems of innovation. Indeed, the 'functions approach' was developed as a methodological tool to handle this complexity by aggregating various influences (of different origins) on the dynamics of a TIS into a set of key processes» (Bergek et al., 2015, p. 52).

At the core of the TIS approach lies the notion that system performance cannot be measured by merely looking at presence or absence of various system components, as has been commonly seen in traditional innovation system analysis. To achieve a more detailed description of system dynamics, the TIS approach has introduced its characterising focus on *functions*, where central processes within the system are analysed in order to understand exactly what goes on within the system and how well each function is currently fulfilling its role in supporting innovative activity (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 410; Mäkitie et al., 2018, p. 814).

TIS has been critiqued for often adhering to national boundaries as a delineation, and thus not providing scholars and policy makers with sufficient understanding of how innovation activities are organised on a global level and how innovation processes occur in and between different spatial domains (Binz et al., 2014, p. 138). However, it can be argued that institutional components of a TIS often are national, which makes this a natural delineation especially if the purpose of analysis is to contribute to formation of national innovation policies. Where regional and sectorial approaches have often been used for descriptive purposes, the TIS approach allows us to analyse the interaction between the structural components, enabling a qualitative review of functionality and thus contribute to deciding appropriate measures to strengthen the development of the innovation systems (Bergek et al., 2015; Bergek, Jacobsson, S., Carlsson et al., 2008).

The aim for this thesis is not to study how the Norwegian Triaxial Model was established and developed over time, but to study *how well* it performs in its current version. There is no gold standard for what the correct attributes should be in actors, networks and institutions in order to have a well-functioning innovation system, which means that it is difficult to measure quality only by looking at those three components in themselves. In order to explain causal effects between structural elements and performance, we need to study the variables that connect them. The chosen TIS framework provides an instrument for doing that, through a systematic analysis of seven variables that connect structure and performance, the *functions* of the innovation system, enabling us to separate content from structure and focus on what is achieved in the innovation system (Jacobsson, S., 2011, pp. 50–51). These seven functions will be discussed in detail in chapter 2.7:

- Knowledge development and diffusion
- Influence on the direction of search
- Entrepreneurial experimentation
- Market formation
- Legitimation
- Resource mobilisation
- Development of positive externalities

2.5. Suitability and application of the TIS functions framework

When the functions are discussed in literature, phrasing like "for an emerging TIS", "as a TIS evolves", and "the formation and growth of a TIS" are often used, indicating how this particular systemic approach to innovation studies predominantly has been applied to investigate how a TIS forms and develops in competition with an old regime it seeks to replace (Bergek, Jacobsson, S., Carlsson et al., 2008; Jacobsson, S., 2011).

However, a key takeaway from the TIS functions framework is that the TIS always has actors, networks and institutions, and that the seven functions are always present – albeit the relative importance, and to which degree they are fulfilled, varies. The seven functions are all connected to one or more of the other functions, and some of them more so than others. *Development of positive externalities*, for instance, can be seen as a *dependent variable*, an indicator for how many functions are strengthened through the internal dynamics of the TIS (Jacobsson, S., 2011, p. 53).

This means that this approach is quite flexible and suitable for my project. This aim for this thesis is not the national level as such, even though the Norwegian Triaxial Model is by definition an instrument on a national level. And it is not focussing on a particular technology, but on the dynamic processes that unfold when this policy instrument is operationalised through innovative collaboration that can produce many different types of technology.

By using the theoretical construction of the Norwegian Triaxial Model as the starting point, and integrating it with the TIS functions framework, I will in the following construct a framework that can be used to analyse how the different actors in the Norwegian Triaxial Model play their part and how the seven functions are fulfilled in the two cases studied.

2.6. Structural components

The structural components of a technological innovation system are those actors, networks and institutions that, coupled together in a systemic manner, actively contribute to development, production and diffusion of the technology in focus (Bergek et al., 2015, p. 52; Bergek, Jacobsson, S., Carlsson et al., 2008, p. 408; Carlsson & Stankiewicz, 1991, pp. 111–112; Jacobsson, S., 2011, p. 45). Components of a TIS are not limited to those that are exclusively dedicated to the technology in focus, but include all components influencing the innovation process for that technology, and interaction between components is not necessarily structured and deliberate as they may be pursuing different goals (Bergek, Jacobsson, S., Carlsson et al., 2008, pp. 408–409).

2.6.1. Actors

Actors in the system include firms along the entire value chain, educational organisations, research institutions, public bodies and various interest organisations, investors, organisations deciding on standards, and so on (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 413; Mäkitie et al., 2018, p. 818). All of these can fulfil different roles and influence the innovation process, both directly and indirectly. For example, interest organisations, although not directly involved in the innovative process surrounding a particular technology, can exert influence through building coalitions or informal networks and contribute to building political momentum in favour of a certain legislation or facilitate knowledge transfer between firms and institutions that would otherwise not occur. In addition to the entities listed above, individuals within them can perform the role of an actor through their influence on their parent organisations effort and development, thus embodying Schumpeter's *entrepreneurial* function in innovation; being a driving force for creativity and new ways of doing things (Fagerberg, 2003, pp. 131–133).

According to Jacobsson and Johnson (2000, pp. 629–630), some actors can be particularly powerful in terms of technical competence, financial strength or political influence, empowering them to be *prime movers*, meaning they have the capability to initiate or strongly influence the development and diffusion of a new technology.

Some of the actors might be active in several industrial areas, and as such have operations outside the system in focus. This overlap gives room for a dual role; on the one hand such actors can contribute positively through bringing in resources and knowledge from outside the system, while on the other hand their engagement in other areas might constrain their commitment due to fear of negative effects on those other business areas – effectively resulting in a constraint on the development of the TIS (Mäkitie et al., 2018, pp. 814–815).

2.6.1.1. The roles of the main actors in the Norwegian Triaxial Model

This section describes the roles of the main actors in the Norwegian Triaxial Model the way they are presented in the FFI publication "Videreutvikling av forsvarssektorens innovasjonsmodell" (Bjørk et al., 2018, pp. 17–18).

2.6.1.1.1. The Ministry of Defence

The principal responsibility for providing materiel for the defence sector lies with the Ministry of Defence (MoD). Through establishing good framework conditions, the MoD sets the stage for planning and implementation of procurement processes that allow the Norwegian Armed Forces to acquire equipment that meets the decided planning requirements in a cost-efficient manner.

The MoD also safeguards cooperation with foreign governments on research, development and procurement of defence materiel. Anchored in national security interests, the MoD is further responsible for assessing the need for maintaining or further developing technological competence in the defence industry. On behalf of the Norwegian state, the MoD is the owner of all materiel in the defence sector.

2.6.1.1.2. The Armed Forces

The Armed Forces is the *user* in this model, and as such it owns the *needs* for equipment. This means that the responsibility for defining operational needs and specific requirements for systems that are to be procured lies with the Armed Forces. This includes functional requirements, operative requirements, security related requirements and readiness requirements. The Chief of Defence is the Defence Ministers closest advisor on military matters, and shall support MoD in short-, medium- and long-term planning for material procurement.

2.6.1.1.3. The Norwegian Defence Materiel Agency

The Norwegian Defence Materiel Agency's (NDMA) responsibility is to ensure that the Armed Forces can access cost-efficient and safe materiel in accordance with decided long-term plans. NDMA is responsible for procuring materiel through planning and execution of materiel projects and delivering such materiel to the Armed Forces. NDMA administers materiel ownership on behalf of the MoD, and supports MoD in short-, medium- and long-term planning for material procurement.

2.6.1.1.4. Norwegian Defence Research Establishment

The Norwegian Defence Research Establishment (In Norwegian: Forsvarets Forskningsinstitutt, abbreviated FFI) seeks to understand and assess the impact of technological developments on military activities and give research-based advice to the defence sector on the procurement and use of military materiel.

With its expertise in technology and its interdisciplinarity, FFI can contribute to reducing delays and risk in materiel projects by assisting in the process of defining requirements, evaluation of offers from the industry, testing and evaluation of materiel, as well as helping in concept development and necessary adaptations when implementing new equipment.

In addition to this, FFI is to develop technology and knowledge that supports development of capabilities suited for Norwegian demands, as well as contributing to the competitiveness of the Norwegian defence industry.

2.6.1.1.5. The Norwegian Defence Industry

The role of the defence industry is to develop and deliver technology and solutions that contribute to increase Norwegian defence capabilities through delivering on the needs of the Armed Forces in a cost-efficient manner, and to maximise the benefits of scale through delivering products and solutions to international customers.

The defence industry also uses its competencies to contribute to developing solutions the Armed Forces need, typically through collaboration in early stages or in concrete development projects.

2.6.2. Networks

The diversity in knowledge and capability across different actors can be accessed through forming relationships with others, and the formal and informal interaction between actors in the system constitute networks (Malerba & Montobbio, 2003, p. 418). These networks are conduits for exchanging both explicit and tacit knowledge, as well as technology and money. Some networks help identify new problems and develop new solutions to them, while others offer more of an arena for general diffusion of information, while yet others are focused on promoting particular products or technologies or on influencing policy decisions.

Strong integration into a network can increase the knowledge base for a firm, providing access to knowledge or technology, and broadening its horizon in terms of helping it to identify new possibilities. At the same time, strong integration might also constrain the individual firm and reduce its freedom in technology choice (Jacobsson, S. & Johnson, A., 2000, p. 630).

The effectiveness of networks can be enhanced through the presence of well-functioning bridging institutions acting as nodes in the system, having the capacity to assess new technology and possibilities, providing meeting places and functioning as centres for information exchange (Jacobsson, S. & Johnson, A., 2000, p. 630).

Networks do not automatically form between actors in a system but are the results of active nurturing of relationships towards a systemic form of interaction. Several different types of networks between the actors can play important roles in an innovation system. Links that couple suppliers to users, universities or institutes to industry or firms to collaborators or competitors in order to facilitate the transfer or sharing of knowledge are labelled *learning networks*. As a result of sharing knowledge, these networks can also help individual firms to see new business opportunities by illuminating what is possible and desirable, thus guiding decisions on direction and investment (Bergek, Jacobsson, S. & Sandén, B. A., 2008, p. 577; Jacobsson, S. & Johnson, A., 2000, p. 630). *Advocacy networks*, often labelled lobby networks, are another type, where actors that share a common set of norms or beliefs can come together to form powerful alliances competing with other networks for influence on policy decisions, affecting the institutional set-up of the system (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 413; Sabatier, 1998, p. 103).

2.6.3. Institutions

Sometimes referred to as "the rules of the game" for the innovation system, institutions are the regulators of how actors in the system can behave. Laws, regulations, standards and policies are typically codified and highly visible, and can be labelled formal institutions. Culture, norms, routines and visions, on the other side, are informal institutions, and are usually less tangible. A fundamental characteristic of institutions is that they are relatively stable over time, enabling them to provide needed stability in the environment surrounding innovative efforts. Institutions are the constituting elements of the innovation system, and they can influence the direction of development in a TIS, for instance through how economic support systems are constructed, or how established standards can offer guidance for development of new technology. Similarly, the lack of standardisation can lead to fragmented markets, offering less incentives for innovation. While institutions directly and indirectly guide how actors behave, they can also be influenced by actors, inside or outside the TIS, and can change over time. An implicit effect of the need to adjust institutions is that actors not only compete in the marketplace, but also for influence over the development of the institutions. (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 413; Edquist, 2006, p. 182; Jacobsson, S., 2011, p. 47; Lundvall, 1992, p. 10; Mäkitie et al., 2018, p. 815).

2.7. Processes in the TIS: functions

The way components in a TIS interact forms a complex system, which develops gradually over time through a multitude of different links and feedbacks. In order to achieve an analysis that goes beyond the mere structural dynamics, the concept of *functions* was added to the TIS perspective of innovation studies in 2001.

The functions framework provides a tool for analysts to study the dynamics of the processes within the system and evaluate how each of these processes contribute to development, production and diffusion of technology. This approach helps us separate structure from content, and the resulting assessments of strengths and weaknesses in the system provide detailed information which can then be used by politicians or other stake-holders who wish to make changes in order to improve the overall performance of the innovation system (Jacobsson, T. & Jacobsson, S., 2014, p. 812; Mäkitie et al., 2018, p. 816).

Drawing on scholars from various fields of study, Bergek et al. (2008, pp. 414–419) list the following seven functions: 1) knowledge development and diffusion, 2) influence on the direction of search, 3) entrepreneurial experimentation, 4) market formation, 5) legitimation, 6) resource mobilisation and 7) development of positive externalities. In addition to their direct impact on the overall performance of the innovation system, the functions also have an indirect impact through being interdependent. Activity in one function can influence the development of another. For instance, the processes of legitimation or market formation can both motivate firms outside the system to change their direction of search, which in turn could lead those firms to enter the TIS. In this example, functional dynamics within the system have an effect on the structural set-up of the system through encouraging new actors to participate, demonstrating that there are feedbacks between functions and structure in the TIS. (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 408; Jacobsson, T. & Jacobsson, S., 2014, p. 813)

This interplay between the structure and the activity in the system lies at the core of the analysis of the dynamics of a TIS. While the system concept can seem to suggest coordinated action, an innovation system is primarily an analytical construct, helpful for describing and understanding the dynamics in it. Interaction might be both unplanned and unintentional; actors in the system might strive towards different goals, and even if they share goals, they do not necessarily work together consciously. Assessing the systems overall performance and the various processes within it requires the analyst to take a holistic view and study all activities in context. (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 408; Jacobsson, T. & Jacobsson, S., 2014, p. 813)

Different categories of functions have been developed for different TIS analysis, indicating some flexibility as far as what the functions represent and how they are defined and analysed. Hekkert and Negro (2009, p. 585) point out that this makes it difficult to show empirical evidence for which functions are most relevant for understanding technological development. The TIS framework can therefore be said not to be fully developed yet. However, as Pavitt (2006, pp. 86–109) demonstrates, innovation processes can be so heterogenous across different sectors, areas of knowledge, type of innovation, geographical area and historical period that development of generic concepts and indicators might not be possible.

Nevertheless, the TIS framework offers a point of departure for a systematic understanding of innovation processes. And while it might be difficult to compare across different analyses, the functions approach can be useful for studying one TIS in detail. In this thesis I will build on the framework presented by Bergek et al. (Bergek, Jacobsson, S., Carlsson et al., 2008) to perform a functional analysis of the Norwegian Triaxial Model for innovation in the defence sector.

2.7.1. Knowledge development and diffusion

Bengt-Åke Lundvall (2016, p. 108) has said that the most important outcome of industrialisation was that it made learning "a much more fundamental and strategic process than before".

Jensen et al. (2007, p. 680) distinguish between two ideal forms of knowledge production: codified scientific and technical knowledge, and the more informal process of learning-by-doing. Their study concludes that firms that manage to combine the two seem more likely to succeed in their innovative endeavours than firms relying solely on one or the other.

The *knowledge production and diffusion* function covers all aspects of the available knowledge base in the TIS and how it changes over time, including how knowledge is produced, disseminated and combined in the system, making it a central function for the overall performance of the innovation system (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 414).

Based on the description of actors' roles in the Norwegian Triaxial Model, this function can be expected to primarily fall within the domain of the FFI and the industry actor itself. Secondarily, one might presume that the Armed Forces, in order to best understand what might be possible when articulating their operational needs and the different requirements for desired materiel, should seek to stay well informed and take part in knowledge development and diffusion.

2.7.2. Influence on the direction of search

This function deals with the different incentives or pressures that stimulate firms and other organisations to take part in the development, production and diffusion of technology in a TIS. It covers motivation for entering a TIS, as well as what motivates behaviour within the TIS. Changes in regulations or official policies, articulation of demand, and belief in growth potential can be positive incentives for entering a TIS, while a crisis in current business can force a firm to seek new opportunities and lead it to enter a TIS. Several mechanisms can influence the direction of search within a TIS, such as developments in competing technologies, applications, markets or business models. While the state can influence through regulations, the different influences are not directly controlled by any single actor. It is the combined effect of the different factors that influences a firms decision to enter a TIS or how it behaves within it (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 415).

Being responsible for providing materiel to the Armed Forces, the MoD can be expected to play a part in influencing the direction of development processes, especially through their ability to dictate some of the institutions that regulate innovation and procurement processes. Likewise, the Armed Forces, as the end user owning the need that is to be served by new materiel, can be expected to show an active interest in influencing progress. Also, the role description for FFI suggests that it should have an active role to play here. The industry actor is, of course, likely to have a say in what is possible and what product it wants to develop, but having to adhere to the guidelines drawn up by the customer (the Armed Forces), I will suggest that the industry actor might be expected to be in more of a supporting role to the other three here.

2.7.3. Entrepreneurial experimentation

A TIS typically forms and grows surrounded by considerable uncertainty in terms of both technologies, applications and markets, and the degree of uncertainty correlates with how radically new the technology in question is (Kline & Rosenberg, 1986, p. 294).

For a TIS to grow, or a technology to mature, someone must be willing to take on the risks associated with uncertainty of application or market access for that which is new, to attempt new discoveries, or to create windows of opportunity (Jacobsson, S., 2011, p. 51).

Through entrepreneurial experimentation, new technologies and applications can be tested, and the lessons learned can strengthen the knowledge development in the system, especially for applied knowledge, and contribute to improvements in future versions of the product. Not all new technologies are destined for success, and the more actors that are involved in testing, the more likely it is that experiences will lead to learning and subsequently strengthen the knowledge development in the system (Bergek, Jacobsson, S., Carlsson et al., 2008, pp. 415–416; Jacobsson, S., 2011, p. 51).

In the setting of the Norwegian Triaxial Model and the two cases selected for study, the question is maybe not so much whether the two can compete against other technologies or products and win, but rather a question of whether they can deliver a product or solution that meets the demands and serves the needs of the customer – or customers, if they aim at a broader market than the Norwegian Armed Forces. Likewise, the Armed Forces should have an interest in helping the industry achieve their goal of delivering the best possible product to service the needs of the end user. It is therefore sensible to expect that both the industry actor and the Armed Forces to be very interested in engaging in testing and experimenting that can contribute to product development. The description of FFI's role indicates that they should be expected to take a supporting role in facilitating and otherwise contributing to testing and experimentation.

2.7.4. Market formation

For new technologies, markets might not exist, or they might be severely underdeveloped. The product might have an undesired performance to price ratio, the potential customers might not have articulated their demands, or even be able to, and standards might not be developed. (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 416).

According to Bergek et al. (2008, p. 416) market formation typically passes through three distinct phases. The first phase is one where "nursing markets" provide learning space for a TIS to develop, normally of very limited size. The second one is labelled "bridging market", providing a space for growth in volume and the entrance of new actors, which in turn might transition into the third phase, with the development of "mass markets" (in terms of volume).

Governments have a multitude of ways to influence the development of markets. The behaviour of firms can be dictated, governed or nurtured, for example through the laws they pass, policies they implement, government purchases, tax concessions, or funding through loans or grants (Geels, 2014, p. 26). Charles Lindblom has summed up the vast reach of government behaviour this way: "If the market system is a dance, the state provides the dance floor and the orchestra" (Lindblom, 2001, p. 42).

As mentioned in the introduction, the market for defence materiel is particularly challenging, with strong political control, protectionism and limited access, regulated by a multitude of policies and other mechanisms that influence competitiveness and procurement practices. Having succeeded in getting a Norwegian Triaxial Model collaboration started is a major achievement, but it is only the first step on the way towards developing a successful product. Again, in the cases selected, the challenge might be more one of trying to exceed a defined set of criteria rather than competing with other technologies. Nevertheless, those criteria must be met in order to trigger a procurement process. In the Norwegian Triaxial Model setting, I propose that this function can be distilled to three central issues: the end user must experience a need and articulate demands accordingly, the product must meet or exceed the requirements of the user, and the necessary funding for purchasing must be available. Impact on the performance of this function in the innovation process consequently lies primarily with the MoD, in terms of plans for materiel acquisition and the associated funding, and with the Armed Forces, in terms of defining user needs and product requirements. Secondarily, the industry actor is responsible for delivering a product that serve the needs of the Armed Forces, placing it in a supporting role here.

2.7.5. Legitimation

Legitimacy can be explained as the social judgement of acceptance, appropriateness and desirability. Increased legitimacy can be an important means for gaining access to other resources, such as funding, competent personnel, the trust of customers, and knowledge networks, and it can contribute to amassing the political strength required for inducing change in the institutional framework, should that be necessary. All of these effects can help newcomers overcome the *liability of newness* that scholars find is an important factor in explaining why many new ventures fail (Bergek, Jacobsson, S., Carlsson et al., 2008, pp. 416–417; Zimmerman & Zeitz, 2002, p. 414).

Established firms can gain legitimacy through a proven track record of sustained commercial success, which in turn can provide them with an advantage when introducing new products. For new firms, or when established firms introduce entirely new types of technology, legitimacy must be built. A variety of strategies can be pursued in order to achieve this, such as selecting a favourable geographic location or a domain where norms and values are sympathetic to the vision or product, conformance to regulations or norms, or the more challenging task of changing regulations or relevant norms and values through advertising campaigns or lobbying.

The firm can also try to shape expectations or define what is desirable, which can be done by having subject matter experts provide assessments and rational arguments in favour of the technology, or it can try to increase the number of stakeholders through getting new actors to engage in networks to share ideas and knowledge. (Agterbosch & Breukers, 2008; Bergek, Jacobsson, S. & Sandén, B. A., 2008, pp. 581–582; Zimmerman & Zeitz, 2002, pp. 414–428).

Noteworthy here is the interplay between the different functions; the development in one has an effect on one or more of the others. Institutions and legitimacy is one, and another is that legitimacy can have an impact on the function *influence on the direction of search*, by giving decision makers in firms expectations that cause them to adjust their strategies (Bergek, Jacobsson, S., Carlsson et al., 2008, pp. 416–417).

The “fast-track” version of the Norwegian Triaxial Model is about building something new based on existing technology. That means that some of the basic technology exists but must be further developed or adapted in order to become suitable for military purposes. The products legitimacy must therefore probably be built, as it is unlikely that it can be inherited from previous merits. Likewise, new companies cannot draw on an established reputation but must prove themselves capable and increase their legitimacy.

In the context of the Norwegian Triaxial Model, a combination of adherence to regulations and norms, the managing of expectations, and positive assessments from subject matter experts seems likely to be a rational strategy for increasing legitimacy for both product and producer. For this function, the leading role consequently should belong to the industry actor, trying to affect all three factors listed. A supporting actor should be the Armed Forces, aiming at getting their desired solution approved for procurement. The FFI, with its subject matter experts, could help in legitimacy building, but probably indirectly through helping the industry actor, more than having an independent desire to increase legitimacy for the technology, making it a partially involved actor.

2.7.6. Resource mobilisation

The development of a TIS depends on its ability to access a wide range of resources. *Financial resources* are both seed and venture capital and can be sought from public or private actors. *Human capital* in the form of technology-specific knowledge must be accompanied by competence in management, finance, logistics and so on. *Complementary resources* are all the other things that help support the development in the TIS, like infrastructure, networks, and complementary products (Bergek, Jacobsson, S., Carlsson et al., 2008, pp. 417–418).

This factor can be assessed as primarily important for the industry actor, needing to mobilize resources in order to achieve the goal of getting a viable product to market. Secondarily, it could be deemed important for the Armed Forces, having an interest in seeing their requirements met and a product becoming available for them, making them a supporting actor. Depending on the level of commitment or involvement in each case, the MoD and FFI could also take an active interest in making this function perform at its best, which places them in the category partially involved actor.

2.7.7. Development of positive externalities

Innovation processes are highly dynamic and inherently complex, with a multitude of uncertainties and possibilities, in all stages of the process ((Kline & Rosenberg, 1986). Development of positive externalities can help expand the knowledge base, talent pool, number of firms or collective ability to influence the institutional framework, all of which might help firms to reduce uncertainties or better exploit possibilities.

Some policy and management literature emphasise that the formative phase for a TIS predominantly consists of a contest between actors promoting different designs until one of them prevail and a dominant design gains an upper hand and to a large extent dictates the direction of development from then on, meaning that firms are in a competition for limited resources and market access (Utterback, 1994).

However, given the unpredictability of innovation processes, another perspective on the interplay between firms is that it can have positive reinforcing effects on several of the other functions. Entry of new firms into a TIS can help strengthen both *market formation* and *influence on the direction of search*. Furthermore, more firms can directly and indirectly contribute to *legitimacy*, increase the success rate for *resource mobilisation,* strengthen *entrepreneurial experimentation*, and improve *knowledge development and diffusion*. In sum, the greater the number and variety of actors stimulating each other in the system, the better the chances are for genuinely new solutions to be found. *Developing positive externalities* primarily works through strengthening the other six functions, which in turn strengthens the functional dynamics of the system, and can therefore be seen as an indicator for the overall functioning of the TIS (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 418; Bergek, Jacobsson, S. & Sandén, B. A., 2008, pp. 585–587).

In the context of the Norwegian Triaxial Model being activated in a targeted effort to develop an existing technology into a single product or system, it can be inferred that no existing product or system (fully) satisfy the requirements of the Armed Forces, or even that no other industry actor is working on a similar technology development. This means that in this context, many of the factors in this function will be more or less unavailable or even non-existent. Nevertheless, it is possible that the innovation process can benefit from closely related activities in other firms or domains. The industry actor is likely the primary in this case, while the role description for the FFI, both with regards to competence building and its task of contributing to the development of the Norwegian defence industry, suggests that it should be considered a close supporting actor in developing externalities.

2.8. The Norwegian Triaxial Model actors and functions matrix – in theory

Through the integration of the role descriptions for the main actors in the Norwegian Triaxial Model and the theory on TIS functions I have established a theoretical framework indicating which roles the different actors could be expected to play in the process of making each function contribute to the innovation process. The following table provides an easily accessible overview of which actor(s) the theoretical framework indicates should be expected to play a leading role, a supporting role, and which actor(s) are only partially involved in fulfilling a given function.

Function	Leading actor	Supporting actor	Partially involved actor
Knowledge development and diffusion	FFI Industry Actor	Armed Forces	
Influence on the direction of search	MoD FFI Armed Forces	Industry Actor	
Entrepreneurial experimentation	Industry Actor Armed Forces	FFI	
Market formation	MoD Armed Forces	Industry Actor	
Legitimation	Industry Actor	Armed Forces	FFI
Resource mobilisation	Industry Actor	Armed Forces	MoD FFI
Development of positive externalities	Industry Actor	FFI	

Figure 1: Table showing which actor(s) should be expected to play a leading role, a supporting role, and which actor(s) are only partially involved in fulfilling a given function.

3. Methodology

It all begins with the phenomenon I wanted to study; *innovation in the Norwegian defence sector, how it works in practice and how the actors involved behave in the process.* In order to illuminate this and answer the research questions, I had to figure out which methodology was best suited. In doing so, I dealt with questions of quantitative vs. qualitative approach, theory vs. empirical data, method for collecting data and how to analyse and assess what I found.

This chapter will describe and discuss why a qualitative approach using case studies was chosen, why interviews are the primary method for collecting empirical data and how those data were organised and analysed. Strengths and weaknesses with the chosen approach will be part of the discussion, and the chapter will be concluded with a discussion on legitimacy and credibility.

3.1. Qualitative research

A quantitative approach to study a phenomenon typically demands access to comparable data from a large number of units, which are then expressed in the form of numbers, to be subjected to a statistical analysis (Hellevik, 2016, p. 110). This would be the preferred approach if I was looking for answers to questions of what or how many.

Qualitative research, on the other side, is typically capable of providing insights into the experiences of the people involved in different activities, through focusing on how social interactions shape reality and produce meaning, and is suited when trying to understand complexity, detail and context in dynamic social processes (Pawson & DeLyser, 2016, p. 431). This makes a qualitative approach the most suitable for my research questions, as they deal with *how* the innovation model functions in practice and *how* the actors involved perform their part; processes expressed as functions in the TIS in question.

3.2. Case studies

Case studies are intensive studies of one, or a few, defined units, in order to explore nuances and contextual influences, for the purpose of understanding a larger class of similar units (Baxter, 2016, p. 130). A unit can be an organization, a decision, a process, a discourse and so on. In case studies it is important to differentiate between what is being studied and what constitutes the context for it (Andersen, S. S., 2013, p. 14).

For this thesis, researching the innovation processes and how the actors played their part in developing a nano-drone, the Black Hornet case, and in developing a container-based solution for field production of spare parts, the FieldMade case, framed within in the seven *functions,* comprise the two cases, while the *structural components* comprise the context of the study.

Case studies can provide rich detail and can contribute to a depth of understanding that helps broadening academic understanding of a phenomenon; it can help to generate or expand theory. Rather than a *method* (a mechanism to collect data), a case study is better categorised as a methodology, an approach to research design. An important underlying assumption is that thorough examination of one manifestation of a phenomenon can yield valuable insights even though it does not account for some, or all, other manifestations of that phenomenon. In other words: while one case is unlikely to be entirely representative of a phenomenon, it is at the same time unlikely to be entirely unique. A good case study must be so richly described (theorised) that it is possible to see the parallel to contexts outside the case(s) studied (Baxter, 2016, pp. 131–135).

Consequently, ensuring a detailed and comprehensive description is a good strategy for creating credible and trustworthy qualitative case study work. In order to achieve this, a qualitative researcher typically chooses to study many "sub-units" in one specific case intensively and holistically, in order to understand both how subjects interact and the context in which they interact, rather than taking the extensive approach where a few units from each of a wide array of settings are dealt with more superficially (Baxter, 2016, pp. 133–134).

I have chosen to study two cases, two separate innovation processes conducted in the framework of the Norwegian Triaxial Model. They are cross-sectional, in that the collection and analyses of data was carried out during one period of time and focused on each innovation process as a whole, as opposed to a longitudinal study – where the same phenomenon is first studied and then revisited after a period where no research was done on the topic.

Using multiple cases is often called comparative case study or parallel case study. The reason why I decided to examine two cases is two-fold. Firstly, having more than one case provides a broader basis for exploring the theoretical concepts and explanations for what goes on in the Norwegian Triaxial Model, as it yields more data, and different perspectives – it is part of a strategy to increase legitimacy and credibility. Secondly, collecting data on events that span years back in time through interviews require informants to think back and remember how things were, which makes recall bias a potential problem. Having many informants, with varied vantage points can help mitigate this.

3.3. Access to cases

Very early in my project, I was introduced to the head of the "Innovation and Industrial Development" division at FFI, Hanne Bjørk, by a friend of mine who had a professional relationship with her and the division she leads. This turned out to be a very fruitful meeting for my project. Bjørk was very positive to my project and welcomed research into the Norwegian Triaxial Model. She helped with suggestions for cases to study, and, more importantly, the meeting led to the Innovation and Industrial Development division helping my work through providing me with an office space at FFI.

Being situated on the inside of this institution provided me with access to research reports that would otherwise not be available to me, as well as direct access to researchers at FFI. It is also quite possible my relationship with FFI contributed to make access to other informants easier.

It is important to stress here that FFI has in no way sought to influence my research. I do not report to the FFI, and my work has not been subject to approval from any research director at FFI. I am, however, aware that a somewhat close relationship with one of the central actors in my research topic could influence my view of their contributions and have made an effort to remain critically reflexive.

3.4. Data collection

Studying the behaviour of different actors in an innovation system is empirical in nature. It is impossible to answer the research questions without gathering data in the field.

A method is the approach used by a researcher to gather empirical data, organise them, and analyse them, in order to arrive at new knowledge (Hellevik, 2016, p. 12). For this thesis, data was first collected through studying documents pertaining to the Norwegian Triaxial Model and its actors, followed by some examination of written documentation of the cases I have chosen. This was a necessary phase, as though I had some prior knowledge, it was far from sufficient as a platform for academic research into the matter.

In order to investigate how roles and processes actually played out in real life, I had to add to the document studies, and to do that I carried out a series of interviews with a diverse set of informants. A total of 14 interviews were conducted, all of a semi-structured nature, and on average a little over one hour long. The following sections will explain the rationale for my choice of methods.

3.4.1. Document studies

In order to strengthen my understanding of what the Norwegian Triaxial Model is, and which actors are involved, I started my research process by reading white papers, project reports, and how the different actors presented their activities on their respective websites. The aim for this phase was to build my knowledge to the point where I could establish a theoretical framework for my research and start collecting empirical data.

Two key factors when using documentary sources is whether it is possible to establish the authenticity of the source and the accuracy of the information recorded (Roche, 2016, p. 233). Using official documents as a source makes it easy to establish the authenticity of the source and know that it is genuine and the information in it is precise. And, since the Norwegian Triaxial Model is an arrangement set up by the Norwegian Ministry of Defence and described in a government white paper, that white paper is a primary source of information about it.

To find relevant cases to explore, I also studied FFI reports from collaboration projects that falls within the specific variant of the Norwegian Triaxial Model I wanted to research. These reports typically describe what the purpose of a project is and activities that have been carried out, as well as evaluating results of those activities. The reports also helped identify potential candidates for interviewing.

These document studies helped me gain sufficient knowledge about the Norwegian Triaxial Model and how it was meant to function, and the actors, networks and institutions involved, to build a theoretical framework and start collecting empirical data through interviews.

3.4.2. Interviews

Interviews are especially suited as a research method when investigating complex behaviours and motivations, and to collect a diversity of meaning, opinion and experiences (Dunn, 2016, p. 150). The Norwegian Triaxial Model, with its rather intricate institutional framework and with dynamic processes involving many actors, constitutes an arena with a complex set of behaviours and the people involved are likely to have a diverse set of experiences and opinions. I therefore chose to use interviews to gather empirical data.

Maccoby and Maccoby (1954) defined an interview as “a face-to-face verbal interchange in which one person, the interviewer, attempts to elicit information or expressions of opinion or belief from another person or persons” (quoted in (Dunn, 2016, p. 149). There are three major forms of interviewing: structured, semi-structured and unstructured. The *structured interview* has a predetermined standardised list of questions that ensure that each interview is carried out as equally as possible. The *unstructured interview* is quite different, with fewer guidelines from the interviewer, and the progress of the conversation is directed more by the informant than the interviewer. Somewhere between these two on the spectrum lies the *semi-structured interview*, in which the researcher has broad questions or topics that he seeks to cover during the interview, while there is also room for delving into topics that come up during the interview or expanding the scope as the interview progresses. For my research, I chose the semi-structured variant, because of this combination of ensuring that important topics are covered, while still leaving room to explore aspects that the interviewee finds important in more detail than a strictly structured interview does. This approach also leaves room for including topics that I had not beforehand determined or realised were important, and thus possibly allows for gathering even more relevant empirical data than expected.

3.5. Analysing data

Objectivity is desirable in two forms, both in terms of personal involvement between the informants and the researcher, and in terms of the researchers independence from what is being studied. Entirely dispassionate interpretation, however, is very difficult, since researchers always bring personal histories and perspectives to their research (Dowling, 2016, p. 39). Having met two of the informants earlier, through my career in the Norwegian Armed Forces, this was something I paid extra attention to. While I did my best to create interview settings that made the informants comfortable enough to share their thoughts, I simultaneously did my best to maintain a professional setting throughout the interviews.

The same desire for objectivity applies to the stages of analysing the data, with the same challenges. Avoiding subjectivity, the insertion of personal opinions and characteristics, in the interpretation of the data material gathered is undesirable, and to reduce the risk of doing so as much as I could, I applied critical reflexivity to remain conscious that my role in this project as a researcher, not a career military officer.

I transcribed all interviews myself, which took a lot of time given the number of interviews and the length of each interview, but at the same time a process that made me very familiar with the materiel and likely saved me time later on. The transcribed interviews were then coded using

Nvivo[2], another time-consuming process, but, again, one that severely cut time in the final stages of analysing.

Through coding, data is reduced in volume through sorting out key themes and pieces of information, as well as organised in a way that make it easier to sort through it, and process is another iteration of combing through and becoming better acquainted with the empirical data (Cope, 2016, p. 377).

3.6. Methodological considerations: legitimacy and credibility

3.6.1. Validity and reliability

Validity and reliability are terms used to evaluate whether the results of a study can be trusted; the credibility of it (Grenness, 2013, p. 119). Validity is used as an expression of how relevant the data gathered and analysed are for the research questions, while reliability is used as an expression of whether the data can be trusted to be true (Hellevik, 2016, p. 102).

As part of the effort to ensure reliability of the data gathered through interviewing, I made an effort to stay as neutral and objective as possible when meeting my informants. Results from interviews are dependent on the rapport between interviewer and interviewee and the more comfortable the informant feels in the setting, the more likely he is to divulge insights and opinions (Dunn, 2016, p. 160). To make sure the interviewees felt comfortable in the situation, all interviews were conducted in locations chosen by the informants, most often in their own office. For every interview only the informant and myself were present, avoiding the potential for them feeling constrained by the presence of others.

Dealing with a subject matter that involves both possible industrial secrets and personnel from different units in the Norwegian Armed Forces, all informants were promised confidentiality, in that their names would not be mentioned in the master thesis. While this is not optimal in terms of replicability, it was an absolutely necessary precaution, especially as parts of the Armed Forces are not allowed to be identified by name. Facing this dilemma, I chose access to information over traceability, as the study would have been much poorer without that empirical data.

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[2] "NVivo" is software that is used for coding and analysing text, video, sound and more.

Another way to increase reliability is to triangulate sources. I recruited informants from all three main actors in each of the two cases studied, as well as several sources from relevant institutions closely connected either with a case or with the formal set-up of the Norwegian Triaxial Model. This way I increased the likelihood that the topics covered would in sum be correctly represented, while at the same time making sure they were illuminated from various perspectives (Stratford & Bradshaw, 2016, p. 127).

Triangulating interviews can also contribute to the validity of the findings, by letting the researcher elicit opinions on the relevance of the questions from sources with different perspectives on the subject matter, thus in effect cross-checking the relevance and significance of the issues that are addressed during the interviews. Doing this gave me an indication that I was actually researching what I set out to, which speaks to validity (Grenness, 2013, p. 112).

In conducting semi-structured interviews, the interview guide is an important tool to ensure validity in the sense that data collected is relevant for the research questions. I therefore spent some time on developing my interview guide so that it would help steer the interviewees towards talking about the important issues, and I consulted my master thesis supervisor before using it in interviews. While I varied my questioning a little bit from interview to interview, adapting them to the position of the informant, all main topics were consistently included in all interviews.

According to Andersen (2013, pp. 30–32), case studies are often described as the antithesis to generalisability, because of a lack of statistical representativity. This falls within a tradition of thinking where the ideal was to achieve something more than generalisability, it was to find universal laws, and predominant thinking held that "proper" science dealt with quantitative data and statistical representativity. An alternative view maintains that case studies are powerful precisely because they reject ambitions of generalising and testing hypothesis, and instead focus on how case studies are much better suited for capturing the importance of complex and dynamic social contexts than classical quantitative studies and experiments (Andersen, S. S., 2013, pp. 30–32).

In his discussion on whether case studies can be generalisable, Baxter states that the short answer is "yes". He goes on to explain that the term generalisability (or external validity) is primarily a term used by quantitative social scientists, while many qualitative researchers prefer to use the term *transferability* instead. Both terms are used to describe whether findings in a case study can also apply to other cases of the phenomenon in question (Baxter, 2016, p. 142).

In order to achieve transferability, it is important that the explanations arrived at through case study are *credible*. While statistical generalisation can be achieved through large probability samples, transferability – and thus credibility – can be accomplished through carefully selecting cases and creating theory that is neither too abstract nor too case specific. Even though a case study might rely on a low number of samples, it can produce robust, credible and trustworthy theoretical explanations. These explanations are generalisable, or transferable, in an analytical sense rather than a statistical sense, if they are well rooted in the concrete aspects of the cases studied and at the same time sufficiently abstractly described that they might apply to other cases that take place in a similar context (Baxter, 2016, pp. 142–144).

It is my aim for this thesis that through researching two cases intensively I can achieve just that, by applying a relevant theoretical framework on comprehensive empirical data and contribute to an expanded theoretical understanding of how the Norwegian Triaxial Model for innovation in the defence sector actually works.

3.6.2. Selection of informants

FFI aided my work by affording me an office space and providing me with access to their data systems, including getting an FFI e-mail address, and direct access to researchers involved in the cases I wanted to study clearly helped my efforts to find informants. I could seek out relevant researchers directly and approach them for an interview, and through them get help identifying possible informants in the two industry actors.

Snowballing was thus part of my strategy for recruiting from the start, and I kept this up through the process by asking my informants whether they knew anyone else, inside or outside their organisation I should talk to. When time came to make contact with informants outside FFI, I assume the fact that my inquiry came from an FFI e-mail address likely lowered the threshold for getting a positive response. There is no way to know whether this was the case or not, but all my attempts at establishing contact and get an interview panned out.

In order to paint as complete a picture as possible, I wanted to find informants that represented different perspectives on the Norwegian Triaxial Model and the two cases. As there are three main actors involved in every Norwegian Triaxial Model innovation process, it was important for me to make sure all three were represented, for both cases. This was accomplished, and accounts for 9 of my 14 informants.

In addition to the main actors directly involved, I also wanted informants from other relevant institutions, to collect data that could help complement the picture, especially with regards to framework factors. The remaining 5 informants were representatives for: *the Ministry of Defence*, which is the governmental organisation that formally "owns" the Norwegian Triaxial Model and is responsible for much of the regulatory framework, *the Norwegian Defence Materiel Agency*, which is responsible for equipping the Armed Forces with materiel, *Innovation Norway*, which is an organization funded by the Norwegian government to support innovation and development of Norwegian enterprises and industry, *the Norwegian Army Staff*, responsible for the army's project management in procurement processes at the time of the Black Hornet procurement, and *Forsvars- og Sikkerhetsindustriens Forening*[3], an interest group for defence industry actors.

I only interviewed one person from each of the two industry actors, and also only one person representing FFI in one of the cases. This is clearly less than ideal, but as far as the FieldMade case goes, this is a case that has not yet run its full course and the industry actor is very small, so more informants were not really an option for that case. In sum, I believe that 14 long interviews, with representatives from a wide variety of institutions, and ranging from the soldier level to the Ministry of Defence, has provided me with a sufficient amount of data to conduct my research into the research questions.

3.6.3. Ethical considerations

Some ethical considerations are integrated in the methodological considerations, such as trying to find empirical data that truthfully represents reality, and to then use them in a manner that do not distort their meaning. But there are a few aspects of research ethics that I want to briefly discuss explicitly here.

When I approached my informants and asked for an interview, I presented them with written information about my research project and made it clear that they had the right to withdraw from the study at any point. I then gave them time to consider the project before giving me a written consent to participate, in order to adhere to the principle of informed consent (Dowling, 2016, p. 32; Dunn, 2016, p. 163).

[3] Forsvars- og Sikkerhetsindustriens forening (FSi) is an independent Norwegian interest group comprising about 130 member companies that have business interests related to delivering products, goods and services to defence and security markets both nationally and internationally (Om FSi, 2019).

To empower my informants to speak freely about issues that are potentially controversial or share information that they would prefer not to be traced back to them, I gave a promise of confidentiality. To maintain their confidentiality all informants are represented only by numbers and an indication of which actor they represent so that they cannot be easily identified. I have also made sure to store recordings and transcripts of the interviews in a safe manner, so that they can only be accessed by me (Dowling, 2016, p. 31; Dunn, 2016, p. 163).

4. The Norwegian Triaxial Model for military high-tech innovation

This chapter will delineate the “fast-track” version of the Norwegian Triaxial Model that is under scrutiny in this study. It will present an overview of the structural components in the system, by describing the most central actors, networks and institutions involved. But first I will give a very brief introduction to the two technologies and the companies behind them.

4.1. FieldMade

Figure 2: The NOMAD container-based microfactory, picture courtesy of FieldMade AS

FieldMade AS is a small company, headquartered in Lillestrøm, a small city just outside Oslo, Norway. Their mission is to deliver container-based solutions for field production of spare parts, using additive manufacturing (AM) methods. They are primarily focussing on military application, but their solutions can also be suitable in other areas, such as the energy sector.

The product they are bringing to market is called NOMAD and is a series of “micro-factories” with various technologies for additive manufacturing using different materials. In addition to the container-based production facilities, FieldMade also develops software solutions to support the integration of additive manufacturing into the supply-chain, and provide assistance to customers in developing strategies for transition from traditional spare parts logistics to digitalised, on-demand production with AM.

The idea originated with a few enthusiasts at FFI, a feasibility study in 2015, and building a demonstrator primo 2016 that was deployed to military exercises for testing and demonstration. FFI joined forces with Kjeller Innovasjon, and in 2016 FieldMade AS was founded. Since then, with additional funding from the Research Council of Norway and Innovation Norway, FieldMade AS has continued to develop their solutions, and aim towards being ready to deliver their first product to a customer ultimo 2019.

4.2. Black Hornet

Figure 3: Black Hornet 3, picture courtesy of FLIR Systems Inc

The Black Hornet is a nano-drone in the shape of a helicopter. It can be configured with both optical and infrared cameras, making it capable of night-time as well as daytime streaming of live images to its operator, with a flight-time of up to 25 minutes. Extremely small and lightweight it has a very low signature, helping it avoid detection, and a kit consisting of two helicopters, display and remote control, is easily carried as part of a soldier's gear in the field.

The Black Hornet was developed by Prox Dynamics AS, a company launched to the public in the spring of 2008 by a handful of highly competent people with complementary expertise within miniature helicopters, electronics and signal processing. The pre-launch history is an interesting case in itself, as the founder already had decades worth of experience with small helicopters, including having patented an advanced rotor system that yielded millions in income from toy helicopter producers, and having been a consultant for a DARPA[4] project that gave him invaluable insight into what kind of product the US Armed Forces wanted – and that other military organisations might utilise as well.

Prox Dynamics AS established contact with FFI, and several projects were collaborated on the following years, combining in-house development resources and FFI researchers' competencies as well as involving the Norwegian Armed Forces in testing and user feedback. By 2011, the product was mature enough for the first sale, contracted by the British Armed Forces. The following years several other countries, including Norway, procured the Black Hornet.

In 2016, FLIR, a US company that provided the camera technology for the Black Hornet, bought Prox Dynamics AS for USD 134 million and renamed it FLIR Unmanned Aerial Systems. With development and production still predominantly done in Norway, FLIR UAS now employ more than 100 people.

4.3. Defining the TIS in focus

Having chosen to apply a technological innovation systems approach to study the Norwegian Triaxial Model, the TIS in question is to some extent defined through government white papers and FFI reports on the subject. The central triangle of the Norwegian Triaxial Model is constituted by two actors that are always represented. One is the FFI, which is the Norwegian Defence Research Establishment, responsible for both long term basic research, applied research and heavily involved in concept development for defence materiel and technology.

The other is the Armed Forces themselves, which both represents a market for products being developed (not the only market, as Norwegian defence industry also produces for international sales) and contributes with inputs on functionality and applicability. The Armed Forces is a large organisation, comprised of several branches and numerous units, and which part of the Armed Forces that take part in innovation processes vary, normally closely connected with

[4] The Defense Advanced Research Project Agency (DARPA) is an agency of the United States Department of Defense, with responsibilities similar to what FFI has in Norway. On their website they display some of their major achievements on a timeline, and among them are the first computer mouse, ARPANET (the precursor to Internet), and Unmanned Airborne Systems.

where in the organisation a demand either exists or is deemed likely to emerge, which is also where relevant expertise is most likely to be found.

The third corner of the triangle is the industry actor seeking to develop and introduce a new product to market. For each different project, a different industry actor can constitute this corner of the triangle.

In addition to the three core actors, a number of other entities can play a role in the endeavour to bring an innovation to commercialisation. These can provide financing, knowledge, components and so on, and the number and make-up of these will vary from case to case.

In sum, a short description of the TIS might be "all those who contribute to an innovation process resulting in a new product or technology being made available either to the Norwegian Armed Forces or to the international defence industry market".

4.4. Structural components of the Norwegian Triaxial Model

4.4.1. Actors

The actors in the Norwegian Triaxial Model are those that are directly involved in development, production or use of products within the framework of the Norwegian innovation model for the Armed Forces. For the two cases I have studied, the main actors are as presented in this chapter.

FFI, the Norwegian Defence Research Establishment, is the prime institution responsible for defence related research in Norway and provides advice to the Ministry of Defence and the Norwegian Armed Forces' military organisation. FFI covers a broad spectrum of research topics, ranging from the assistance of operational units to the support of national security policy via defence planning and technology studies. FFI collaborates with both national and international scientific institutions and industry. (Norwegian Defence Research Establishment, 2019)

Prox Dynamics AS was founded late 2007 and publicly launched in the spring of 2008, as a technology company with a clear ambition of developing a personal reconnaissance system for soldiers, in the form of a small, light-weight helicopter UAS (Unmanned Aerial System): a nano drone for the military market. The company was later, in 2016, bought by the American company FLIR Systems AS, and was renamed FLIR Unmanned Aerial Systems AS. Data gathered for this thesis pertains to the development of their first product, the PD-100 PRS, or the "Black Hornet", which took place before the sale to FLIR, and this industry actor will be referred to as Prox Dynamics throughout the thesis. The first sales contract was entered into in 2011, with the British Armed Forces, and the Black Hornet has since then been sold to a large number of countries.

FieldMade AS seeks to develop and produce container-based solutions for 3D printing (additive manufacturing) of spare parts in military operations in the field. Research and development activities started in 2015, when a few enthusiasts working at FFI began working towards establishing a project to explore possibilities in this area. After building a demonstrator version of the concept in a shipping container, and displaying it on several military field exercises, FFI entered into a contract with Kjeller Innovasjon AS in the summer of 2016. The contract regulated how the two should cooperate in an endeavour to commersialise the product, and stipulated that if certain criteria were met, a Kjeller Innovasjon AS-owned company should be established in the fall of 2016. FieldMade AS was established in September 2016.

Several different units in The Norwegian Armed Forces contributed in the two cases, ranging from logistic support units to combat units, from all three branches of the armed forces (Army, Navy, and Air Force) contributed with personnel, competence and facilitated testing in the two cases studied. In addition to this, Norwegian Battle Lab & Experimentation (NOBLE), has contributed. NOBLE is a joint battle lab and part of the Norwegian Concept Development and Experimentation programme, set up as part of the National Joint Headquarters to conduct both operational and tactical level concept development and exploration (CD&E) tasks.

Kjeller Innovasjon AS is a business incubator situated in Lillestrøm, right next door to FFI, and has close ties to both FFI and several other research centres in Norway. Kjeller Innovasjon AS seeks to help initial ideas become growing companies, through providing expertise in obtaining capital, heading business development and preparing Intellectual Property Rights (IPR) strategies. (2019)

Forsvarsmateriell, The Norwegian Defence Materiel Agency (NDMA), is responsible for equipping the Armed Forces with materiel – ranging from personal clothing and equipment to submarines, aircraft and technological solutions. NDMA provides advice, make investments, and manage materiel throughout its lifespan. (Forsvaret, 2019) NDMA was established primo 2016, by transferring parts of the Norwegian Defence Logistics Organisation and accompanying responsibilities to the new organization. For the sake of simplicity, I will use the name NDMA when discussing relevant activities both before and after the formal establishment of NDMA.

The Ministry of Defence (MoD) is the Government Office with responsibility for the formation and implementation of Norwegian security and defence policy. As such, it is the "owner" of all activities in subordinate agencies and has the role of process owner in procurement processes. Coordinating authority and most of the practical work in procurement is delegated to subordinate agencies, such as NDMA and the Armed Forces.

Innovation Norway (IN) is an organization funded by the Norwegian government to support innovation and development of Norwegian enterprises and industry. IN has offices spread around Norway, as well as in about 30 countries abroad, and can help with financing, counselling, and networking.

The Research Council of Norway (RCN) works to promote research and innovation of high quality and relevance on behalf of the Norwegian Government. It invests approximately 10 billion NOK[5] each year in research and innovation projects through grants given to the university and university college sector, research institutes, the public sector and the business sector. One of the programs is called FORNY2020 and is a Research Council of Norway program for increased commercial application of publicly funded research in Norway. FORNY2020 invests in the most commercially promising projects across all industries, bringing promising research results closer to, or all the way to, the market place (FORNY2020 - Forskningsbasert nyskaping, 2019). The Research Council of Norway also administers "SkatteFUNN", a government R&D tax incentive scheme designed to stimulate research and development in Norwegian trade and industry. The incentive is a tax credit and comes in the form of a possible deduction from a company's payable corporate tax (About SkatteFUNN, 2019).

4.4.2. Networks

Networks are constituted through interactions between the structural components. Some networks are formally established and organised, while others are informal and can be difficult to categorise.

FFI has conducted out numerous different tests and experiments together with personnel from the Special Operations Forces (SOF) branch of the Armed Forces, over a long period of time. Through this, personnel from FFI and SOF have come to know each other well, a level of trust

[5] https://www.forskningsradet.no/sok-om-finansiering/midler-fra-forskningsradet/ accessed 2019-10-24

is established, they have knowledge of each other's interests and abilities, and communication flows more easily. This is typical for an informal network, where both parties know who would be interested in which types of materiel and technologies. Researchers at FFI knows of Armed Forces personnel that might be interested in and suitable for involvement in tests and experiments. Likewise, personnel from those units in the Armed Forces know the areas of expertise for researchers at FFI, and who to approach when they have ideas or questions. This makes it possible to establish informal contact on an early stage of a project and can reduce time when initiating new projects (Informant 1 (FFI), 2018).

As mentioned in the introduction, the international market for defence materiel is a particularly challenging one, characterised by strong political control, protectionism and limited access for foreign competitors (Ministry of Defence, 2015, p. 5). In order to gain market access in such a challenging domain, extensive networking and lobbying is necessary. As soon as Prox Dynamics established contact with actors within the US military establishment, they started building networks in the USA to support their efforts. For instance, they contacted the Norwegian Embassy in Washington D.C., where a dedicated staff member serves as a point of contact between Norwegian defence industry and the Pentagon[6], to inform that person about what they were doing, and make use of his contacts with the Pentagon and lobbyists. Soon, Prox Dynamics employed a dedicated person to handle the US market and invested a lot of resources to gain access to new contacts and expand networks. Typical for USA is that one has to work all levels of the system; you need to reach the user, you need to reach project managers, you need to reach the generals making decisions, and you need to reach the politicians who secure funding through budget processes. Much of the same applies for Norway, albeit on a smaller scale. The early success with selling to the British made the Black Hornet a showcase for successful collaboration in the Norwegian Triaxial Model, and as a consequence it became sort of a pet project for many of the actors invested in the Norwegian Triaxial Model. While this helps Prox Dynamics' access to Norwegian decision makers, the footwork still has to be done, and considerable efforts must be put into networking to succeed (Informant 4 (Industry), 2019).

[6] The Pentagon is the headquarters building of the United States Department of Defense.

4.4.3. Institutions

The procurement process is the sum total of the written rules and the bureaucratic practices regulated by those written rules, and this whole can be viewed as an institution affecting how an idea moves through the Norwegian Triaxial Model and becomes a product that is acquired for use in the Armed Forces. When new technologies arise, they can prove especially challenging for military procurement processes, by introducing challenges that are new to the system. The Black Hornet can serve as an example of this, in the way that it highlighted the maturity, or lack thereof, in the military organisation when it comes to thinking about how small drones challenge traditional military aviation and procurement processes. Gradually, the system matures and adapts, but the transactional costs can be enormous, as they were in this case, because of discussions that didn't really have anything to do with "what is this thing, what are the risks associated with a rapid procurement and distribution to military units?". (Informant 13 (Armed Forces), 2019). For the Black Hornet, certain aspects of the procurement process were especially challenging, such as the process for technical approval of new aerial systems (see chapter 5.7.1 for a brief discussion).

5. Functional analysis of the empirical data

This chapter will describe the "functional pattern" of the innovation system, through analysing the 7 functions explained in chapter 2.7. The main aim here is to discover to which degree the different functions are fulfilled, without passing judgement on the systems overall performance; it is not a normative chapter.

5.1. Knowledge development and diffusion

Knowledge development and diffusion deals with the breadth and depth of the available knowledge base in the innovation system, and how this knowledge is diffused and combined and how it develops over time (Bergek, Jacobsson, S., Carlsson et al., 2008, p. 414).

In general, it is to be expected that the industry actors produce significantly much more knowledge on a specific technology when you look at the entire development process – they typically work intensively on that technology for many years, generating a lot of knowledge. FFI's role is primarily in bridging the gap between applied research and development, so they bring a slightly different type of knowledge to the table. Through collaboration within the

Norwegian Triaxial Model the two actors' type of knowledge complement each other (Informant 3 (Industry association), 2019).

5.1.1. Black Hornet

Prox Dynamics AS had in-house knowledge on core competencies such as mechanics, electronics, signal processing, and telecommunications from the very start. The four people that founded the company had acquired different, but complementary, skillsets through their previous careers, and continued to build on these competencies through in-house research and development leading to the product they took to market a few years later. As one of my informants put it:

> *"it was a very good combination of competencies and skills, they had no blind spots" (Informant 1 (FFI), 2018).*

Early in the development, some units were distributed to users in the Armed Forces, who tested and reported back, and their experiences were systematised and described in several research reports written by researchers at FFI (all of these reports are classified pursuant to Norwegian law) (Informant 1 (FFI), 2018).

FFI researchers had extensive prior experience in collaborating with units in the Armed Forces on related topics, from which they had learnt a lot about user needs, and how to translate input from the user milieu to relevant and actionable information for the industry actor. One of FFI's main contributions was to describe possible applications for the product, and in doing that it was necessary to filter some of the feedback from users that was often presented as absolute demands (Informant 1 (FFI), 2018; Informant 8 (FFI), 2019).

Developers and programmers at Prox Dynamics and researchers at FFI were frequently in contact, discussing concrete tasks and challenges along the way. A formal framework for collaboration was established, with meetings and minutes, but these were supplemented with extensive direct communication and collaboration whenever it was deemed advantageous; the back-and-forth between researchers at FFI and personnel at Prox Dynamics was carried out in a very pragmatic manner, with few formalities restricting interaction (Informant 1 (FFI), 2018).

The feedback from one group of users from the Armed Forces, who tested the product, and developers at Prox Dynamics was carried out in much the same way, with little focus on formalities and more focus on expediently conveying their findings and desires/demands. Sometimes input was channelled through FFI, and other times the users reached out directly to

Prox Dynamics. Informant 11 could not, however, remember any contact with other user groups from the Armed Forces (Informant 11 (Armed Forces), 2019).

Whenever there was a need for troubleshooting, FFI encouraged the us to contact the industry actor directly, and the industry actor responded eagerly. These were typically smaller issues that were sorted via e-mail, there were no face to face meetings (Informant 9 (Armed Forces), 2019).

Through participation in user testing, personnel from the involved units build competence on the system. At least one person involved later left his job in the Armed Forces to work for Prox Dynamics. And another individual switched the other way around, leaving Prox Dynamics to work for one of the units that use the Black Hornet (Informant 11 (Armed Forces), 2019). So, within this small TIS, the involved parties have had mutual benefit from taking part.

Prox Dynamics also cooperated with another industry actor, through a project partially financed by the Research Council of Norway, and they had a relationship with Norges teknisk-naturvitenskapelige universitet (Norwegian University of Science and Technology; NTNU), where they helped define the scope of several master thesis projects. However, little came from these, as in-house knowledge already covered the researched areas adequately. There was one notable exception: a student at Arkitektur- og designhøyskolen i Oslo (The Oslo School of Architecture and Design; AHO) wrote his thesis on industrial design in collaboration with FFI and Prox Dynamics. His work heavily influenced the final design of the Ground Control Station (the GCS consists of a base station/docking station for two Black Hornet nano UAS, a controller and a display) (Informant 4 (Industry), 2019).

5.1.2. FieldMade

In the autumn of 2016, during a military exercise called FLOTEX 2016, a 3D printer was set up on one of the Norwegian Navy's ships. Both FieldMade and FFI had representatives onboard the vessel to study how the 3D printer would perform under conditions where waves meant continuous motion. An accelerometer was attached to the printer to get exact logging of movement. Parts produced by the 3D printer onboard the vessel were replicated by an equivalent 3D printer on land, and the quality was compared between the two systems. This type of research activities have been carried out throughout the duration of the collaboration between FieldMade and FFI (Informant 10 (FFI), 2019).

At FFI, several divisions were involved, and research was carried out on both materiel technology, different types of 3D printers and other hardware, and development of the container solution. Much of the work was done in the form of work packages that would deliver different partial solutions to the project. An example of such a work package is that the NDMA tasked FFI with looking at this from a logistics perspective, and see how 3D printing could fit into a logistics concept – that is, not just the printing itself, but the whole chain from raw material to a part is delivered to the intended user (Informant 10 (FFI), 2019).

In order for 3D printing to be effective in a military setting, it is necessary to have a good digital platform with a library of 3D files for all parts that are to be manufactured. This system needs to include requirements specifications, whether the component is approved for 3D printing (where Intellectual Property Rights come into play), and it needs to log all data from the printing process so that all aspects of producing a component is properly documented. All of this is required for accountability, and software to do this was not available and has to be developed as part of the project. FieldMade has initiated a dialogue with Thales[7], trying to find a way to make use of the offset system that is in place for military purchases, where Thales could fulfil some of their offset requirements through helping to develop the required software. The offset system is quite complex, and no agreement has been reached yet on how to accomplish such a collaboration. The dialogue with Thales continues, but meanwhile, FieldMade has begun developing this software on their own. (Informant 2 (Industry), 2019; Informant 10 (FFI), 2019).

In order for FieldMade to succeed in commercialising their idea for producing spare parts under field conditions, a good system for quality assurance is necessary, a system that helps verify the quality of 3D printed parts and ensure repeatability, and cover all aspects pertaining to IPR with the original producer of the equipment. But building a system for quality assurance was not really a part of the FORNY2020-project that funded much of the early activities. NDMA wanted FFI to work on this, and to some extent FFI did, but this was not well funded, and therefore lacking in momentum. Now, in the spring of 2019, funding will hopefully be available for FFI to start more focused work on this, but it should have been done sooner (Informant 10 (FFI), 2019). In a follow up e-mail correspondence (2019-08-29), the informant says that

[7] Thales is a global technology company serving five key sectors: aerospace, space, ground transportation, digital identity and security, defence and security. (https://www.thalesgroup.com/en/global/about-us, accessed 2019-08-05)

funding is in place for 2019, and FFI are setting up collaboration with both the Finnish Navy and with Hägglunds to produce and field test spare parts for verification of the quality. Funding beyond 2019 is not in place at the time of writing.

The lack of a system for quality assurance and approval procedures has led to some challenges for user testing, since the parts that are manufactured for testing cannot necessarily be put into proper use. User testing has, as a consequence, been somewhat less coordinated than what is ideal seen from the FFI's perspective. Also, the Armed Forces have not had a coordinated approach to building user experience with 3D printing technology, for instance, the Norwegian Defence Logistics Organisation has tasked Bjerkvik Tekniske Verksted (one of their technical workshops, located in Northern Norway) with buying a few 3D printers and start testing them to build competence on 3D printing for the Logistics Organisation. And there is currently no link between these efforts and those of the FFI. This lack of overall coordination might result in sub-optimal use of resources, and FFI is therefore now (primo 2019) taking the initiative to try and improve overall coordination through the establishment of an "AM forum" for the Armed Forces, where relevant parties can meet up once or twice a year to inform each other and coordinate activities (Informant 10 (FFI), 2019).

Another unit in the Logistics Organisation, situated in the South-East, is also involved in 3D printing. This unit has had a closer cooperation with both FieldMade and FFI, but agrees that there is a need for a closer coordination of the efforts "defence-wide":

> *"so far, there has been one person in Bjerkvik, one person here, and perhaps one person in NDMA, all doing things on their own – with no interaction" (Informant 12 (Armed Forces), 2019).*

During the school year 2016-17, three students did their bachelor's degree in machine engineering in cooperation with FieldMade. One of the three had become acquainted with FieldMade the year before, during a summer engagement at FFI, and when starting their bachelor's degree, the students contacted FieldMade, who responded positively and presented a number of cases that could produce results relevant for their development of container-based 3D printing. The students chose one relevant for their specialisation, and thus helped produce knowledge for the FieldMade project while educating themselves in the field (Informant 12 (Armed Forces), 2019).

When the Norwegian Armed Forces now seek to develop more knowledge about AM, it is natural to seek collaboration with industry actors. And even though there are activities abroad, such as in the US, no one else can today deliver a solution for additive manufacturing like the one FieldMade is developing. This makes FieldMade the obvious choice for collaboration (Informant 12 (Armed Forces), 2019).

Engaging in collaboration with FieldMade has provided an arena for the War Damage Repair unit to rapidly expand their competence on additive manufacturing technologies, through being hands-on together on field exercises, as well as lectures in the classroom; FieldMade has visited the unit and held a course in 3D printing. Attendants afterwards said they had gained new insights into both complexities and possibilities with additive manufacturing. This helps the unit keep up with the latest developments in this technology area and increases their ability to decide when this type of technology has matured to a level where the Armed Forces are ready to implement them in their operations, and where it can best be put to use (Informant 12 (Armed Forces), 2019).

The Armed Forces unit working most closely with FieldMade on this project has previously relied heavily on traditional machining of parts when producing spare parts for emergency repairs, and was very interested in contributing to, and learning from, FieldMade's endeavours. Knowledge development and sharing has been done both through close interaction on field exercises where they have collaborated on operating the 3D printing container and in office settings, where they have met up to discuss how different parts are meant to function and collaborated on 3D print design (Informant 12 (Armed Forces), 2019).

In the autumn of 2015, one of the persons who initiated the FieldMade project wrote a master thesis on the potential value of 3D printing in the military supply chain, in which he studied logistics for deployed units. He found that control over what equipment had been shipped was lacking, and there was no good system for identifying what were critical components. Together with key personnel he identified a number of important parts and established a provisional list over items that could be replaced by 3D printed spare parts. The focus was on what was technically possible, given size, material, and complexity – IPR, guarantee, verification and contractual issues were not part of this. But the study concluded that there was a theoretical potential for replacing up to 55 percent of the identified critical components. This knowledge, together with the prototype container, was the foundation for an application to the Research Council of Norway in the spring of 2016 (Informant 2 (Industry), 2019).

Additive Manufacturing (AM) comprises 7 different technological areas, and few people have advanced knowledge of 2 or more of these areas. Different actors in the field of additive manufacturing use different technologies, and have different specialised competencies, so information sharing across businesses is beneficial for all. So far, the will to share is good, through discussions, consortiums and joint projects. This situation will likely change in the near future, as competition increases (Informant 2 (Industry), 2019).

FieldMade has hired highly qualified personnel and is continuously working on increasing their knowledge base. In addition to 3D printing itself, FieldMade is focusing on building structures to support this, such as a virtual warehouse and software to digitalise physical parts – important components of a system that aims to conquer the niche of mobile additive manufacturing for military use (Informant 2 (Industry), 2019).

5.1.3. Main findings on knowledge development and diffusion

My research shows that both industry actors and FFI contribute with knowledge development. Slightly different, but complementary, kinds of knowledge. The empirical data suggests that knowledge on the technology that makes up the product is primarily developed by the industry actor, while FFI contributes with developing concepts for operative use of the product, and concepts for quality assurance. Also, the two collaborate to some extent on knowledge production, especially during field testing.

In both the studied cases, the industry actor has sought to benefit from academic research carried out at higher education institutions. While some efforts did not pan out, others did, and for both cases external knowledge production provided input that was directly useful in the development process. The application that landed FieldMade funding from the Research Council of Norway was largely based on knowledge from a master's thesis, and Prox Dynamics built the Ground Control Station for the Black Hornet on the basis of a thesis in industrial design.

To some extent, the level of organisational maturity when it comes to new technology can be said to have a slightly limiting effect on knowledge production in the user/tester corner of the triangle for the FieldMade case. In this case, FieldMade actively engaged in educating users on the technology, and FFI has taken an initiative to improve coordination within the Armed Forces, in an effort to increase overall performance of the innovation system.

When it comes to diffusion of knowledge, the pattern that emerges from empirical data is that instead of formal arrangements and bureaucracy, all involved actors tended towards pragmatism and preferred informal communication and a low threshold for making contact. That said, documentation in the form of progress reports and test reports from users were made.

Also, the long-term relationship between FFI and test users from the Armed Forces has prepared the ground for efficient interaction, not only between those two, but also in those cases where FFI is an intermediary between the industry and the user/tester. FFI translates needs from users to useful input for the industry actor, and also can help calibrate the users' expectations so that testing is as targeted as desired.

Personnel mobility between actors, where an employee switch from one employer to another, also contributes to knowledge diffusion.

One interesting thing to note is that FieldMade tried to make use of the offset system in an effort to have an international actor develop some software. The complexities of the offset system cause this to take much time, and the result is not known at the time of writing this thesis.

5.2. Influence on the direction of search

5.2.1. Black Hornet

Prox Dynamics had a very clear vision from the start; to build a system made for soldiers in combat, it should be carried by a single soldier, be readily available and controlled with one hand, it should not require pilot experience and it should deliver live imagery to the user. This clarity of purpose helped the developers stay "on track" and not branch out to serve other potential customer segments, and it helped Prox Dynamics maintain supremacy in all decisions going forward. In a way, this approach made Prox Dynamics the hub of the Norwegian Triaxial Model for the development of the Black Hornet (Informant 4 (Industry), 2019).

In general, Prox Dynamics handled most of the technical development themselves, while FFI, with the help of the user groups, concentrated on the conceptual framework and how to ensure that the technology resulted in a product that met the needs of the Armed Forces, and avoid ending up chasing an unrealistic dream product that, while technologically superior, had limited operational relevance. Important aspects in that regard were weight, size, graphical user interface, simplicity for the operator, tolerance for field conditions and low temperatures, all of which were discussed at length with participation from both Prox Dynamics, FFI and users carrying out field testing (Informant 1 (FFI), 2018). FFI's early contributions included very concrete demands, based on previous experience, for instance size – it should not exceed the size of a standard ammunition pocket for the combat vest – and flight preparations – it should boot up and be ready for deployment within a very short time period in case a unit came under a surprise attack (Informant 8 (FFI), 2019).

Testing began early, well aware that the prototypes were not “field ready”, but nonetheless demonstrated possibilities, and important feedback was channelled into the development process (Informant 1 (FFI), 2018). Before field testing, FFI would hold separate meetings with the users to explain the readiness level of the technology to calibrate user expectations. For instance, early prototypes came with a screen that was not waterproof – which, of course, is unacceptable in an operational setting – but FFI made sure users were prepared to see past such issues, as they would be dealt with later in the process. “Focus on this part now, this is what is important at this stage” type guidelines, which requires an intermediary between industry and user that has intimate knowledge of both technology and how the users think (Informant 8 (FFI), 2019). FFI had clear ideas about what should be considered success criteria and were particularly adamant about the need to make it easy to use for the operator. A good pilot can achieve much with a drone, but a central issue here was to eliminate the need for a “pilot” and make the device easy to operate for a soldier with limited drone flying experience (Informant 4 (Industry), 2019; Informant 8 (FFI), 2019).

Another unit testing the Black Hornet had frequent contact directly with the industry actor to inform them of desired capabilities, such as the ability to reconnoitre inside buildings. This particular demand was not met in the early versions but is something that Prox Dynamics continued to work on for later models. This unit also signalled clearly that they could accept a slightly heavier UAS, but apparently that was not an alternative for the industry actor, for fear of losing out on other markets, like the US Army (Informant 11 (Armed Forces), 2019).

There were discussions on size and weight – building a slightly bigger UAS likely would allow for increase performance, and probably also reduce cost – but Prox Dynamics had a very clear vision of where they wanted to go with their product, and stayed true to their early ideas about the importance of low size and weight (Informant 1 (FFI), 2018).

FFI has carried out research on UAS s for a long time and has maintained a close relationship with UAS users in the Armed Forces. This has resulted in extensive knowledge in the UAS field, including user needs and modi operandi, as well as having established report with the users that facilitates effective communication when cooperating. All of this benefitted the FFI’s function as a link between users/testers (personnel in the Armed Forces) and the industry actor (Prox Dynamics). In chapter 5.1.3. I mentioned some benefits of informal and pragmatic approach to sharing information and experiences. It is also pertinent to mention that this comes at a cost; on some occasions the most eager individuals involved in the testing, likely meaning no harm, did short-circuit the information flow by approaching Prox Dynamics directly when it probably would have been more correct to include FFI in the communication. (Informant 1 (FFI), 2018).

Prox Dynamics also received feedback on the development from actors outside the Norwegian Triaxial Model. For instance, the British Armed Forces were interested at an early stage, and provided feedback that played into the development process (Informant 4 (Industry), 2019). This is not covered in the data collection for this thesis and will not be discussed in detail.

FFI facilitated field testing by purchasing a number of systems and hand them out to different units in the Armed Forces. The results of experiments carried out by the Armed Forces were formally reported to FFI, who systematised findings. Seen from the perspective of Prox Dynamics, it appeared as if it was primarily FFI's own experience with UAS and knowledge of the needs of the Armed Forces that shaped FFI's inputs to Prox Dynamics, while direct feedback from users to Prox Dynamics was sparse. And an observation from Prox Dynamics is that the critique they do receive from users tend to address issues present in early versions, issues that have been dealt with in later production models (Informant 4 (Industry), 2019).

5.2.2. FieldMade

What eventually became FieldMade AS started as a small project at FFI, initiated by one person with a passion for 3D printing, studying production of spare parts under field conditions. A few more people became involved, among them one from the SORD[8] team at FFI. He came up with the idea of building a demonstrator, a deployable, container-based production unit (Informant 10 (FFI), 2019).

After building the demonstrator and testing it on several field exercises together with different parts of the Armed Forces, the next goal for FieldMade was to construct a solution with an industrial focus. This called for upgrading the machine park and the design of the container itself to a technical level where they could produce components from different materials, and by end of year 2018, this concept was ready (Informant 2 (Industry), 2019).

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[8] SORD: Special Operations Research & Development, a collaboration between Norwegian Special Operations Forces (NORSOF) and FFI in the form of a multidisciplinary team of researchers and officers conducting strategic analysis and coordination of research & development for NORSOF. (www.ffi.no/no/Forskningen/innovasjon-industriutvikling/asymmetrisk-krigforing/Sider/default.aspx, accessed 2019-07-23)

The motivation for trying to build a solution for a deployable production unit for additive manufacturing originated from the logistical situation for spare parts. The Armed Forces spend vast funds on spare parts, keep huge stocks of components, some of which might never be used, and a lot of systems are old and will eventually become difficult to acquire spare parts for. Then there is the desire to have control of the entire supply chain, which can be challenging for spare parts that are produced by foreign companies. And on top of that, delivering supplies to military units that are deployed to an area outside of Norway, say Afghanistan, is complicated, costly and carries a lot of risk. This means there are a lot of advantages to having the ability to produce what is needed, where it is needed, when it is needed. And in principle, all that would be required was 3D printing equipment, the raw material, and a digital chain of information about the part in question. That was the background for the project at FFI, and why it was assessed as something worth pursuing (Informant 10 (FFI), 2019).

For additive manufacturing in the field to become a viable alternative to the traditional logistics surrounding spare parts, proper quality assurance of the entire production chain is necessary. This was identified at an early stage, but funds were not available to work on this topic at the time (Informant 10 (FFI), 2019).

The Armed Forces' unit working most closely with FieldMade is a unit from the Logistics Organisation. It is the Armed Forces' national authority on war damage repairs[9], and Norway is one of NATO's lead nations[10] in this field. The primary focus for their collaboration with FieldMade is to find ways to utilise deployable additive manufacturing to support war damage repair efforts. In order to get there, this unit has facilitated field testing of the FieldMade container solution on military exercises (Informant 12 (Armed Forces), 2019).

The first time FieldMade applied for funding from the MoD was in the fall of 2017. At that time, FieldMade had mulled over their concept for three years, and felt ready to work on all aspects relating to mobile additive manufacturing; the container, the 3D printing machines, the virtual warehouse architecture and so on. A huge project. The MoD was not ready for such an

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[9] "War damage repairs" is my translation of the Norwegian word "krigsskadereparasjon", which is defined as decisive repair, often improvised and/or temporary, carried out rapidly in a combat environment in order to render damaged or otherwise non-operative equipment operative. (https://forsvaret.no/prinsix/kunnskapsomrader/terminologi, accessed 2019-07-23)

[10] The term "lead nation" in NATO typically means that a nation has assumed responsibility for coordinating research and development and/or providing special capabilities in a field.

all-encompassing endeavour, and told FieldMade to reduce the scope and risk, and focus on the physical solution and let the rest wait (Informant 2 (Industry), 2019).

When the MoD grants R&D funds, a project management group is constituted, typically with representatives from all branches of the Armed Forces, the Logistics Organisation, FFI and the industry actor in question. Their mandate is to oversee that the project proceeds according to the plan in the application, and help the progress, for instance by facilitating field testing during military exercises or integrated with daily operations (Informant 2 (Industry), 2019).

5.2.3. Main findings on influence on the direction of search

In the Black Hornet case, the industry actors' original vision for their project was very clear, and stayed extremely important throughout the process, making it possibly the most central factor influencing the direction of search. It helped Prox Dynamics maintain supremacy in all decisions going forward, and in effect made them the hub of the process. The Black Hornet project was one where an idea for a cutting-edge product guided the way, and the market would have to follow. Direction for the FieldMade project came, in part, from a good, research-based, understanding of the logistical situation for spare parts in the Armed Forces. FieldMade combined an understanding of the marketplace with interest in and knowledge about additive manufacturing and sought to introduce a product that covers an existing user need (even though the user might not fully realise that need at the time).

Commencing testing as soon as possible provided user input at an early stage. FFI and users concentrated mostly on what would make the Black Hornet operationally relevant – concepts and capabilities, operational requirements – *what* it should do, not *how* it should do it. FFI held the reins when it came to user testing, in terms of guiding the users. FFI calibrated user expectations to maximise effect of testing by helping them focus on the right features and see past issues that were not meant to be ready until a later stage.

From Prox Dynamic's point of view, user feedback seemed to mostly come via FFI, and the feedback relayed from FFI to Prox Dynamics seemed shaped by FFI's own experiences and knowledge of UAS. Interestingly, both FFI and users report that feedback was often given directly from users to the industry during testing. FFI also reports that they at times felt left out of the information loop because of this. It is possible that the amount of time that has passed between these activities and the interviews must account for some of these differences of opinion. It is also possible that the preference of informal communication over formal arrangements makes experiences more dependent on degree of personal involvement in the different exchanges.

Prox Dynamics also experienced that user input tended to focus on issues from early versions of the Black Hornet – issues that were already resolved in current versions. This could indicate that there was quite a bit of lag in the communication of results from field testing, but it is also possible that this is the result of users being less involved in the latest stages of development and formed their opinions based on the version that was purchased – which they have extensive operational experience with. After the Norwegian Armed Forces purchased Black Hornet, a new and updated model has been developed, with upgraded specifications.

Prox Dynamics also benefitted from input from users/testers outside of the Norwegian Triaxial Model project, such as the British Armed Forces.

When it comes to the FieldMade case, it had a different origin; it began with one eager researcher at FFI. More people at FFI became involved, and a 3D printing container was built as a demonstrator. Results from field testing the demonstrator then led to a more industrial focus, towards upgraded technology and capability for multi-material additive manufacturing.

Direction for the FieldMade project came, in part, from a good, research-based, understanding of the logistical situation for spare parts in the Armed Forces.

Army units involved in user testing have their own priorities, which translates into a special focus on a particular segment of the spectrum of possibilities within additive manufacturing. This likely impacts on contribution both in terms of how they facilitate for FieldMade participation on field exercises, and on what they focus on in their feedback.

Funding matters. When MoD provided R&D funding, it came with clear demands influencing direction of search. FieldMade had to reduce scope and risk and had to focus on the physical solutions first (meaning software and other surrounding/support systems got a lower priority).

MoD funding also came with a project management board, which has oversight on the progress and seeks to keep the project on track according to plans. It can also help progress, for instance by facilitating participation on field exercises for testing.

5.3. Entrepreneurial experimentation

5.3.1. Black Hornet

FFI facilitated the distribution to user groups in the Armed Forces and encouraged them to test the Black Hornet in as many and varied scenarios as possible. Aware of the high price one of the user groups wondered how much risk could be taken – what were the boundaries for testing – to which FFI replied that as long as they didn't *plan* to crash it into the sea, everything was within the scope. And so the unit carried out all the tests and scenarios they could think of for their possible operative use of the equipment, and reported back the results (Informant 9 (Armed Forces), 2019).

In addition to testing the Black Hornet in different scenarios, one of the informants said that they tried connecting it to other electronic equipment – attempting to *network* it – and reported on technological challenges they faced in that process. Most of the feedback was routed via FFI, but often the more software-related issues were communicated directly to Prox Dynamics, and trouble-shooting and problem-solving was usually done by e-mail (Informant 9 (Armed Forces), 2019).

Most of the testing was carried out by Prox Dynamics in their own facilities, they had both the competence and the systems required for testing, but for input from users, it was necessary to engage personnel in the Armed Forces. Due to the special working relationship between FFI and the SOF part of the Armed Forces, most of the feedback from testing done by military personnel came from SOF units (Informant 4 (Industry), 2019).

The culmination of the first collaboration project between Prox Dynamics and FFI on the Black Hornet project was flying a light-weight prototype with on-board camera to demonstrate both functionality and user friendliness. During this test, a researcher from FFI, with prior experience in flying UAS, but no training on the Black Hornet, managed to operate the system. This indicated that they were on track with regards to both size, weight, capabilities and ease of use (Informant 8 (FFI), 2019).

Not all experiments were immediate successes. The first time Prox Dynamics wanted to demonstrate on-board GPS was a bit of a mess. It didn't work at all. So, they went back to their drawing-board and stayed there for a while. But that was pretty much the only time that sort of thing happened. One of the things that impressed FFI was Prox Dynamics' ability to consistently deliver on the milestones they had set. Usually, developers have a lot of energy and bravado, and tend to overestimate their abilities to deliver. Prox Dynamics seemed to know and understand their abilities very well, and except from that one time, they always delivered on what they had promised (Informant 1 (FFI), 2018).

After the first project phase, time had come to involve a broad range of users. FFI bought a number of sets and distributed to different units in the Army, Navy, Air Force and Special Forces. The users were given a crash course in how to use the drone and were asked to test it in every conceivable way and report the results to FFI. During this period software updates were frequently released, and FFI helped the users keep their systems up to date. FFI’s ambition was to gather ample data on possible uses and on how the system worked, and few restrictions applied. From time to time a system was lost or destroyed, and the users could then visit FFI and get a replacement set. At this stage, no procurement process had been started by the Norwegian Armed Forces, so the FFI took an independent responsibility to serve users with test units and ended up buying quite a few sets to facilitate thorough testing by potential interested parties in the Norwegian Armed Forces. During this period, testing facilitated by FFI generated a lot of interesting data for Prox Dynamics, feeding into the design process on version 2 of the Black Hornet – which was a clear improvement from version 1 (Informant 8 (FFI), 2019).

Grand ideas and visions are good for mobilising interest, but it is when a product physically takes form that the number of compromises needed becomes clear. And the only way to find them is to actually start building something and test it. In the case of the Black Hornet, some experiments began even before a flying prototype was ready. In the very early stages, a simulator was built, making it possible to explore different configurations of menus and buttons – *“what if we make this button do that..?”* – in an expedient manner (Informant 8 (FFI), 2019).

One of the units involved in testing also deployed it for operational use in Afghanistan, at a rather early stage. They experienced several problems with it, such as loss of communication link, problems with the GPS, and felt that it wasn’t reliable enough – yet. So they shared their concerns with Prox Dynamics, and while some personnel lost interest, others figured that the technology just needed some time to develop and mature into a solid product (Informant 11 (Armed Forces), 2019).

5.3.2. FieldMade

Late 2015 through early 2016 FFI acquired a container and equipped it with a working station for 3D modelling and a 3D printer, making it the first demonstrator of the concept for deployable AM. Through SORD's close relationship with NORSOF, arrangements were made to participate on the military exercise Cold Response, co-located with a NORSOF unit. During the course of the exercise, FieldMade and FFI representatives worked together in the container on modelling and producing a number of items on demand (Informant 10 (FFI), 2019).

Then, by the fall of 2016, the Norwegian Navy had become interested, and wanted to test this at sea during a naval exercise. A 3D printer was set up on a Norwegian Navy ship for the duration of exercise FLOTEX 2016. Again, FieldMade and FFI representatives worked together, this time to test specifically how the 3D printer would perform under open water conditions and both prototypes, modifications and spare parts were produced (Informant 10 (FFI), 2019).

NATO ACT (Allied Command Transformation), focusing on transformation, development and technology, were very interested in the additive manufacturing project, and wanted FieldMade and FFI to participate on several large field exercises, and helped facilitate participation on exercises CWIX in Poland (2018), and Trident Juncture in Norway (2018) (Informant 10 (FFI), 2019). During the CWIX exercise, FieldMade invited two personnel from the war damage repair unit to accompany them, strengthening the cooperation between FieldMade and this unit (Informant 12 (Armed Forces), 2019).

During Trident Juncture, the container from FieldMade was set up next to the war damage repair unit from the Logistics Organisation, facilitating close cooperation and exchange of experiences (Informant 10 (FFI), 2019). At this exercise the war damage repair unit was set up with their container-based machining workshop. Several different experiments were carried out, such as giving the two different production containers the same task (end product) to compare process and result, or collaboration, including hybrid production where FieldMade 3D printed a part while the war damage repair unit machined a part, and then the two were assembled together and handed over to a user in need (Informant 12 (Armed Forces), 2019).

Trident Juncture also represented an opportunity to show other NATO members the FieldMade concept for additive manufacturing, and during the exercise the FieldMade and FFI team collaborated with the US Marine Corps (USMC). Dialogue with USMC had been close leading up to the exercise, and during Trident Juncture experiments on how to securely transfer encrypted data from the USMC into the additive manufacturing production facility and have FieldMade and FFI manufacture parts for the USMC were carried out (Informant 10 (FFI), 2019).

The FieldMade and FFI project on additive manufacturing has participated in projects run by the European Defence Agency (EDA)[11], such as the production of parts using different 3D printing equipment in different countries and compare the results with parts manufactured under field conditions (Informant 10 (FFI), 2019).

All the activities carried out together with the Armed Forces allows FieldMade to test a functional prototype, identify errors and incrementally build a better solution. The finished product will likely be bespoke, with machinery, materials and other equipment tailored to each customer's needs, but it is the knowledge developed through all the testing that helps FieldMade develop a product that is ready for sale (Informant 2 (Industry), 2019).

5.3.3. Main findings on entrepreneurial experimentation

Users got the directions for testing from FFI, not the producer. FFI bolstered the entrepreneurial spirit by imposing very few limitations and encouraging users to test "everything". FFI signalling high acceptance for mishaps likely helped yield rich data from testing. FFI also bore the financial risk, by buying the sets that were distributed to users for testing.

Troubleshooting/problem-solving during test periods for Black Hornet was mostly handled through direct contact between users and Prox Dynamics.

FFI has a longstanding relationship with Norwegian Special Operations Forces (SOF) community. SOF units are typically very demanding users, and most of the feedback from users testing the Black Hornet came from this community.

Entrepreneurial experimentation sometimes involve failure, like when the onboard GPS completely failed the first time it was demonstrated. With Prox Dynamics doing most of the experimenting themselves, few failures were exposed to FFI or users. This might be part of the

[11] EDA is a European Union agency established in 2004 "to support the Member States and the Council in their effort to improve European defence capabilities in the field of crisis management and to sustain the European Security and Defence Policy as it stands now and develops in the future". (https://www.eda.europa.eu/Aboutus/Missionandfunctions, accessed 2017-07-23)

reason why FFI researchers were so impressed with Prox Dynamics' ability to deliver on progression promises.

To expedite the feedback process, a simulator was built early on, so that some experiments could begin even before a flying prototype was ready.

Even early test-versions of the Black Hornet were put to operational use – some were brought to Afghanistan and tested during deployment there. This might have been premature, as problems experienced there disheartened some personnel, even though FFI had tried to explain limitations in early versions. Just like other tests, results from operational use was shared with Prox Dynamics.

Quite shortly after conceiving the deployable concept for additive manufacturing, a demonstrator version was built and brought to a military exercise for field testing with Army units. Experiments were also conducted under open water conditions, onboard a Navy ship later that same year, with production of prototypes, modifications and spare parts.

Interest from NATO's Allied Command Transformation (ACT) led to them helping facilitate further field experiments, including deployment to participate in military exercises abroad.

Co-locating FieldMade's production facility with the Norwegian Army's war damage repair unit strengthened collaboration and allowed for experiments where the two solved some of the same tasks and compared results, as well as complementary work, where they each produced parts that were then assembled together into a finished product.

On NATO's Trident Juncture exercise FieldMade collaborated with units from the US Marine Corps on experimenting with transferring encrypted data from the user to the production facility.

Experiments have included comparing results from FieldMade's 3D printing with parts manufactured by other additive manufacturing actors in other countries, as part of projects run by the European Defence Agency.

The end product from FieldMade will likely be bespoke deliveries tailored to the need of each customer. Progress towards that goal has been incremental, based on feedback from experiments in the field.

5.4. Market formation

The Armed Forces are used to procuring large systems, meant to be in service for many years, often decades. This carries with it a very comprehensive and rigid documentation regime, with procedures and regulations, which is of course very reasonable when a large organisation does that kind of procurement – but it does not necessarily make it easy to implement new technology. There is a need for a more agile approach, with incremental implementation of new technology and new solutions (Informant 3 (Industry association), 2019).

5.4.1. Black Hornet

When Prox Dynamics was founded their aim was to develop a nano UAS for military use, in a segment that until then did not really exist. Their goal was not to answer a question already asked or respond to needs already formulated by the Armed Forces, but to introduce something entirely new to the marketplace. On the one hand this gave them a sort of freedom of manoeuvre in defining the end product, letting them stay true to their vision, but on the other hand it also meant that they had to prepare the ground for their product. They had to convince future customers that their product would serve a purpose, and help potential customers realise they needed the product that was coming.

Staying true to the low weight and small size vision probably helped in getting market access, particularly for the US market, where those characteristics likely were important criteria (Informant 11 (Armed Forces), 2019).

Potential users in the Norwegian Armed Forces, involved in testing of the first version of the Black Hornet, had mixed feelings about the feasibility of the product. They reported that this was exciting and fascinating, but not really robust enough for operational use. These first impressions did not result in a bottom up demand strong enough to trigger any procurement processes (Informant 1 (FFI), 2018).

The first buyer of the Black Hornet was the British military. They were facing severe challenges in Afghanistan and were looking for something that could help reduce casualties. The Black Hornet could contribute in that regard. Selling to the British secured an influx of money that helped cover costs for further development and getting a pilot customer likely had a positive effect on getting the attention of other potential customers. Soon videos showing British soldiers using the Black Hornet appeared on YouTube, adding to the attention (Informant 1 (FFI), 2018).

Procurement processes in the Norwegian Armed Forces are often very lengthy, for a number of reasons – such as funding and budget processes – but acquiring UAS systems were particularly challenging due to the special approval process for airborne systems. At the time, even small UAS were subject to technical and administrative approval regimes closely resembling those used for manned aircraft. From the perspective of someone involved in the development process this regime was to comprehensive and rigid, it takes too much time getting things approved and necessary paperwork done (Informant 1 (FFI), 2018).

Some of the reasoning behind the comprehensive regime is probably to make sure that when purchasing large systems, meant to have a long time of service, sufficient attention is paid to all aspects; logistics, maintenance, resupply and so on. But for UAS, and probably a lot of other equipment, the technical lifespan is shortening – state of the art items become obsolete few years later. A more expedient procurement process would be beneficial for all involved parties:

> *"You cannot use three years to get a system approved if it is outdated in two" (Informant 1 (FFI), 2018).*

The initial Norwegian purchases were a few dozen sets of the first version, bought by FFI to facilitate user testing. It is possible that Prox Dynamics tried to convince decision makers that the Black Hornet was a useful product, but when the Norwegian Armed Forces started formal procurement processes, they were likely initiated by users who saw potential in the product – in particular parts of the Special Operations Forces community (Informant 1 (FFI), 2018).

UAS were not new to military units, or the FFI, when the Black Hornet appeared. But all available drones were much larger, and typically more difficult to use. The Black Hornet was something entirely new and more or less created a new niche. According to one informant, interest for the product was almost instant, but it still took a while before the Norwegian Armed Forces decided to purchase it, and he would have liked to see Norwegians being the first to put it to operational use (Informant 11 (Armed Forces), 2019).

When procurement processes began, a lump sum was allocated, and the procurement project was tasked with buying as many systems as possible for the allocated amount of money. The intention was to distribute the system to different units in all branches of the military and start building user experience and competence, and through that discover possibilities for use and over time develop this into a valuable tool. No doctrine or other visions for use existed, and there was little interest and engagement on the ministry level. It was a user driven, bottom-up, process (Informant 13 (Armed Forces), 2019).

In the spring of 2009 Prox Dynamics received inquiries from a lot of different actors, ranging from security firms to academic researchers wanting to explore the pyramids in Egypt. True to their strategy of developing a unique tool for the military market, Prox Dynamics ignored most of the inquiries. One that stood out was an e-mail received from the British Ministry of Defence's Defence Equipment and Support in May 2009. They wanted more information about the Black Hornet. Prox Dynamics decided to go "all in" and described what they were doing and the cooperation with FFI. This quickly resulted in a meeting, where Prox Dynamics learned about URBEX, a British programme seeking to mitigate urgent operational requirements though acquiring off-the-shelf technologies. At the time, the British were suffering casualties in Afghanistan, something the Black Hornet could potentially help reduce. At this stage, the Black Hornet was not yet ready for production, it was still under development. Over the next year and a half, the British Ministry of Defence's Defence Equipment and Support and Prox Dynamics stayed in touch, and by the end of 2010 a Black Hornet prototype was ready. To avoid showing competitors what they were working on, Prox Dynamics still wanted to avoid public displays, and managed to arrange a non-disclosed demonstration with restricted access in connection with a bigger vendor event. This demonstration led to the British Ministry of Defence's Defence Equipment and Support establishing a programme to purchase a nano UAS system, and in February 2011 they publicly stated they were interested in buying up to 160[12] systems, with specifications corresponding to Prox Dynamics description of the Black Hornet (Informant 4 (Industry), 2019).

Early in the summer 2011, Prox Dynamics received an invitation to tender from the British Ministry of Defence's Defence Equipment and Support, with a five-week deadline. And in October 2011 they entered into a contract to deliver 160 systems. A little over one year from initial meeting to contract means things developed very quickly, a pace possible only because the British had that urgent operational need. And that contract was invaluable for Prox Dynamics, helping them launch their product and secure funding for future operations. By comparison, initial contact with US actors was made in 2009, and it took 9 years before a contract was signed (Informant 4 (Industry), 2019).

> *"Without the British, we would never have achieved what we did so quickly" (Informant 4 (Industry), 2019).*

[12] The exact number might have been slightly higher, but the gist of it was that DE&S signaled a demand for a relatively large number of systems.

On the soldier level, especially in the Special Operations Forces community, several individuals were fascinated with what the Black Hornet could potentially contribute with on the battlefield. On a system/unit level, however, the attitude was more “let’s wait and see” what this might become. And considering the size of the Norwegian Armed Forces, even if all relevant units were to be given a set, the total number of units sold would not secure substantial revenue for Prox Dynamics. This made the British endeavour extremely important, since securing a customer of that size would both mean revenue to support further activity in the firm, and also serve as a validation of the products usefulness and relevance (Informant 8 (FFI), 2019).

The uniqueness of the Black Hornet was also one of the main challenges when trying to sell it. There was no prior demand, because nobody knew the technology existed or could be built. This meant that Prox Dynamics had to get potential customers interested enough to initiate formal proceedings that lay the ground for procurement. The British were an exception, as described, but for all others, this took long term efforts. Small batches to be used for testing and evaluation is one thing, but establishing a program of record, with large purchases, takes a lot of foot work. Getting a customer interested is only the beginning. After that, programmes or projects have to be started, where user needs must be defined, concepts for use developed, and financing secured. Typically, financing must fit into a long-term plan, which means that money cannot be allocated from current budgets but must wait for a revision or a new budget cycle. This can take years. So the upside of having no defined user needs to dictate the direction of search, corresponds with the challenge of getting potential customers to identify and define a demand and allocate resources to pursue that demand through, usually time-consuming, formal processes (Informant 4 (Industry), 2019).

5.4.2. FieldMade

Part of building a market for a new type of technology is to build user competence on the technology. FieldMade has had an especially close collaboration with some of the personnel in a unit in the Armed Forces that are among those most likely to use the finished 3D printing container; the national authority for war damage repair. In addition to working closely together during experimenting and testing, FieldMade also arranged a course for personnel in this unit so that the entire unit would gain a better understanding of what 3D printing can and cannot deliver (Informant 12 (Armed Forces), 2019).

Some of the funding from the MoD was allocated to acquiring necessary equipment for the container solution, but an important part of the reason why the MoD approved funding to

FieldMade's additive manufacturing project was to finance participation on various field exercises. This serves two purposes: on the one hand it helps development through testing and feedback, and on the other hand it serves to demonstrate the technology for relevant personnel in the Armed Forces, making the capability known for those who are most likely to use it themselves and those who are likely to benefit from the components it can manufacture (Informant 10 (FFI), 2019).

Operating the most high-tech additive manufacturing equipment effectively requires a level of education and experience that might be difficult for operators from the Armed Forces to achieve, the way Norwegian Armed Forces are currently organised (with a large number of conscripts, compared to career soldiers). Due to this, it seems unlikely that the war damage repair unit can maintain in-house competence on the most advanced equipment, and their involvement in the project helps them figure out which part of the technology to focus on, and whether there might be ways to organise how it is manned that can alleviate such challenges. And, of course, additive manufacturing technology in general is improving rapidly, including continually becoming easier to operate. Part of the war damage repair unit's focus is to monitor this development and assess when it reaches a user threshold suitable for their use (Informant 12 (Armed Forces), 2019).

3D printing technology has been around for some years, for example in the car industry. In the Armed Forces the general impression has probably been that has been a bit out of reach, too advanced for it to be put into practical use. This all started to change when FFI first managed to get the MoD interested about 5 years ago. That was probably the eye-opener for the decision-making level. And when FieldMade materialised, focusing on the Norwegian Armed Forces and on delivering a product designed for military use, 3D printing suddenly seemed more relevant, and that was probably what triggered the war damage repair unit to decide to spend time and resources to engage and learn more about additive manufacturing (Informant 12 (Armed Forces), 2019).

For FieldMade, the beginning was an uphill battle, in that there was little knowledge about additive manufacturing in the Norwegian Armed Forces, and it was not something the Armed Forces had decided to acquire. There was no market for it in Norway at the time. FieldMade had to create a demand, through proving the potential and relevance. In the US Armed Forces, additive manufacturing was already "in process", they had begun gathering experience through testing and experimenting, adapting incrementally, not wanting to miss out on the potential. They have more of an entrepreneurial spirit, thinking "we'll learn along the way". Norway tends to be more conservative when facing new technological possibilities, preferring to see proof that something works from an ally that has taken the leap early (Informant 2 (Industry), 2019).

In reality, additive manufacturing should be much easier to implement in the Norwegian Armed Forces, with a smaller organisation and fewer systems. It should be possible to identify the potential, launch an effort, and capitalise on being first to market with a well-functioning product (Informant 2 (Industry), 2019).

With Norway being a very small market for this type of product, FieldMade is also looking at foreign markets. In Norway, the status quo is still one of "this is interesting, let's see where this goes", and there are no acquisition programs in place. Other countries have programs that are moving along much faster than here at home. Realising that some success at home is extremely beneficial for attention abroad, FieldMade has capitalised on the R&D funding from the Norwegian MoD and the fact that they have a certain level of interest from the Norwegian Armed Forces. They have established dialogue with several actors abroad, and are paying close attention to developments in Sweden, Finland, the Netherlands, Great Britain, Germany and USA (Informant 2 (Industry), 2019).

In order to attract investors, with the defence market moving so slowly, FieldMade has also looked for additional markets. The military market is still important, and they continue to focus on that, but have also begun looking at the oil and gas industry, where there is a lot going on and things move much faster. Trying to penetrate both those markets is very demanding, but after careful consideration FieldMade has chosen to do so – with things moving so slowly in the defence sector, attracting other investors might be necessary for survival (Informant 2 (Industry), 2019).

The Navy is chronically in short stock on spare parts, which means that production by additive manufacturing could be highly interesting. An important part of the participation on FLOTEX 2016 was therefore to make sure that as many of the important personnel on lower levels, not the admirals and such, but the end users, visited the production facility and were briefed on the capability and potential of AM. The idea was to get people to start ordering parts from the 3D printer, to build a demand bottom-up (Informant 7 (Armed Forces), 2019).

5.4.3. Main findings on market formation

The Norwegian Armed Forces' procurement processes are primarily adapted to acquiring large systems with long life spans. This makes it difficult for smaller new technology, often with frequent incremental updates, to gain access and enter into those procurement processes.

Introducing cutting edge technology with entirely new types of capabilities can mean freedom to define your product, but at the same time it can mean that you have to establish a new niche, and have to convince potential customers that it would serve a purpose – before there is a defined user demand for it. Achieving such a radically low weight and small size, the Black Hornet was something so entirely different that this likely helped establish such a new niche, both at home and in foreign markets. While the Black Hornet already is a commercial success, FieldMade began it journey many years later and has yet to sell its first unit. But FieldMade also adheres to a long-term strategy of helping the customer realise there is a need for the 3D printing product they are developing, such as educating the customer on the possibilities that additive manufacturing brings.

Uniqueness means that there is no prior demand. That calls for long-term efforts to prepare the ground for users defining needs, developing concepts for use, approving funding and so on. With the US military this took 9 years. And with the Norwegian Armed Forces it took 6-7 years. With the British military it was different. The British Armed Forces had an operational requirement, and the Black Hornet delivered a solution. It took a little more than one year from the first meeting to contract signing. The Norwegian market is too small to secure substantial revenue, so the British contract clearly helped Prox Dynamics financially. Another effect was also very important: The British purchase meant that a pilot customer was in place, validating usefulness and relevance of the product. FieldMade also realises the limited potential in the Norwegian military market and are looking at foreign markets as well for potential customers – trying to capitalise on the interest the R&D funding from MoD implies.

FieldMade is also looking towards the oil and gas industry for potential customers and investors. Such a dual focus is demanding, but the slow progress in the military venture makes it worth the risk; attracting other investors might be necessary for survival. The long-winded military processes represent a huge risk for small start-up companies. And as a consequence, the Armed Forces risk missing out on opportunities, if promising new technology companies go bankrupt before they can deliver their product to market.

Military application for a product means special military approval regimes. The Norwegian Armed Forces have very strict rules and regulations for airborne systems. At the time, the technical and administrative approval regime was the same for nano drones as it was for large aircraft. That regime was not at all suited for miniature drones, which carry entirely different risk when operated. Getting the Black Hornet approved represented a severe bottleneck for market access in Norway.

Products with a short technical lifespan and frequent incremental upgrades have to fight an uphill battle to gain market access within the Armed Forces, where approval time can be longer than the systems lifespan. A more expedient procurement process would be favourable for the industry, but also for the Armed Forces – in order for them to benefit from rapidly developing technologies.

Early user interaction can come at a cost; seeing the flaws in early versions might have dampened user interest a little, resulting in less of a bottom-up demand than Prox Dynamics might have hoped for in the Norwegian Armed Forces. But uphill struggle sometimes pays off; when the Norwegian Armed Forces eventually procured the Black Hornet, it was probably more a result of a bottom-up pressure having built up over time than of top-level engagement. There was little interest in the MoD, and no doctrine or vision on military top-level that called for that type of capability. FieldMade proceeds in a similar fashion, using field testing as an arena to make the product known for potential future users. Involving users in testing also helps those users assess when the technology is mature and ready for procurement.

3D printing has been around for a while, but it has not been on the radar for the Armed Forces, before FFI's project caught the MoD's interest about 5 years ago. And FieldMade's strong focus on the military applications might contribute making 3D printing seem more relevant for the Armed Forces.

The US military market seems more "entrepreneurial", in that they are more willing to gather experience and adapting incrementally as technology evolves, wanting to make sure they don't miss out on promising technologies or products. In the face of new technology, Norwegian Armed Forces are more conservative, they prefer to see success before they commit to buying. Being so much smaller and with fewer systems, the Norwegian military should have the potential to be more agile in their approach to new technology.

Prox Dynamics had opportunities to pursue markets other than the military but stuck with their vision of delivering a nano-drone for soldier use.

5.5. Legitimation

Generally speaking, to increase acceptance for new products there is a need for a closer relationship between the Armed Forces and industry actors. The end users need to interact more with those that have the technology and competence to turn that technology into operative capabilities. In the Norwegian Triaxial Model there are two corners that function like well-oiled machineries; FFI and the industry, but the Armed Forces, on the senior officer level that represent the Armed Forces in project management boards, are lagging behind in terms of visons and understanding potential applicability for new ideas. The decision cycle in the Armed Forces is too long-winded to be able to utilise rapidly developing new technology (Informant 3 (Industry association), 2019).

5.5.1. Black Hornet

One researcher at FFI said:

> *"the first time I saw the Black Hornet, the craft itself seemed pretty useless, more of a plaything than something that might have military use".*

But there was something about the person presenting it. He had already successfully developed and industrialised miniature helicopters for the toy market and had sold a substantial number of units; a big commercial success. He had both the technical genius of the inventor and demonstrated acumen in business matters. He came across as someone who knew what he was talking about and was worth listening to (Informant 1 (FFI), 2018).

Petter Muren, the miniature helicopter entrepreneur, had assembled a small team of people with different specialised competencies to form Prox Dynamics AS. Between them, this small handful of people ensured in-house deep knowledge of helicopter mechanics, technical know-how, administration, communications- and electronics development, and signal processing. Without doubt, they were on the cutting edge of all relevant technologies. And that was important, because what they intended to do had never been done before. No one else offered anything with the capability of conducting close reconnaissance – to see what or who is on the other side of the next-door building – the way Prox Dynamics aimed to do (Informant 1 (FFI), 2018). The fact that Petter Muren, some years prior to establishing Prox Dynamics, had worked as a consultant for AeroVironment (a US manufacturer of UAS systems) on a DARPA project, building further expertise on what could be possible in the realm of nano UAS, also helped underpin the credibility of Prox Dynamics in the eyes of FFI researchers (Informant 8 (FFI), 2019).

FFI researchers often meet people who have what they feel is a great product idea that they want to pursue. Most times they fail to convince FFI that they can actually pull their project off and see it through to a finished product. But in the case of Prox Dynamics, it was soon clear that they knew what they were doing. They demonstrated the ability to build miniature helicopters and miniature cameras, they had the radio link, and they knew how to combine these and build a nano UAS. And they had a sound business plan and development plan, and they consistently delivered results according to their progress plan. Over the whole period, they only fell behind on one occasion, due to some hardware issues, but the rest of the time they demonstrated new features on time, give or take a few days (Informant 8 (FFI), 2019).

When first exposed to the early version of the Black Hornet, the military units had no prior ideas about what this could be or do and had not defined a need for that specific capacity. But upon seeing it, one informant recalls that an important first impression was that some of the technology involved was very impressive; the communications link. That component alone was interesting enough to motivate them to contribute as much as they could to help develop the product further (Informant 11 (Armed Forces), 2019).

Soon thereafter, this unit realised that the size and the speed, providing the capability to fly very close to the target area, combined with the picture quality and ease of use made this a unique product – nothing else could do what it could do. They quickly concluded that "we need this. This is good" (Informant 11 (Armed Forces), 2019).

In the early stages of the cooperation between Prox Dynamics and FFI, SOF units were approached and asked if they would like to take part – "we have this technology, could this be interesting for you guys?" – and the personnel quickly responded that it looked very interesting and they wanted to take part, and that contributed to the legitimacy of the development project (Informant 13 (Armed Forces), 2019).

Many units in the Armed Forces are interested in UAS, and personnel directly involved can be said to constitute a UAS community within the Armed Forces. This community became involved in the Black Hornet project in an early phase. And just like FFI with their scientific/research-based technical know-how acknowledged the potential in the project and through that helped build legitimacy, interest from the UAS community represented another facet of legitimacy (Informant 13 (Armed Forces), 2019).

When Prox Dynamics first travelled to the USA to present their project, they made a point of their cooperation with FFI, because FFI represented an important actor in the home market, and through that lent credibility to the project. Likewise:

> *"having the FFI on board, with researchers/scientists to refer to, was probably a decisive factor in getting access to the British system so quickly" (Informant 4 (Industry), 2019).*

In May 2011, The British hosted a field test experiment where Prox Dynamics demonstrated the Black Hornet. A researcher from FFI was present as an observer, and he was impressed with the dramatic improvements made over just a few months. During this period the FFI researcher became convinced that this would become a viable product (Informant 8 (FFI), 2019).

5.5.2. FieldMade

One possible use for the additive manufacturing container from FieldMade could be to complement the current container-based workshop solution in use by the war damage repair unit, where it could be used to manufacture parts for temporary use when something brakes – until the correct spare part can be obtained. For this type of articles and usage, a simplified approval regime might be possible, lowering the threshold for acquiring an additive manufacturing container and putting it into production (Informant 10 (FFI), 2019).

FFI has entered into an agreement with Hägglunds[13], the producer of the CV-90 combat vehicle used by the Norwegian Armed Forces. With this agreement, FFI seeks first to get Hägglunds involved in identifying a number of parts on the CV-90 that could be produced using AM. The next step is to manufacture those parts and test them in FFI's laboratories to document the quality and then to compare with original parts. Hopefully, this will help demonstrate that additive manufacturing can produce components that are good enough for use. It would not be "final proof", that would require fully developed quality assurance regimes and establishing

[13] BAE Systems Hägglunds is based in Sweden and provides and upgrades vehicle systems for both military and civilian use, including combat vehicles. (https://www.baesystems.com/en/our-companies/our-businesses/platforms-and-services/locations/sweden#, accessed 2019-07-24)

standards and so on, but it would be a step on the way to making users and bureaucrats realise that additive manufacturing could work (Informant 10 (FFI), 2019).

With traditional logistics, the supply chain for a spare part can be very long, from the manufacturer to the end user. For instance, if a part on your vehicle brakes down in a desert far away, it can probably take up to a month to move the spare part from a warehouse somewhere in Europe, via different intermediate locations, to the country you are in and then out to your exact location. Having the capability to manufacture that part in a container on the spot could reduce that time period to maybe one day, and that is quite a revolution. Making the relevant personnel realise that additive manufacturing could be an improvement this radical, would help justify spending time and resources on development (Informant 12 (Armed Forces), 2019).

FieldMade's first application for R&D funding was rejected by the MoD, but with very clear feedback on why and on how to proceed to have a better chance at getting the next application approved. That process took some time but ended up being a fruitful dialogue that FieldMade learnt a lot from. In addition to the written project presentation applicants are put in front of an interview panel and cross examined so that the MoD can learn as much as possible about the project, and better assess the credibility of the project, and the people behind it. Such a thorough process at the same time helps to start building legitimacy, by making the decision-makers knowledgeable about the technology and the product. And having been vetted in the application process also means that it becomes easier to engage Armed Forces personnel when the time comes for user involvement and testing (Informant 12 (Armed Forces), 2019).

During the field testing as part of FLOTEX 2016, an effort was mad to engage weapons technical officers and engineers and have them order parts they needed, so that they could see and experience the potential, and that way contribute to building legitimacy for the concept of 3D printing from the bottom up (Informant 7 (Armed Forces), 2019).

Convincing the Norwegian Armed Forces, the desired buyer and end user, to believe in the product and initiate procurement processes is ultimately up to FieldMade. Their efforts to do so likely benefit from the collaboration with FFI, and also from the project management group that oversee the R&D project funded by the MoD. And to convince the uniformed personnel, FieldMade has taken part in a number of field exercises to demonstrate up close how their concept works (Informant 2 (Industry), 2019).

5.5.3. Main findings on legitimation

The Armed Forces, on a system level, are not good at seeing potential in new ideas. The decision cycles are too slow to be able to exploit rapidly developing new technology. This means that legitimacy for new products does not come easily.

While the earliest version of the product itself seemed quite useless, the credentials of the inventor (tech genius and business acumen) and the way he represented himself and his product made FFI interested. Previous involvement in a DARPA project also spoke to him having relevant insights into possibilities for nano UAS. His credibility translated into legitimacy for the product.

The core team involved in developing the Black Hornet was a very good mix, their individual competencies in sum represented the cutting edge on relevant technologies. This level of talent made their attempt at building something no one else had accomplished appear realistic, and underpinned legitimacy for the project.

Prox Dynamics' level of consistency in delivering on promises for progress in the development contributed to build legitimacy for the project at FFI, where many other actors visit with ideas and plans, but fail to convince that they can accomplish what they set out to do. The sheer speed with which Prox Dynamics improved their product during development also impressed FFI, convincing them that this would become a viable product.

The Black Hornet represented something so new and different that it initially didn't fit with any known user needs, but one component alone was so impressing that one of the SOF personnel involved in testing instantly became very interested in contributing to develop the product further. Soon thereafter the Black Hornet convincingly demonstrated its potential, and the user group felt that "we need this, this is good!" Those early positive signals from the SOF community likely contributed to legitimacy, as did the interest from other personnel in the "UAS community" in the rest of the Armed Forces.

Likewise, FFI's level of competence on UAS gives them a certain standing, and their acknowledgement of the Black Hornet project also contributed towards legitimacy. Having FFI involved helped Prox Dynamics penetrate other markets; having FFI on board was probably a decisive factor in getting access to the British system so quickly.

Quality assurance might represent a challenge for FieldMade's project, but a loophole could be emergency repairs for short term use, as a simplified approval regime might be possible for that scenario. Seeing opportunities instead of hindrances might encourage belief in the project.

Involving end-users and letting them experience the benefits from additive manufacturing builds legitimacy at a grass-roots level. And having FFI involved likely contributes to convincing personnel higher up in the system.

Involving producers of the larger systems, such as Hägglunds, in quality assurance research might increase the likelihood of convincing users and bureaucrats of the viability of the 3D printing container solution.

Additive manufacturing of spare parts can radically cut time, producing on the spot, when the need arises, instead of having to rely on a very long logistics supply chain. Making the right category of personnel, the decisionmakers, understand this would help build legitimacy for the concept.

The application process for R&D funding from the MoD is very thorough and includes both a written application and an oral Q&A session. This means decisionmakers become quite knowledgeable about the technology and the product, which also helps build legitimacy for it. Such a rigorous vetting procedure also builds legitimacy for the product with possible users.

5.6. Resource mobilisation

Innovation, research and development have several potential sources for funding in Norway. The Research Council of Norway and Innovation Norway have been mentioned briefly already, in chapter 4.4.1 on actors, as institutions that can provide funding for R&D and innovation, as well as helping through a tax incentive scheme. The Norwegian Armed Forces also has its own system for funding Concept Development & Experimentation, or Innovation and Experimentation (I&E), as the arrangement is currently called. I&E funds are typically granted for activities that seek to understand and exploit opportunities that existing technologies and systems provide, through new and smarter use. Another potential source for early funding through the Armed Forces is what is called "risk reducing measures" (previously known as pre-project funding); typically used in early stages to investigate whether a suggested project should be pursued.

When development or procurement projects are approved, funding is a part of the approval. Although the Armed Forces and the MoD operate according to long-term plans, funding is subject to annual budget processes. A consequence of this is that if something more urgent arises, funding for a project can be postponed due to changed priorities. In the perspective of the MoD, the money isn't taken away, but from the perspective of a user, who helped speed up the process of identifying and articulating a demand, years can go by with no tangible result (Informant 13 (Armed Forces), 2019).

For the Norwegian Triaxial Model to function better for rapid development processes, it would be beneficial to have the Armed Forces become more engaged. But therein lies the problem; the Armed Forces don't really have any money for that sort of activities. The have some R&D funds, but in the grand scheme of things those funds are loose change. The real money belongs to the Ministry of Defence and the Norwegian Defence Materiel Agency. Whenever a need for something is identified, it has to go through a bureaucratic process of prioritisation, in a system built for long term planning. Many of the people involved would likely welcome a system adjustment that more easily allows for "ad-hoc procurement" or "urgent operational requirements" (Informant 5 (NDMA), 2019).

An example of the challenges with mobilising funding for fledgling projects is "Hacking4Allies", a hackathon held in the USA where participants were invited to present solutions for some identified problems. Businesses that engage have no guarantee that they will receive funding, even if they come up with a promising idea. The Armed Forces simply cannot demonstrate that there are development programs, with funding, that are prepared to help bring their idea to fruition (Informant 6 (Innovation Norway), 2019).

The current system for funding development of promising new technology from an early stage is not optimal. Available R&D funding, for instance, is nominally smaller today than it was two decades ago. The government budget system leaves little room for free funds, but there is *some* room.

> *"If we wanted to prioritise making money more easily available for funding such projects, it would be possible, the Ministry of Defence has the authority to do that."*

And this issue is continually discussed, but the fact of the matter is that R&D is often the first budget post to see cuts whenever money is short. And instead of cutting projects, there is a tendency to spread them out in time – making reprioritising – which is already difficult – even harder. (Informant 14 (MoD), 2019).

5.6.1. Black Hornet

The Black Hornet project was very a-typical, in that they had a financial platform that enabled them to go for it. That success would never have been possible if it had depended on funding from the Armed Forces – the product would have never seen the light of day. For the Armed Forces to spend money on something, they prefer that it has already been through the entire process of approval. That makes it nigh impossible to develop a product that is ahead of the curve as far as technology development goes, a product that continually improves as technology evolves during its development phase (Informant 3 (Industry association), 2019).

At FFI 3-5 researchers were involved in the Black Hornet projects with Prox Dynamics, with some variation in how many work hours. FFI's contribution was funded by the MoD, both in terms of purchases made and work hours covered (Informant 1 (FFI), 2018).

Activity in the units involved in user testing and feedback was carried out as part of everyday operations, as the units found it to be in their best interest to take part because they deemed it likely to produce results they were interested in (Informant 13 (Armed Forces), 2019).

Prox Dynamics was founded with money from Petter Muren and one external investor, Geir Førre, who, in addition to having money, also knew how to navigate the public funding system. Innovation Norway had a concept where they would provide part of the funding for the development of a new product if some criteria were met. The financial part of these criteria was that if the industry actor (Prox Dynamics) managed to secure a demanding customer that would cover 1/3 of the project cost, Innovation Norway would cover half of the industry actor's 2/3 of the sum total. In the case of the Black Hornet, the MoD provided 1/3 of the funding, which was primarily used to cover FFI's involvement. FFI, in turn, provided both man hours from its own researchers and access to a reference group (users/testers from the Armed Forces) – including travel cost and so on for probably about 20 people. The total cost for this first phase of development was approximately 20 million NOK, where Prox Dynamics, Innovation Norway and the Ministry of Defence covered 1/3 each. This covered early development, but Prox Dynamics spent a lot more than that to complete a marketable product (Informant 4 (Industry), 2019).

At a later stage, after presenting their product to representatives from the US Armed Forces, Prox Dynamics entered into two separate contracts with NSRDEC (the US Army Natic Soldier Research, Development and Engineering Center), which secured funding for further development (Informant 4 (Industry), 2019).

During 2008 Prox Dynamics grew from 4 to 6 people employed, and a few more were hired early in 2009. When Innovation Norway came aboard with funding, in 2009, their demonstrated interest helped secure more funding from more investors. And that would not have been possible without the collaboration with FFI and the Norwegian Triaxial Model; that was the catalyst for raising more funds and being able to hire more people (Informant 4 (Industry), 2019).

Investors in this market tend to think that if you are not interested in paying part of the development cost, you are not really interested in the finished product. That is why it is so important to have the demanding customer underpin their expressed interest through contributing money. And when an industry actor applies for funding from the MoD, some of that funding will go to FFI. What the MoD does, in reality, is to make FFI researchers time available for that company (Informant 8 (FFI), 2019).

When it comes to human resources, it was important to get people with the right combination of technical know-how and personality to ensure smooth and quick progress. At first, recruitment was done exclusively through the personal networks of the founders, so most of the early hires were personnel they knew from Tandberg (in 2010 Tandberg was purchased by Cisco Systems). At a later stage, an interesting symbiosis formed between Prox Dynamics and Teknisk Ukeblad (TU)[14]. TU found the Black Hornet project very interesting, and it frequently printed articles about it that were widely read and thus important for TU, and which in turn generated a lot of interest in Prox Dynamics. So when Prox Dynamics eventually started recruiting outside their own networks, TU was frequently used as a channel (Informant 4 (Industry), 2019).

After the May, 2011 tests already mentioned in chapter 5.5.1 FFI initiated a meeting with a project coordinator in the Norwegian Army Staff to discuss the status quo, and at that meeting they agreed that it was time to initiate proceedings aiming at acquiring the Black Hornet for the Norwegian Armed Forces. This paved the way for a Concept Development and Experimentation phase, which was how funding was secured so that FFI could purchase 10 sets to be distributed to various units for testing (Informant 8 (FFI), 2019).

However, obtaining MoD funding for industry development is a process entirely separate from the procurement process: A MoD decision to support industry development does not

[14] Teknisk Ukeblad is a Norwegian monthly publication and a website (www.tu.no) that focuses on technology for business. (annonsere.tu.no/about-tu-no, accessed 2019-07-17)

automatically mean that a potential procurement project is initiated. And it is procurement that will keep a business alive over time. Oftentimes, development is supported, without being followed up by procurement, and the project dies.

> *"If a development is successful, the industry actor should not have to risk bankruptcy while waiting for a potential procurement process, so it might have been smart to have a closer connection between the two processes"*
> *(Informant 8 (FFI), 2019).*

The Norwegian Armed Forces are at any given time involved in a large number of procurement processes, some are at an early stage, others are further along the way, and some are ready for the NDMA to sign binding contracts with industry actors. In the summer of 2014, the contracts ready for signature amounted to much more money than was available. So much more, that if they had all been signed, it would have meant committing more funds than the Armed Forces were allocated for the next 2 years. It was simply too much, and led to a very tough prioritisation process to identify which contracts should be entered into at the time (Informant 13 (Armed Forces), 2019).

5.6.2. FieldMade

Part of FFI's funding is called *basismidler*; basic funding. This part of their funding has few strings attached and is meant to secure the independence of R&D research and provide room for long-term research and/or competence building (Forsvarsdepartementet, 2013, p. 13). In 2015 FFI was beginning to look into spare parts for military units in the field, but only in the form of a feasibility study, with no funding to actually invest in materiel and start building something. The effort was, in practice, voluntary work by a few very interested individuals. They soon realized that a purely theoretical discussion on additive manufacturing could go on "forever", and that they had to find a way to start building and experimenting (Informant 2 (Industry), 2019). Near the end of 2015, it turned out that there was some money available in FFI's budgets, and the enthusiasts involved applied and were granted approximately 800 000 NOK. This enabled them to buy a cargo container and other necessary equipment, and early in 2016 a demonstrator version of the deployable additive manufacturing concept was ready (Informant 10 (FFI), 2019).

> *"We bought a container and an expensive 3D printer, the rest we borrowed and stole from others at FFI, and built a mobile production facility with 3D printing" (Informant 2 (Industry), 2019).*

After testing the container on exercise Cold Response 2016, FFI began working with Kjeller Innovasjon to get a project accepted into Research Council Norway's FORNY2020-program, in order to fund a bigger effort towards developing a commercial solution. In this process, several different technologies and possible uses were considered, but in the end the focus was put on the additive manufacturing concept for production of spare parts under field conditions (Informant 10 (FFI), 2019).

Early summer 2016 Kjeller Innovasjon and FFI entered into a contract where they agreed on a joint project to commercialize a concept for AM. The contract regulated rights and responsibilities, such as IPR, management, compensation and so on. In essence, FFI were responsible for R&D, while KI were responsible for business development. An application for funding was sent to FORNY2020, and when funding was granted, KI established the company FieldMade AS (Informant 10 (FFI), 2019).

Resource mobilization internally at FFI became a challenge when, at one point during the process, responsibility for FFI's involvement was transferred from a research division at FFI to FFI's Prototype Workshop (PW). This has to do with how FFI handles project funding; the PW was not part of a research division, and therefore had no independent access to research funding. The PW, as a supporting unit, typically provided services to the research divisions based on need arising in their research projects, and have, traditionally, not had research projects of their own. When the responsibility was transferred, the intention was to establish a project that would fund activities at the PW, but with limited funds, the research divisions simply could not prioritize allocating money to what was now, essentially, a Prototype Workshop project. The Prototype Workshop kept trying, helped by the Innovation and Industrial Development Division (IIDD), and eventually (in 2019), IIDD managed to provide 1 million NOK to support the Prototype Workshop efforts on additive manufacturing and FieldMade, especially their work on verification of the quality of 3D printed parts – which is essential to prove the viability of spare parts produced with additive manufacturing technology (Informant 10 (FFI), 2019).

Based on the feasibility study, the prototype and experiences gained through participation on field exercises early in 2016, an application was sent to the FORNY2020 program in the Research Council of Norway. FORNY2020 granted around 10 million NOK, to be paid out in installments over 2 years. This should sustain FieldMade operations for 2 years, from summer 2016 through summer 2018, during which they would work on developing their container-based solution, called NOMAD microfactories. The final installment in 2018 was withheld from FORNY2020. Details regarding what happened with that last installment is not available to me, informants were not at liberty to discuss them. But by that time, FieldMade had entered into deals with subcontractors for containers, 3D printers and other equipment. When the final installment from FORNY2020 didn't come through, 2018 became a very challenging year for FieldMade, financially (Informant 2 (Industry), 2019; Informant 10 (FFI), 2019).

During this period, the people working at FieldMade bought the company from Kjeller Innovation, thereby taking over the financial commitments made to subcontractors.

Early in 2018 FieldMade applied for R&D funding from the MoD. The first attempt did not yield any money, but through the application process FieldMade gained knowledge about what it would take, and some guidance on how they could proceed in their endeavour (see brief discussion in chapter 5.5.2), and when a renewed application was forwarded, the MoD accepted it, and an R&D contract was signed with the MoD in May 2018 (Informant 2 (Industry), 2019; Informant 10 (FFI), 2019).

By now, summer of 2018, FieldMade had progressed to a level of maturity that placed them somewhere between the early stages that the Research Council of Norway would fund and a commercially viable product. Time had come to seek help from Innovation Norway, which they did, and their application was well received. From fall 2018 FieldMade operations were funded 1/3 by the R&D contract with the MoD, 1/3 with money from IN, and 1/3 with private investments. The private investments were partly made by those who bought FieldMade from Kjeller Innovation, and partly by new, external investors (Informant 2 (Industry), 2019).

NATO's Allied Command Transformation, already interested in the product being developed, also made a small financial contribution. ACT did not invest in the company as such to finance development efforts, but it did cover some costs related to transporting personnel and materiel to take part in field exercises and thus helped provide an arena for demonstrating the capability and get feedback from potential users (Informant 10 (FFI), 2019).

Human resources are also important for a young company trying to develop something new, and through having connections at NTNU FieldMade managed to get a student to write a master's thesis on a relevant topic. This helped in knowledge development, but also served as part of a recruitment process – after finishing the thesis, that student came to work at FieldMade (Informant 2 (Industry), 2019).

To broaden their potential customer base, and their potential investor base, FieldMade has also started to look towards civilian industry. Based on the assessment that there are many synergies to be found if combining the military market with the oil and gas industry, FieldMade is also looking towards that market. At the time of writing this thesis, this work is in its very early stages, and nothing concrete has materialized yet. Having successfully utilized the available public funding agencies in Norway in the different phases so far, those sources are likely exhausted for FieldMade, and the strategy for the future is to seek venture capital (Informant 2 (Industry), 2019).

Worth noticing about the public funding mechanisms is that the Research Council of Norway is tuned in to be part of early stages of development, that phase when there is a lot of insecurity, where research and knowledge development is the main effort, while Innovation Norway focuses more on the commercialization processes. On paper, this presents as being a reasonable division of responsibilities and should facilitate a smooth transition between the two main actors in public funding of bringing an idea to market. However, in reality the gap between the two can be trickier to navigate. One challenge for a budding company is that bureaucracy takes time, which means that many months passed from the FORNY2020 application was granted in the spring of 2016 to a contract was signed and funds released late fall 2016. Another challenge is the phase of transition between support from the Research Council of Norway and support from Innovation Norway. For FieldMade, they ended up in a situation where, towards the end of the two-year contract with FORNY2020, FieldMade was at a technology readiness level that was beyond what the Research Council of Norway typically funded – they were too close to commercialization. Innovation Norway, on the other hand, wanted to support commercialization, but FieldMade were not quite there yet. FieldMade had come too far along for the Research Council of Norway, but not quite far enough for Innovation Norway. In an effort to bridge that gap, FieldMade sought the R&D contract with the Ministry of Defence, but when their first attempt was dismissed, dire straits lay ahead. Luckily, their second attempt secured a R&D contract with the Ministry of Defence (Informant 2 (Industry), 2019).

5.6.3. Main findings on resource mobilisation

Getting a development project approved by the MoD/the Armed Forces include funding. But although plans are long-term, funding is subject to annual budget processes. This makes projects vulnerable for changes in priorities. Funding isn't cut but can be postponed for quite some time. This can prove a challenge, especially for smaller businesses and start-ups, who typically do not have the financial resources to tolerate long delays.

The military funding system is part of long-term planning. For rapid versions of the Norwegian Triaxial Model, the Armed Forces should probably become more engaged, but they do not really have money available for that type of activities. System adjustment towards more room for "ad-hoc procurement" or "urgent operational requirements" would likely be beneficial.

Interestingly, available R&D funding is nominally less today than two decades ago. And R&D is often the first budget post to suffer if money is short. The MoD has the necessary authority to prioritise R&D through allocating more money. In addition to budgets being tight to begin with, there is a tendency to postpone projects, instead of cutting them, when there is a problem with money. And as a consequence, re-prioritising becomes even harder later on.

Sometimes there is money left near the end of a budget period. For the FieldMade project, this was the case when FFI had some money available near the end of 2015, which was used to purchase a container and a good 3D printer. And the resourceful 3D printing enthusiasts at FFI managed to "steal and borrow" some additional equipment from various units at FFI and were able to build a demonstrator.

At one stage, responsibility for additive manufacturing research was transferred from a research division at FFI to the prototype workshop at FFI. Due to the way FFI was organised, the latter had no funds for such research, and progress slowed down until one of the research divisions eventually provided funding to the prototype workshop. This shows how "location matters", not only in the real estate business.

The Armed Forces tend to prefer something to be fully vetted before funding it, making it difficult to get funding for a project that is on the cutting edge of technology and keeps improving in lockstep with technological developments.

FFI's involvement in the Black Hornet project was funded by the MoD, covering both purchases and time spent by researcher. Users in the different units in the Armed Forces primarily contributed with their time and expertise. It seems likely that the units did not make any special considerations about how to fund their involvement, probably because their primary cost was in terms of hours spent, and that the activity was deemed to be relevant for exploring interesting new technology and possibly also new ways of conducting operations.

Prox Dynamics had private funding, and one investor was well versed in utilising public funding. Through getting the MoD onboard as a "demanding customer", Prox Dynamics managed to secure 6-7 million NOK from Innovation Norway in 2009. At a later stage, Prox Dynamics also secured research funding from the US Army.

The public funding available through the Research Council of Norway is meant for early stages of development, where R&D is the focus and insecurity is high, while Innovation Norway is tuned towards the commercialisation phase. On paper, this is a good model, but the reality is less seamless. Firstly, there is a significant lag between funding granted and funding received, and secondly, the gap between what the Research Council of Norway covers and what Innovation Norway covers can be challenging. FieldMade AS found themselves very vulnerable in that gap; too far along for the Research Council of Norway, but not quite far enough for Innovation Norway. The R&D contract with the Ministry of Defence fortunately covered that gap.

Through a collaboration between FFI and Kjeller Innovation, funding from Research Council Norway was secured, and FieldMade AS was established in 2016. Securing funding from the Research Council of Norway was a great achievement, but it was to be paid out in instalments, and when the last instalment didn't come through 2018 looked very challenging for FieldMade AS financially. A process to get funding from the MoD during the spring of 2018 paid off, and by summer a R&D contract provided money for further activities. And based on the commitment from the MoD and private funding, FieldMade AS also managed to secure funding from Innovation Norway, helping them further towards commercialisation.

Private investors want to see a customer that is interested enough in the product to cover part of the bill. Entering into the Norwegian Triaxial Model and having FFI and Innovation Norway involved helped Prox Dynamics secure more private investors.

During the "financial crisis" in the Armed Forces in 2014, a lot of projects were shelved or not initiated, which can illustrate how forces entirely external to any single Norwegian Triaxial Model project might have severe impact on progress and introduce financial risk for industry actors. Even under normal circumstances, the Ministry of Defence giving financial support for a development project does not mean that procurement will follow. Closer ties between development funding and procurement processes might be beneficial, so that industry actors who succeed in their development don't risk bankruptcy while waiting for a potential procurement process. The lack of a connection between development and procurement probably contributes to firms being less inclined to engage when invited to come up with new ideas and solutions.

Resources in terms of competent personnel was, by both Prox Dynamics and FieldMade, sought out through personal networks in the early days. For Prox Dynamics, a strong interest from a leading “technology for business” publication, “Teknisk Ukeblad”, was beneficial; it secured quite a lot of publicity, and later it also served as a recruitment channel.

5.7. Development of positive externalities

5.7.1. Black Hornet

After seeing the success of the Black Hornet in the Norwegian Triaxial Model, several other Norwegian UAS firms have contacted FFI and presented their ideas, trying to initiate a Triaxial collaboration to develop these ideas into products. These are probably capable people, but none of their projects have been promising enough for the FFI to engage in a collaboration (Informant 1 (FFI), 2018).

Whenever FFI researches visited Prox Dynamics, there seemed to be more offices, more people, bigger labs, ever more packages of drones ready for delivery, than the last time they visited. While industry development was not part of the job for the FFI researchers directly involved in the Black Hornet projects, they learned a lot about it, and found it very interesting to see how Prox Dynamics evolved during the process (Informant 1 (FFI), 2018).

A major challenge during the procurement process was that the Norwegian Defence Materiel Agency’s (NDMA) procedures for technical approval of new systems were extremely complicated and rigorous – the procedure was the same for a nano UAS as for a full-size aircraft such as the NH-90 helicopter or the Hercules transport aircraft. These approval procedures are important, as they among other things are there to ensure that safety is upheld, and so they focus a lot on risks involved in operating the equipment. But the risks involved in flying a 18 gram nano UAS are quite different from those of operating a NH-90, and following the exact same procedures for technical approval resulted in a massive amount of work to push the Black Hornet through. And on top of that, the office responsible for approving new aerial systems is a quite small one, with limited capacity. Primo 2019 a new, simplified, procedure for approving small UAS was approved, making it a lot easier to get the thumbs up for this type of system in the future (Informant 13 (Armed Forces), 2019). While my informant did not state that the new procedures are a direct result of the Black Hornet project, it is likely that it has been a case that has helped when the UAS community in the Armed Forces have been pushing for such simplified procedures.

The close collaboration with FFI was a decisive factor for how rapidly Prox Dynamics established a working relationship with the British. A positive effect of this relationship for FFI was that it helped secure a cooperation agreement between FFI and the British Defence Science and Technology Laboratoy (DSTL) on nano UAS that let them discuss experiences, analyses and assessments (Informant 4 (Industry), 2019).

Some of the components for the Black Hornet are purchased from Asia, where some of the few mega-factories that make them are, but a lot of the parts are also made or assembled in Norway, so there are some ripple effects in Norway (Informant 8 (FFI), 2019).

The collaboration on the Black Hornet opened up the nano UAS-field for FFI, contributing to developing new knowledge in a milieu that is primarily busy with slightly bigger unmanned aerial systems, thus adding to the total knowledge bank of the FFI (Informant 8 (FFI), 2019).

5.7.2. FieldMade

AM technology is developing very rapidly, both in terms of machinery and types of material that can be used for 3D printing, as well as new actors entering the field and helping drive development forwards. It is likely that future use will include combining hard and soft materials, meaning that more and more possible uses can be explored, in more and more different areas, and the defence sector needs to develop knowledge and stay up to date. Actively taking part in this development through acquiring equipment and researching possibilities and uses is beneficial for FFI as a research institution that is meant to serve current and future needs of the Armed Forces. The collaboration with FieldMade has been a driver for this field at FFI (Informant 10 (FFI), 2019).

One challenge for FieldMade has been that because of the explicit focus on the defence sector, some other actors in the field of additive manufacturing technology have been unwilling to enter into cooperation projects or even sell parts to them. Nevertheless, among the very few actors in Norway that are actively pursuing 3D printing as a business model or are doing academic research on the topic, there has been a general willingness to discuss and share experiences (Informant 2 (Industry), 2019).

5.7.3. Main findings on development of positive externalities

After Prox Dynamics' success with Black Hornet several other Norwegian firms have approached FFI with ideas for UAS projects. So far, no one have presented ideas promising enough for FFI to engage in a collaboration. Even though no new UAS projects have been initiated in the Norwegian Triaxial Model, this indicates that one success story can inspire others to try.

Working so closely with Prox Dynamics taught FFI researchers a lot about industrialisation. The experiences from this collaboration could be useful for the new "Innovation and Industrial Development Division" that FFI established at the beginning of 2018.

Pushing a new technology or product through the extremely rigorous and comprehensive procedures for technical and administrative approval of flying equipment clearly demonstrated the need for a simplified routine for approving small, lightweight UAS, which can be operated with significantly less risk. Today, new procedures are in place.

A positive side-effect of being involved in the Black Hornet project is that it opened up the field of nano UAS for FFI, a segment of UAS they had not looked into before. Another positive outcome for FFI is that it led to signing a collaboration agreement on nano UAS with its British counterpart.

Likewise, the collaboration with FieldMade has been a driver for further research into additive manufacturing at FFI, something that will most likely be positive for FFI's role of continuously serving current and future needs of the Armed Forces.

Of course, several sub-contractors manufacture different parts that are used when building the Black Hornet. The same is the case for FieldMade's production of additive manufacturing microfactories, albeit on a smaller scale, as FieldMade have not started large scale production.

One negative effect of focusing on the defence sector is worth mentioning. FieldMade has experienced that some other actors are unwilling to enter into projects or even sell them parts for use in their production. This indicates that, at least for some actors, affiliation with the defence sector is in some form seen as undesirable.

6. Conclusion

The aim for this master's thesis was to examine how the Norwegian Triaxial Model functions for innovation projects that fall into what I have called the "fast-track" category; the ones where new defence systems are developed based on available commercial technology. The research questions are:

- How do the actors "play their part"; what are the different actors' roles and contributions to innovation in this version of the Norwegian Triaxial Model?
- Which drivers positively contribute to innovation and which barriers hamper progress for innovation in this version of the Norwegian Triaxial Model?
- What can be done to improve this version of the Norwegian Triaxial Model?

In the conclusion I will present the results of my research, organised according to the three research questions.

6.1. How do the actors involved play their part?

I have assessed each actors' contributions in light of the seven functions described in the theoretical framework. The results will be briefly commented here and summed up in an updated version of the table presented in chapter 2.7.

The theoretical framework suggested that FFI and the industry would be the leading actors in developing knowledge, with the user in a supporting role. My analysis suggests that the industry actor should be considered the primary actor alone, with FFI in a strong supporting role, and with the users more in the partially involved category.

When it comes to influencing the direction of search, the empirical findings indicate that reality is slightly different from the hypothesis from the theory chapter. In developing the theory, I likely put too much weight on the Norwegian Triaxial Model's task of serving the needs of the Armed Forces. When innovation originates from seeing potential in new technology more than from a defined user need, it is the "owner" of the idea, the industry actor, that leads the way.

The two cases studied indicate that developing a small and autonomous product makes it easier to experiment in a laboratory setting than developing a product that seeks to integrate with existing systems, which demands more integration with those systems during experiments. Common for both is that the industry actor is the leading actor, and that both FFI and users play supporting roles, but the more integration that is needed, the more important the supporting roles become.

Market formation, at least for products that are so entirely new or different as the two cases studied, is primarily the responsibility of the industry actor: when there is no defined user need, footwork to generate a demand is imperative, and the industry actor has the strongest motivation and must take the leading role. When users involved in testing become convinced of the products usefulness, they play a supporting role through generating a bottom-up demand. FFI is partially involved, through facilitating activities.

While the empirical findings suggest that the Armed Forces are slightly less important for building legitimacy for a product than theory suggested, FFI's role is slightly more important, primarily due to the institutions standing lending credibility to projects it is involved with. The primary source of legitimacy, however, is the industry actor's competence and professionalism, and the performance of the product itself.

Clearly, the primary actor when it comes to resource mobilisation is the industry actor, who must navigate both the military funding possibilities, other public funding options, and attract private investors. The FFI is partially involved, mostly by virtue of lending credibility that helps attract private investors and assure the Ministry of Defence of a products potential. The Ministry of Defence is de facto the supporting actor for this function, as they hold the key to funding that activates a Norwegian Triaxial Model process.

The empirical findings support the theory's proposition that many of the factors in the development of positive externalities function will be more or less unavailable or even non-existent in the context of the Norwegian Triaxial Model. It is primarily actors directly involved in the innovation process that benefit from it, and little effect is observed outside the triangle. The industry actor plays the primary role in this function, and FFI is a supporting actor.

Which roles the actors play is visualised in the following table, where the hypothesis from the theory chapter is shown in grey text and the results from the research is presented in black text.

Function	Theory			Results from research		
	Leading actor	Supporting actor	Partially involved actor	Leading actor	Supporting actor	Partially involved actor
Knowledge development and diffusion	FFI Industry actor	Armed Forces		Industry actor	FFI	Armed Forces
Influence on the direction of search	MoD FFI Armed Forces	Industry actor		Industry actor	FFI Armed Forces	
Entrepreneurial experimentation	Industry actor Armed Forces	FFI		Industry actor	FFI Armed Forces	
Market formation	MoD Armed Forces	Industry actor		Industry actor	Armed Forces	FFI
Legitimation	Industry actor	Armed Forces	FFI	Industry actor	FFI	Armed Forces
Resource mobilisation	Industry actor	Armed Forces	MoD FFI	Industry actor	MoD	FFI
Development of positive externalities	Industry actor	FFI		Industry actor	FFI	

Figure 4: Table showing which actor(s) actually play a leading role, a supporting role, and which actor(s) are only partially involved in fulfilling a given function, contrasted with the expected distribution from the theory chapter.

6.2. What are drivers and barriers in the Norwegian Triaxial Model?

Based on the theory and empirical research, my overall assessment of the Norwegian Triaxial Model is that it is a good framework for promoting innovation in the defence sector.

In section 6.2.1 of the conclusion I will highlight four things that stand out as particularly positive for the overall functioning of the Norwegian Triaxial Model in the way they contribute to how this system can be effective in fostering innovative products that are likely to succeed in the market place; drivers of innovation.

Even well-functioning systems can have some weaknesses. My research has identified four factors that can contribute to making innovation less likely to prosper through the Norwegian Triaxial Model; barriers that can hamper innovation. These will be clarified in section 6.2.2.

6.2.1. Drivers

The first driver is the relationship between FFI and the Armed Forces. A long history of collaboration between FFI and units in the Armed Forces has fostered rapport and trust, which helps make dialogue between FFI and users more effective. They understand each other's needs, capabilities and terminology. This type of lasting relationship serves the Norwegian Triaxial Model well, reducing friction in communication.

The second driver is risk acceptance and entrepreneurial spirit. When FFI, funded by the Ministry of Defence, bought and distributed several units of the Black Hornet to users for testing, they encouraged them to try "everything" and told them that anything short of deliberate destruction of the product is acceptable. This way of signalling a very high acceptance for misadventures likely helps yield rich data from experiments.

The third driver is the fact that potential customers become intimately familiar with a product through testing. This serves the industry actor's need for market formation through helping generate a bottom-up demand for their product. At the same time, it lets users become acquainted with products that might provide new capabilities and inspire new operational concepts, while simultaneously evaluating when that product has matured to a level where procurement should be initiated. This is especially beneficial when a product is so unique that the customer has no articulated need for it.

Last, but not least, involvement in the Norwegian Triaxial Model can contribute significantly to the possibility for international success for a product. The international market for defence materiel is a particularly challenging one, characterised by strong political control, protectionism and limited access for foreign competitors. Being part of the Norwegian Triaxial Model carries with it several benefits that can help penetrate foreign markets: FFI's international reputation as a prominent research institution lends credibility to projects that it is involved with, and the Ministry of Defence's funding of an innovation project through the Norwegian Triaxial Model is a clear signal of approval and recognised potential for both industry actor and product.

6.2.2. Barriers

The first potential barrier is FFI's role as an intermediary between the industry actor and the users involved in testing, as it carries with it an inherent risk that FFI's experience and opinions might unduly influence what is communicated to the industry actor as results from tests. There is only one indication of this *might* being the case in my findings, but since communicating through an intermediary always carries a risk of the message being distorted, it is worth mentioning as something to be aware of.

Secondly, The Norwegian Armed Forces' procurement processes are not well-matched for rapidly developing new technologies, as they are primarily adapted to acquiring large systems with long lifespans. In addition, the Norwegian Armed Forces seem to be relatively conservative, preferring to see a product succeed elsewhere before committing to a procurement process. Procurement processes are so slow that they might take longer than the technical lifespan of products that are on the cutting edge of technology, especially those with frequent incremental updates.

Third, military application for a product also means special military technical and administrative approval regimes, adding to the challenges of establishing a new niche or penetrating an existing one. Existing approval regimes might not be suitable for radically new products, such as the revolutionarily small and light Black Hornet nano UAS, and approval times can then become bottlenecks for innovative progress. It is worth noting here that the approval regimen for nano UAS has been revised as a consequence of the Black Hornet project, but it still serves as an example.

Finally, the Ministry of Defence and the Armed Forces make long-term plans, but funding is still subject to annual budget processes. Changes in priorities can result in funding for innovation projects being put on hold for quite some time, as R&D is often the first budget post to suffer if money is short. And funding for R&D is nominally less today than two decades ago to begin with. Postponements can be very challenging for smaller businesses and start-ups, who typically do not have the financial resources to tolerate long delays.

6.3. How can the Norwegian Triaxial Model be improved?

Based on the results in this study, I argue that there are two areas where improvement would be especially beneficial in order to increase the Norwegian Triaxial Model's ability to support rapid development of new defence systems based on available commercial technology.

The first is that more efficient procurement processes would be favourable for products on the cutting edge of technology, especially those with frequent incremental updates. This can likely be solved through several measures, such as adjusting the procurement process or introducing a new one, increasing caseworker capacity, or perhaps simply educating project managers so that they can navigate existing systems more efficiently.

The second improvement is to introduce a promise of procurement for successful innovations, given that the needs of the Armed Forces do not change during the process. Today, financial support from the Ministry of Defence to a development project does not automatically mean that procurement will follow, even if the industry actor succeeds in developing a good product. Closer integration between development funding processes and procurement processes might be beneficial, so that industry actors who succeed in their product development don't risk bankruptcy while waiting for a procurement process to commence.

7. Suggestions for further research

The offset system, where foreign industry actors that sell to the Norwegian Armed Forces incur an obligation to buy something back from Norwegian industry or contribute in other ways – such as investments or development collaboration – is very complex. Understanding it and navigating it, not to mention having the connections and network to utilise it, is extremely demanding, especially for newly established small businesses. Researching how the offset system could be put to better use in connection with the Norwegian Triaxial Model, and whether there are possibilities that are currently not utilised or could be made better use of could possibly help the Norwegian defence sector maximise the effect of the offset system as well as the Norwegian Triaxial Model.

The procurement process is closely connected to the subject matter studied in this thesis, and it would probably have been fruitful to research it more closely, but time and space constraints make it impossible to fully investigate and analyse the complexity of it here. As shown in the conclusion above, there is likely room for improvement that could benefit the Norwegian Triaxial Model. I would therefore suggest that further research into how the procurement processes function, what roles key actors have and how they are carried out would make an interesting topic for further research in order to further strengthen the Norwegian Triaxial Model.

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