Progress in Additive Manufacturing (2022) 7:1037–1052
https://doi.org/10.1007/s40964-022-00280-z

FULL RESEARCH ARTICLE

Capability development in hybrid organizations: enhancing military logistics with additive manufacturing

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Received: 23 August 2021 / Accepted: 27 February 2022 / Published online: 17 March 2022

Abstract

Additive Manufacturing (AM) has the potential to revolutionize key aspects of Military Logistics and partnerships between governmental and industrial organizations. Extreme outsourcing of key capabilities has created complex and deep hybrid organizations between armed forces and the private sector. In this study, the internal and external effects and requirements of Additive Manufacturing in the context of the hybrid organization of The Finnish Defence Forces (FDF) and its strategic partner in Maintenance, Repair, Overhaul (MRO), and Millog Oy were studied. First, with a literature review, we sought to link the capability development processes and the change drivers within them in both military and commercial contexts. Then, we utilized an existing, structured capability model used by the FDF (DOTMLPFI) and its individual change drivers to form an initial concept of AM as a part of the hybrid organization in question. The initial concept shows that AM can increase the performance of the commercially backed Military Logistic System by mitigating the risks of spare parts shortage in case of supply line disturbances and by facilitating localized spare parts production. However, the different primary goals of the military and commercial organizations and the contractual base of the hybrid organization impose constraints on the capability development process. Administrative decision-making across the organizations and the conflict between maximizing military and commercial potential are the key challenges in maintaining joint-capability systems of hybrid organizations.

Keywords Capability development · Additive manufacturing · Military logistics · Change driver

1 Introduction

If an organization is an entity to serve a specific purpose then "the capability of an organization is its demonstrated and potential ability to accomplish against the opposition of circumstance or competition, whatever it sets out to do" [1] or in reverse, the operating logic of the organization guides its capabilities: their need, development, and existence [2]. In this study, the capability is seen as a holistic representation of all the elements that are related to the new technology Additive Manufacturing (AM). This capability is then applied and studied in the context of Military Logistics, specifically in the acquisition of spare parts.

Additive Manufacturing, according to Meboldt and Klahn (2018), has been referred to as a tool or capability enabling the next industrial revolution. The benefits compared to the conventional production methods are not only limited to the actual manufacturing process, but also to the company's marketing and entire value chain such as storing and distributing of products. The added freedom to the design process and generally a smaller number of steps and time from base material to the finished product makes AM a potential capability to support any organization with production resources of their own [3–6] or a need for them in fulfilling their purpose [7, 8].

AM consists of seven different process classes and utilization in different areas is wide: from space application and aerospace to dental and medical [9–13]. In the logistics chains, utilizing AM has been already shown increased responsiveness [12, 14, 15]. Key barriers delaying the adoption of AM in the production of spare parts are quality

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issues, incomplete material and design knowledge, size of build chambers, and costs and availability of design documentation [16, 17]. By solving these issues, AM has the potential to become a competitive-edge-creating capability both in a commercial context and in Military Logistics.

The defence solution adopted by the Finnish Defence Forces (FDF) where an army has both a large reserve and technically high-level equipment is quickly becoming challenging mostly due to both the increasing costs of military equipment and the complexity in their support chains and service models [18]. This becomes evident when looking at the number of different Original Equipment Manufacturers (OEM) that have their products integrated as a part of modern military forces' capabilities. Due to this, spare parts and all their related functions have become a major factor in planning maintenance operations [19]. A characteristic feature of reserve-based armies like the FDF from the value chain agility point of view is the balance between optimization of costs during peacetime and the ability to achieve the needed performance in wartime. To this end, FDF has outsourced secondary capabilities, like maintenance activities, to several strategic partners [18]. The MRO partner, Millog Oy, is responsible for all maintenance activities including spare parts acquisition and storage.

If the overall Military Logistics System of FDF was to have an organic capability to replenish spare parts through own or collaborated production with AM, this would increase the robustness and resilience of the force and increase its performance by adding a separate source of spare parts and making their production agile and scalable. This could help to narrow the gap between the demand for cost savings in peacetime and optimized performance in wartime [20].

The core problem that outsourced capabilities pose to military organizations like the FDF in the capability development is the absence of direct authority towards the resources of another organization. In addition, Operating Logic and the purpose of the commercial and public organizations can vary tremendously which makes focusing joint investments and resource utilization hard. When an organization is combining different operating logics of more than one interest or stakeholder group or sub-organization, it is called a hybrid organization [21].

In military capability development, the use of capability models like DOTMLPFI is a common practice. The introduction of the capability models as a part of military concept creation can be seen as a result of change drivers and needs of different stakeholders. The DOTMLPFI-model epitomizes the change drivers of the military capability. These are Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Interoperability [22, 23]. To evaluate the effectiveness of AM in the context of the spare parts logistics of the FDF an initial and solution-oriented capability concept must be formed. This study is guided by the following questions:

- Can a military performance-driven DOTMLPFI process be used in a hybrid organization where a commercial operating logic also exists?
- Are the concepts of change drivers and the functional elements of the DOTMLPFI-model comparable?
- What are the key aspects of capability development in hybrid organizations?
- What are the key aspects of implementing AM into a commercially backed Military Logistics system?

Since it is a common practice in the military but not in the commercial organizations to engage in a structured capability development process [24, 25], it serves a purpose to examine a case where a new capability is required or considered and joint resources from both organizations to make it happen are required. The aim of this study is to determine if the capability development process used commonly in the military context can be used in a system where both military and commercial operating logics co-exist, and more specifically, in a situation where the initiator for the new or changed capability requirement is military performance. The question is can AM increase the performance of the commercially backed Military Logistic System where for example responsiveness is much more important than direct manufacturing costs.

2 Materials and methods

To identify the aspects of capability development within organizations, an integrative literature review was chosen as a research method. An integrative literature review is suitable for integrating and synthesizing existing literature for new perspectives, in this case from military and business capability development [26]. Based on the identified capability development aspects within military and commercial organizations, we constructed a case study to test the applicability of an existing capability model in the context of a hybrid organization of FDF and Millog Oy and their joint Military Logistic System. In the case study, we examined the implementation of a new technology Additive Manufacturing. The case study was viewed with SWOT-analysis and analytical hierarchy process. With these tools, an initial concept of Additive Manufacturing within the mentioned hybrid organization was formed. With the finished concept, conclusions were made from the process itself to produce answers to the research questions.

The capability development process in hybrid organizations has not undergone a comprehensive review of the literature. By selecting a specific capability model and a capability to conceptualize performance in the framework of the commercially backed Military Logistical System of the Finnish Defence Forces, we can further focus the literature review. As an initial concept, the Capability Framework of the FDF as capability requirement provider and Millog Oy as the commercially motivated party will be analyzed utilizing the capacity of the functional elements (i.e., change drivers of the DOTMLPFI-capability model) to produce the joint-capability system through the use of AM. The initial concept is finally reviewed with the help of a SWOT-analysis. Key aspects of implementing AM to a hybrid organization of FDF and Millog Oy are synthesized to act as an enabling tool for the possible future iterations of capability development and acquisition processes [24] (Fig. 1)

2.1 Capability with respect to systems theory

If we apply the Cambridge Dictionary's definition, the term capability means "the ability to do something". With respect to the Systems Theory, the ability to achieve something by doing requires that the outcome or "Output"-variable can be measured and validated explicitly through some pre-determined conceptualization or a model [27, 28]. To continue exploring the Systems Theory path, each model has Assets

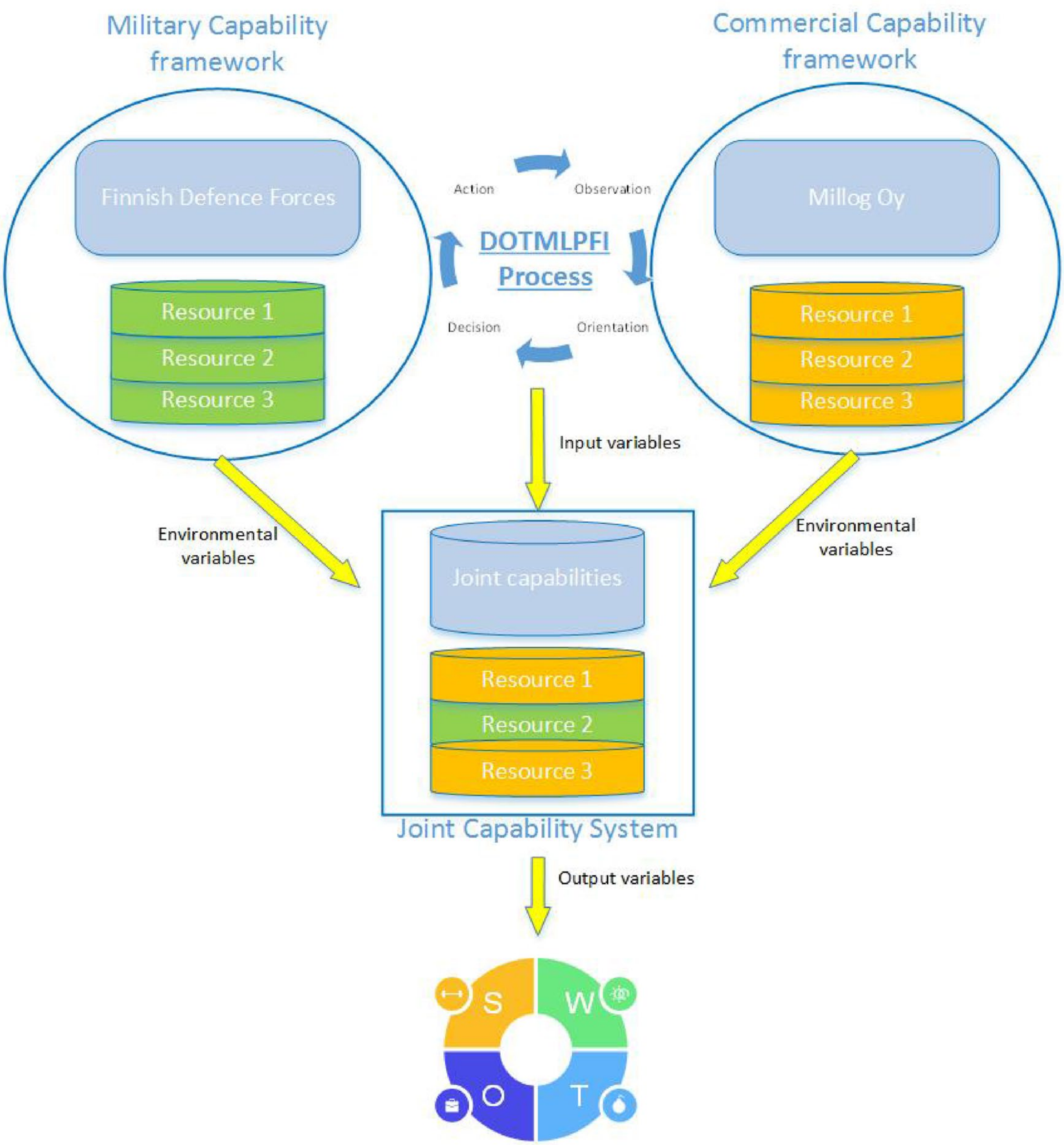


Fig. 1 Research framework

or resources that transform Input variables into Output variables through pre-determined synthesis. All models have also Environmental variables which cause distractions in the process [29].

A capability includes the potential (ability) to achieve a certain goal in a certain context or environment, thus concepts are the tools to illustrate this potential (ability). This definition also includes the embedded hierarchy and causality of the system-of-system: lower level concepts and capabilities are used to form higher level concepts and capabilities.

The idea of lower level concepts and capabilities forming higher level concepts and capabilities is consistent with the idea of military capabilities forming a system-of-systems of different capabilities. The introduction of the concept model in the development of military capabilities is a result of change drivers and needs of different stakeholders. For example, national security, the nature of the tasks, the rapid development of technology and information technology, partnerships, and national and global cooperation are change drivers with different stakeholders [24, 30]. In a corporate context, the change drivers have usually been linked into the business development process or separate business cases [31], which can be seen as a corporate equivalent of military concepts.

2.2 From conceptualization into a concept

Penrose (1959) describes a firm to be an organization where the ability to utilize production resources is built around administrative core functions [32]. This raises the processes, resources, and capabilities to the center of the theory of the firm [31]. When determining the success and reasons for it in an organization with respect to its purpose, recognition of competitive edge factors (e.g., capabilities that make an organization succeed better than the rest) is required. To reach the conceptualization required, all the contributing variables of the success or lack of it will have to be known and the causalities between them resolved. To this end, capability and its relevant variables in the governing context, i.e., Capability Framework must be identified.

Concepts are representations of ideas, which also have a functional role. They are plans and scenarios through which the changes in the governing context can be modeled and analyzed concerning the existing organization and its capabilities [33, 34]. If the organization is formed in the context of an unchanging environment and its guiding policies are set in a way that no changes to the organization or managerial decisions are required [32], this would suggest that a perfect model has been created. However, from the Systems Theory point of view, every model is wrong, or at least there is no perfectly correct model. Models are at their best accurate enough representations of the phenomenon in question [27].

Systems Engineering identifies the concept stage as the first step of a life cycle process. In this stage, exploratory research is conducted to study new ideas and technology areas and to formulate possible solutions for problems or gaps in capabilities. The goal is to clarify the scope of the problem, characterize problem space, identify and refine stakeholders' needs, explore ideas and technologies and explore feasible concepts. These goals help to identify possible issues early on and thus make it possible to address them in the development stage [35].

When organizational capabilities and agility of organizations are developed, conceptual models are often used [36]. It is not common, however, to use a structured model or a process when developing civilian enterprise capabilities. It is mainly done in respect of individual change drivers and a combination of these to emphasize certain aspects. Change drivers, like leadership, participation and globalization are variables that can be precise or more abstract and they are usually not something that can be resolved within existing organizational processes. A two-fold characterization from the mechanism of the change drivers can be made: they can represent a need for change or a tool of implementing a change [25, 31].

Due to constant change and diversity in the operational environment, military capability development cannot only be done on a system-by-system basis. The capability has to be seen through Systems Engineering as a system-of-systems and thus the capability development consists of the identification of individual systems and capabilities i.e., components and their relationships. The individual component then contributes towards the overall military capability. If the overall military capability is seen as a system-of-systems, then a change in one of its elements may have an impact on the overall capability. These changes can be modeled and evaluated through concepts [37].

Change drivers can be internal or external and through these, the organization seeks improvement and/or adaption to the changing governing context, i.e., Capability Framework. In this study, the governing context is the Capability Framework of the Finnish Defence Forces. The operating environment was determined following the existing logistics structure and the requirements and potential challenges in the future operational environment were addressed [38]. A structured and standardized process for concept creation is vital [39]. However, it is equally important to understand that the need and focus of concepts can vary significantly. This means that not all processes can and should not be applied to all concept creation.

2.3 Capability framework of the FDF

The operational environments of the modern military and business worlds are in a constant shift. The changes in the world's security environment shape the doctrinal level of requirements for the world's armed forces. This "big picture" or Capability Framework [24] is mainly influenced through bilateral relationships of nations, military alliances such as NATO, and major incidents such as armed conflicts. Within Finnish Government ministries and agencies and their national Capability Framework, there has been a trend to outsource certain non-critical elements of their capabilities to produce agility in value chains by focusing their resources on their core capabilities [18]. This is a practice used already for many years in the business world [40].

The National Defence Capability consists of the military capabilities of the defense system, as well as national authorities' capabilities and international defense cooperation elements. The defense capability is maintained and developed in respect of a changing operating environment [41]. Most of the military capabilities are sourced overseas, but the industrial and technological expertise needed to operate and maintain critical systems must be in Finland [42].

Military capability development in the Finnish Defence Forces is done in a threat-based manner. This means that there is a new or changed previously known threat that the existing capabilities cannot counter. Thus, a basis for developing a new military capability is an identified gap in the performance of the military organization. A targeted and optimized solution, which builds up from the existing system, is usually developed and revised. For this reason, the need and the solution are separated [43]. The standards that guide the capability development process inside the Finnish Defence Forces are widely based on the US DoD and NATO standards. Table 1 displays the terminology comparison between the USA, NATO, and Finland in regards to capability areas.

National security policy is to be seen as the "principal security policy document that sets the principles, objectives, priorities, and methods of assuring external and internal security and defense of a state" [46]. It defines the outlines of national defense strategy, including, for example, the resources, motives, and limits, which can then be refined into critical technology areas and national security of supply requirements. These technology areas and sets of requirements are used as a framework for military capability development.

The Capability Framework for Finnish Armed Forces is identified and guided through the national Capability Framework and Ministry of Defence. This includes the identification of the most relevant technology areas in close cooperation with the National Emergency and Supply agency. The most relevant technology areas are leadership and networking including intelligence, surveillance, and target acquisition technologies, material and structural analysis related technologies, multi-technology systems and systems management technologies, and biotechnology and chemical technologies. To successfully achieve adequate technical expertise in these areas, ministry strategy dictates that sufficient life cycle management, production capability, research, and development expertise, and also design, integration, maintenance, and damage repair readiness are to be supported nationally. All requirements for the mentioned technological expertise areas in all the possible readiness conditions must be met [42].

To uniquely understand the process of capability development and individual steps within it, several models have been created to achieve this. The most established ones in military capability development are the DOTMLPFI (USA), FIC (Australia), and systems capability model (UK) [24]. In recent studies, these and other capability models are applied to produce Capability Frameworks. The variation between these frameworks springs from the different stakeholder or interest groups, such as political decision-makers, military planners, the acquisition community, field commanders, and the defense industry [24]. DOTMLPFI-model identifies and defines and then combines all the functional elements or drivers-of-change to produce a holistic understanding of the

Table 1 Capability terminology comparison between USA, NATO, and Finland [43–45]

USA	NATO	Finland
Command and control	Capability area C—consult, command and control	Command and control
Battlespace awareness	Capability area I—inform	Situational awareness
Netcentric	Capability area D—project	Netcentric
Logistics	Capability area L—sustain	Logistics
Building partnerships	Capability area R—prepare	Partnerships
Force support	Capability area P—protect	Protection
Force application	Capability area E—engage	Generation of force, force application
Corporate management and support		Corporate management and support

capability. The capability model can be seen as a result of the need to quantify the capability generically. On the other hand, the DOTMLPFI-model acts as a solution-oriented concept through which the individual drivers' for-and-of-change can be observed and implemented and causalities between different change drivers examined.

A key application of the capability development model is the requirements management process. When focused on the requirements management process it acts as a baseline into which the functional, physical and immaterial elements can be attached. Through this and the existing capabilities, the desired end state of the national security policy is transformed into requirements for the specific performance [43].

2.4 Commercial context of the capability framework

According to Kilpinen (2013), "globalization forces, along with rapid technological change, deregulation and intensified completion are shaping the operating environment and redefining the conditions of survival and growth for many firms" [31]. The changing global landscape is forcing the firms to face a setting, where the institutional, technological, or market environment is uncertain. In addition, the complexity in the interdependencies between markets and actors is a reality. For example, the difference and variety in customer-designed products have driven the production industry to strive towards a dynamic and agile value chain from innovation to product design and production, distribution, and logistics to customer support. The most focused areas from which agility is sought are capabilities related to manufacturing methods and marketing [31, 36].

In the economical context according to Bridoux et al. (2017) capabilities are activities that are practiced on a large scale and are identified to be distinct, patterned, and practiced. A common characteristic is also that these are complex, and their purpose is recognizable and serves directly or indirectly the main purpose of the organization. Examples of these capabilities are product development, customer relationships, and supply chain management [47].

There are three different perspectives in the organizational capabilities literature. These are the evolutionary perspective, the resource-based view, and the dynamic capabilities view. The resource-based view is self-explanatory, and it is focused on the organization's resources like personnel, facilities, and production machinery. Because of the trend of outsourcing, many organizations today have resources that are not theirs, but the capacity of the resources is at their disposal. The dynamic capability view completes the resource-based view to comprise all the resources involved in the organizations' processes [48]. Evolutionary perspective shifts the interest from the firm's resources to industrial competition and development or in other words context [31].

Organizational capability development takes a focused approach to capabilities explaining their effectiveness during a specific time or trying to explain why a specific capability could sustain competitive advantage. It is suggested, that integrating dynamic and evolutionary perspectives will provide a more holistic approach to capability development. The model is described in Fig. 2. This idea has similarities to the military capability development where different elements of the capability are identified, capabilities are tight to their respected stakeholder groups and their mutual relationships are solved to form a holistic approach to capability development through a complete Capability Framework [24, 31].

There is also limited understanding of the relationship between internal and external elements of capability development. In addition, the impact of organizational and managerial processes has been reduced to simple "managerial decisions" or "management agency". This disregards the underlying drivers-for-change and focuses more on the drivers-of-change [25, 31].

The case study done by Kilpinen suggested that four different "logics" can be identified as a baseline for capability development in Multi-National Companies: variation base, (internal) selection-based, retention-based and access-based. These are not built-in organizational processes but rather they act as "higher-order" mechanisms producing "complex capability outcomes or patterns" [31].

The capability development in the commercial sector indicates that a structured process could be beneficial at getting and upholding the competitive edge in the market. In a case of strategic partnerships, a contractual relationship is usually formed. This should protect both partners' interests, enable value creation and facilitate and enable change. If

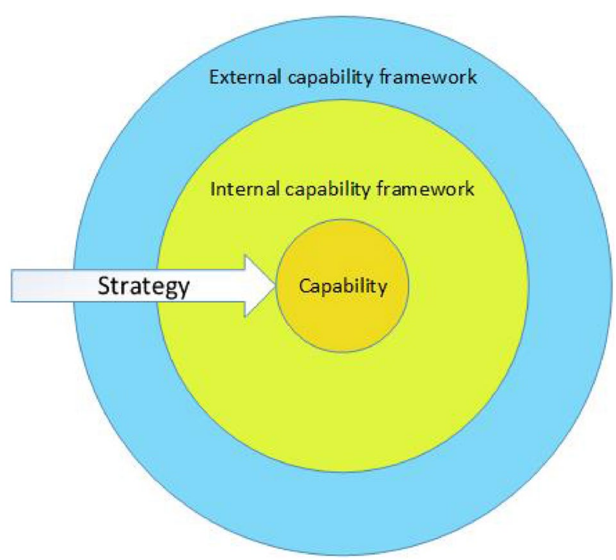


Fig. 2 The integration of commercial capability aspects adapted from Kilpinen 2013

for example, a new capability is sought it should be formed in a way that.

Focus is clear and resources are optimally allocated. This means that no unnecessary procedures should exist, and decision-making should be made at the lowest possible level [49].

The investments made within this capability are built up to have a reasonable return on investment plan. In a business world, all investments should be based upon a carefully built business case. This is a mechanism to judge if the project is viable, desirable, and achievable. If these prerequisites are not met or at some point and time of the project ceases to exist, then the project should be stopped [49, 50].

The partnership should not be static. As an individual organization so should the hybrid organization be prepared to change to meet the changing parameters of the operating environment [49].

2.5 DOTMLPFI elements in AM

As demonstrated, capability development is important to both companies and other entities like public organizations, and as such, the similarities between different capability development approaches are obvious. When determining the applicability of Additive Manufacturing as a part of the Military Logistical System, the first stakeholder group is the National decision-makers. This defines the doctrinal level of Capability Framework, e.g., the "fundamental principles by which military forces guide their actions in support of objectives. It is authoritative but requires judgment in application" [34].

As the Government's Security Guide published by the Prime Minister's office has identified the critical technology areas, it can be stated that Additive manufacturing is included in this scope, because the maintainability and repair capabilities are listed [51]. A specific, logistics-oriented NATO doctrine defines logistics to be the science of planning and carrying out the movement and maintenance of forces. According to this doctrine, Military Logistics has four basic characteristics: sufficiency, efficiency, simplicity, and flexibility [52].

The organization contributing to the Additive Manufacturing process can be formed flexibly. Preparation, simulation, and testing of desired end-products done in a virtual environment make it possible to work irrespective of the location. The selected distribution model of the AM elements sets interoperability and requirements for it. It has been suggested that the AM capability can be implemented to almost any level of the production and/or the logistical chain.

The three main levels of the distribution are centralized, decentralized, and hybrid implementation [7, 19, 53, 54]. If the organization is centralized, the production resources are also easier to lead and manage and the productivity can be maximized. The distributed system sets more complex requirements for the leadership and management of the printing process [53]. The capacity utilization in the decentralized model is significantly lower but from the military perspective, it adds resilience to the capability [54, 55]. In addition, the simplification of the supply chain through a decentralized model (local production) by Additive Manufacturing methods in comparison to centralized production can allow supply chain complexity to be reduced to merely a supply of raw materials such as powder and wire. It can result in a more sustainable after-sales service supply chain.

There are three distinct levels of management and decision-making: strategic, operational, and tactical. At the highest level, decisions are made about the overall process of desired AM level in Military Logistics. The key interest group on this level is the National decision-makers. Viable solutions of AM are then fitted into the existing capabilities, both individual and of those of a hybrid organization. At the operational level, the leadership of the capability itself becomes essential. In the context of national logistics, this means that the military logistic resources are used in such a way that the selected AM method can be executed. At the lowest levels of the logistic organization, the actual 3D-printing is done. This means the practical on-site leadership of the production resources.

According to Chua and Leong, Additive Manufacturing has four major aspects: input, material, application, and method [8]. Using this separation, another grouping can be made to physical and virtual elements of AM. The physical aspect includes all the concrete elements of AM: printers, facilities, raw materials, and the actual end-products. The virtual aspect on the other hand includes the immaterial elements: design data, IP rights, and software for example.

The virtual aspects of AM set requirements for the storing, handling, and transfer of AM-related data. AM also has an impact on the configuration management and Enterprise Resource Planning (ERP) systems and related processes. The printing process requires a 3D CAD model of the object and this suggests that data storage should exist where all the relevant data is upheld. If the ERP system were already being used in the tasking of the maintenance activities and storage management of spare parts, it would be beneficial to add additional design information to this same system. Either in a case where a configuration management system exists separately or in conjunction with the ERP, the configuration management system should hold the baseline design information of the spare parts. If any modifications are made to the configuration in question, e.g., a topology optimization, the information should be maintained in the primary system and re-distributed from there [7, 56].

Petch states, "The biggest barrier for AM for end-production is not qualification and certifications, it is education and training. AM for production is a new mindset and business leaders, designers, engineers, and technicians need to be educated that AM technology is ready to unshackle with prototyping constraints and move into end production. While the choice of materials and the technology capabilities are increasingly closing the gap with traditional manufacturing methods for broader adoption, it is education that will catalyze the right "pull" force from the market for AM in production." [57]

Additive Manufacturing still being a high and very specialized technology area [8] it requires training and skill development. This means both engineer and operator-level training. However, AM is not a core capability/capacity for typical governmental actors. Since according to the premise set by the National Treasury of Finland bureaus under the Finnish Government should focus their resources on their core tasks [18].

3 Results

3.1 Combining the military and commercial capability development in AM

Concept, as an idea of something not yet complete, precedes the actual capability, in the military context of the DOTMLPFI-model. In both military and commercial capability development contexts, the same basic principles exist that can be drawn from the Systems Theory: there is an existing system that resides in the governing context. This can be extended to hybrid organizations as well. The drivers-for-change with respect to AM must be derived from the requirements of Military Logistics and matched to their commercial counterparts. To facilitate the change process, these must then be linked to the drivers-of-change. In Fig. 3, the requirements for Military Logistics according to the Allied Joint Doctrine for Logistics are linked to the benefits of AM and then linked to the functional elements of DOTMLPFI [52]. In Table 2, the demands for Military Logistics, e.g., drivers-for-change, are linked to the drivers-of-change of the DOTMLPFI process and they are matched with the commercial Drivers-for-change of the AM.

Existing literature has identified change drivers as a force of and for change. With the respect to Systems Theory, they can be interpreted as Input variables and Environmental Variables, respectfully. This makes it possible to handle capability development through a process. If a capability is something that can be measured, also the variables to produce the desired outcome can be measured and thus a quantitative model can be constructed. Like in any system and process, an iterative element likely exists. To produce the desired outcome some adjustments to the process variables are most likely required.

OODA-loop is a research and leadership model commonly used in the military context. Its first three steps are defining "Input Information", "System Information" and "Output Information" [39]. The next steps of the process are meant for the implementation of the desired effect, in this case, a new capability model.

Figure 3 combines the Concept Development, Systems Theory, DOTMLPFI Capability model, and OODA-Loop process. It also represents the DOTMLPFI-models functional elements as individual change drivers and equates them into the "Output Variables" of the generic System. Through this process, it is possible to form an initial concept

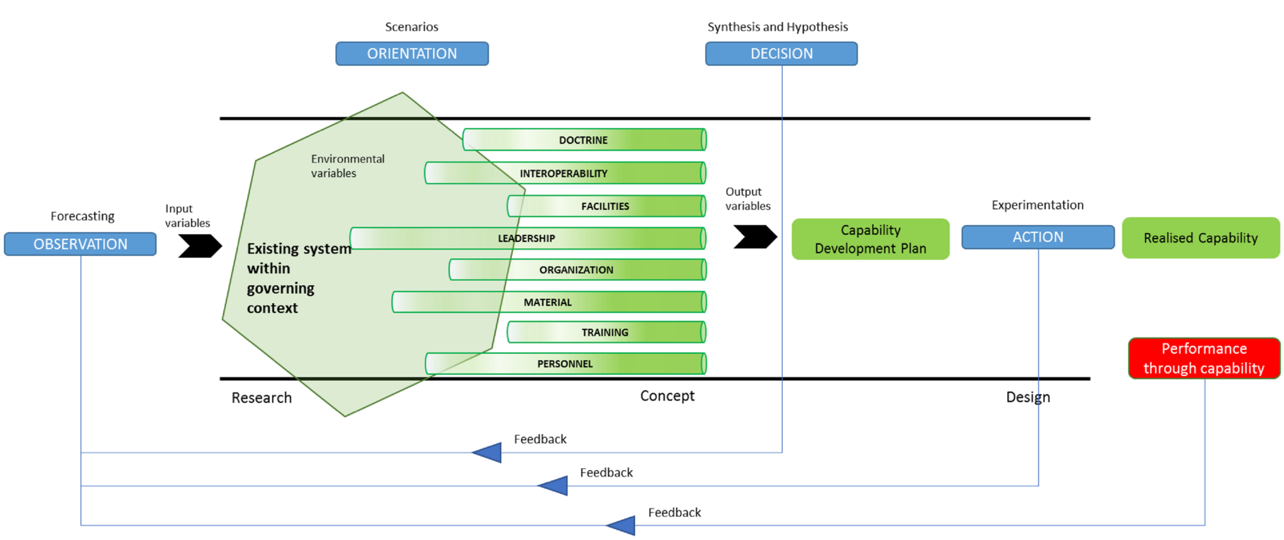


Fig. 3 Synthesis of Concept Development, Systems Theory, DOTMLPFI Capability model, and OODA-Loop process

Table 2 Synthesis from change drivers of AM with respect to DOTMLPFI [52, 56]

Military driver-for-change		Driver-of-change	Commercial driver-for-change	
Sufficiency	Logistic support must be available in the necessary quantity and quality, when and where it is required throughout the full spectrum of Allied Operations and Missions (AOM). It must be ensured for any NATO-led operation continuously for the duration required to accomplish the mission	Organization Doctrine	Logistics optimization and creation of manufacturing capacities "in the field"	The AM technologies are enabling the "transaction from a traditional scenario of centralized production to one in which almost any site can become a production center". This evolution will force the decision-making process and systems, e.g., capability development to consider AM as a viable solution
Efficiency	Logistic resources and capabilities should be used effectively and efficiently. Requirements must be identified and addressed on time to optimize the efficient provision and effective use of such resources and capabilities. Therefore, from the onset of the OPP, NATO and nations should consider multinational solutions and not default to national solutions	Facilities Material Personnel	Autonomous production	Thanks to an autonomous manufacturing system based on Additive Manufacturing technology, the customer's personnel can have access to it any time during the mission and can print components continuously. Waiting time will be no more than the cycle time of the Additive Manufacturing machine, post-processes, qualification, and assembly
Simplicity	Uncomplicated mission-orientated logistic organizations, structures, and procedures minimize confusion and help to ensure that the support provided meets NATO COM's requirements. In addition, clear orders, simple plans, and reporting mechanisms ensure accurate and efficient dissemination of information and minimize misunderstandings	Leadership Training	No economies of scale	Production with Additive Manufacturing methods does not need to achieve economies of scale to minimize cost per part. The manufacturing can always start with just one part without exceeding minimum variable part costs
Flexibility	Logistic support must be adaptive and flexible to be effective. Adequate planning allows NATO and nations to react on time to changes in the operational situation and/or requirements	Interoperability	Production on an "on-demand" basis	One benefit that Additive Manufacturing offers is the ability to manufacture parts on-demand. This will eliminate the challenges that the volatile demand for spare parts brings to the business, and this opportunity will improve availability and allow flexibility compared with traditional manufacturing methods. Having the necessary parts when and where they are needed can have a significant impact on an operation's efficiency

in such a way that it can be later expanded and numeric variables to be attached to different change drivers.

The effects of AM as a new tool or method for creating or maintaining capability shall be discussed in the following sections. In each section, the effects are projected on one or more of the concepts of the DOTMLPFI framework.

3.2 Doctrine

It can be stated that Additive Manufacturing offers advantages towards the principal stakeholders in the center of Military Logistics identified and listed by NATO. It is also a valid argument that to a commercial company with production resources of their own, Additive Manufacturing can offer competitive capabilities and possible cost savings [55]. When determining the implementation of Additive Manufacturing to the hybrid organization of the FDF and its maintenance provider, however, the business case within must be calculated to act as a basis for the investment made by the commercially motivated party. This can be problematic if the market or the competitiveness is somehow regulated with respect to the existing hybrid organization and its contractual base.

As stated earlier, material and production technology along with the maintenance and repair capabilities are among the key technologies set by Finland's Ministry of Defence. In addition, the overall direction given by the Finnish Government to its ministries and their bureaus is to focus their resources on their core tasks. Based on these it is justified to plan to utilize Additive Manufacturing as a part of FDF's capabilities and use hybrid organization in its execution [18].

AM can offer advantages and risk mitigation to an organization like the FDF through shortened supply chains, greater self-sufficiency, and the ability to guarantee the usability of its equipment. To maintenance providers, it can offer new possibilities for optimizing its production network, and through these new commercial opportunities.

3.3 Organization, leadership and interoperability

The pre-existing organization model of the FDF, where the maintenance activities are outsourced to a strategic partner, is a "maintenance service provider-centric" model, where the maintenance service provider operates near the end customer. In the case of Military Logistics and National Security of Supply, this also means the necessary manufacturing capabilities for the military defense [7, 19, 58].

The leadership and management of different aspects of Additive Manufacturing should be based on the processes and organizational culture already in place in the Military Logistics functions and the hybrid organization of the FDF and its maintenance provider. There is a risk of fractured information flow if the production element and engineering element exist while being kept separate. To mitigate the risk, the ERP system that guides spare parts production is linked to storage elements as well. Configuration-related information such as the models of the parts and technical documentation is also needed in the production chain.

Successful leadership and interoperability require processes and standardization. This is crucial in a hybrid organization where the operating logics of the separate companies can vary tremendously [21]. In the Military AM context, this means standardization of methods, skills, training, 3D printing and other manufacturing machines, and technical requirements for the parts.

3.4 Material and facilities

Since the maintenance of military equipment is handled by a strategic partner, it is not surprising that FDF does not possess any manufacturing equipment of its own. In addition, the personnel needed to successfully carry out the tasks in the production chain are located in the strategic partner's organization. The already existing infrastructure of the strategic partner in maintenance makes it possible that the actual manufacturing element of AM, the printing, could be easily implemented to this as a new production method enhancing the existing ones. The manufacturing infrastructure for subtractive manufacturing, e.g., mills and lathes and the measurement instruments (i.e., coordinate measuring machines) are still needed at some stage of the printing process [8, 59].

If the new capability requires investments, it is crucial to make a clear plan on the depreciation of these assets. If there are any obstacles or limitations for the business model or to the possibility of other customers, then it has to be clear how the payback period is formed. For example, the cost of an EOS 100 M metal printer is approximately 300 000€ [60]. With the presumable facility investments, the amount could be as high as 500 000€–700 000€. With only one customer and a limited range of printable parts, this would mean a payback time of decades to the investments.

3.5 Personnel and training

While not vital to the core tasks of the FDF, personnel planning related to the AM is part of the overall logistics system. For this reason, a logical choice is to utilize the existing industry and academic community to obtain, maintain and develop the skills and competencies required to implement and take advantage of the new production method. The average training time of AM specialists (bachelor or master's level) in Finland takes roughly 4 to 7 years, depending on the individual curriculum.

In modern military maintenance, a firm knowledge of complex manufacturing techniques and processes is required to identify and plan the necessary maintenance operations. The basis of this knowledge must be preserved and developed in the peacetime organization of the Finnish Defence Forces (FDF) and its maintenance provider [51]. This includes all the occupational groups within the hybrid organization. In addition, because of the reserve-based army, this knowledge must be extended and to some extent transferred to the reserve elements of the military maintenance components to be able the scale up the AM capabilities during wartime.

Most of the personnel currently on active duty within FDF in the field of military maintenance leadership and management have received their training in military schools (officers, NCOs, warrant officers). The challenge here is that in the current training of soldiers there is a lack of sufficient and specialized technical training to achieve skills and knowledge from any high-tech field. Military training guides the students towards practicality, but without the specific technical knowledge, they cannot perform adequately in military maintenance.

The personnel participating in the numerous tasks of AM are all reliant on the proper training. The maintenance personnel of the maintenance partner of the FDF can be, with reasonable effort, trained to operate the printing machines. They are most probably already familiar and trained to use machining tools and equipment so the required additional training will not be so massive. The biggest challenge is to train an adequate number of capable and carefully positioned operators who can simulate, model, and design the technical data of the AM. Successful modeling and capable production personnel together ensure as flawless end product as possible.

3.6 SWOT-analysis

The SWOT-analysis of Fig. 4 shows the different aspects of implementing AM into an existing hybrid organization of FDF and Millog. The results were gathered from both the commercial and military literature and analyzed with experts from both the FDF and Millog in the context of military capability development. The experience of the experts from the fields of Military Logistics, capability development, and production technology:

Expert 1, Project manager at MRO organization, former officer.

- Master of Military science; M.Sc., Tech.
- 10 years in the field of Military Logistics and capability development in the FDF.
- 3 years of Military Logistics and capability development in the MRO organization.

Expert 2,

- O-4 Officer, research scientist.
- Background in physics, Senior Staff Officer training, and the Advanced Technical Studies.
- 20 years in the field of military capability.
- 10 years in the systems R and D field.

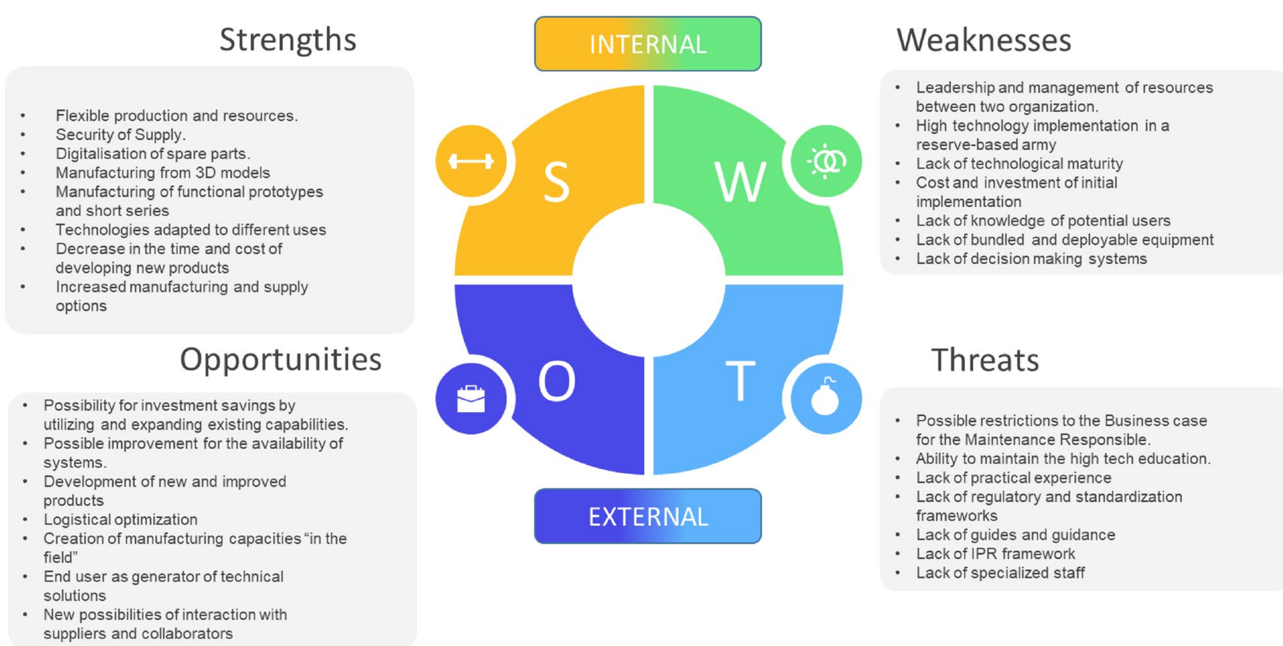


Fig. 4 SWOT-analysis from the key aspects of AM in Military Logistics

Expert 3,

- M.Sc. (Tech).
- 15 years of R and D for the Finnish Navy in the fields of Signature management, Situational awareness, EW, and Systems engineering.
- Involved in all strategic acquisition processes in Finnish Defence Forces—the main role has been taking care of requirement verification and validation between companies and Defence Sector.

In the SWOT-analysis, the goal was to identify the most relevant aspects of the AM implementation which would require the most effort to achieve a consensus between the two organizations. We used a commercial SWOT-analysis tool from CAYENNE apps to analyze the findings. Any numerically calculated operational evaluation was not possible either because of the confidentiality of any such information. As a result of these and because of the uniqueness of the case without any precedents, any numerical evaluation could prove to be misleading. However, based on the experience of the experts a reasonable iteration of the aspects could be achieved.

The first step of the analysis consisted of the identification of attributes of the four different aspects of SWOT. As a base data, we used the results of the EDA feasibility study's SWOT-analysis. These data were then supplemented with our findings (attributes) in the context of a hybrid organization. In the next phase, we selected the most important attributes from the different aspects and weighted them numerically. Attributes and their weighted values are shown in Table 3.

The selected attributes were then cross-evaluated. We analyzed the strengths influence on opportunities and threats, weaknesses influence on opportunities and threats, opportunities influence on strengths and weaknesses, and finally threats influence on strengths and weaknesses. Figure 5 shows the impact of selected strengths and weaknesses have on opportunities and threats.

The cross-evaluation was guided by the following questions:

- "Do selected strengths allow for the use of selected opportunities?"
- "Do selected strengths limit the impact of selected threats?"
- "Do selected weaknesses limit the use of selected opportunities?"
- "Do selected weaknesses intensify the impact of threats?"

The analysis shows that the strengths strongly connect with the opportunities. However, the selected weaknesses also intensify the threats and limit the use of opportunities. There is a lot of potential in the identified strengths but also a lot of uncertainties and risks from the weaknesses and threats.

Table 3 Selected attributes and their individual weighted importance

	Weighted importance (1–100)
Selected attributes (*strengths*)	
Security of supply	100
Flexible production and resources	80
Increased manufacturing and supply options	70
Technologies adapted to different uses	50
The digitalization of spare parts	30
Selected attributes (*weaknesses*)	
Cost and investment of initial implementation	100
High technology implementation in a reserve-based army	90
Leadership and management of resources between two organization	50
Lack of decision-making systems	30
Selected attributes (*opportunities*)	
Possible improvement for the availability of systems	90
Logistical optimization	80
Possibility for investment savings by utilizing and expanding existing capabilities	60
New possibilities of interaction with suppliers and collaborators	30
Selected attributes (*threats*)	
Possible restrictions to the business case for the maintenance responsible	90
Lack of specialized staff	80
Ability to maintain the high-tech education	50

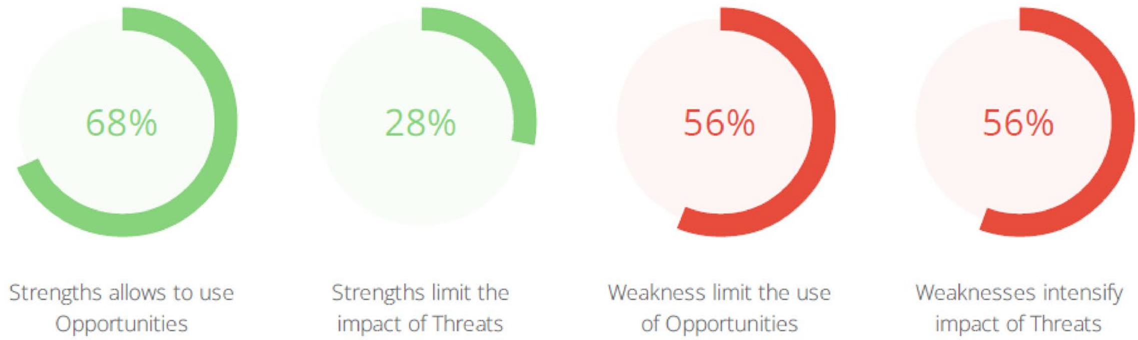


Fig. 5 The impacts of strengths and weaknesses have on opportunities and threats

Major conclusions are that there is potential in the AM with respect to Military Logistics. However, the organizational model being a hybrid brings some aspects to the system that are complex. For example, the leadership and management processes that are directed from one of the organizations do not include the direct mandate to supersede the other organization's processes. This one crucial element has to be solved to effectively utilize the potential of AM in the context of FDF and its maintenance provider. The most relevant impacts of strengths and weaknesses are shown in Fig. 6.

The other major question is the business model for the commercially motivated maintenance provider. If there are restrictions, contractual or otherwise, in the trade, marketing, and manufacturing elements of the hybrid organization's AM capabilities, the investments made by the commercial organization have to be backed with a business case nonetheless. This is usually not the case for a publicly funded organization.

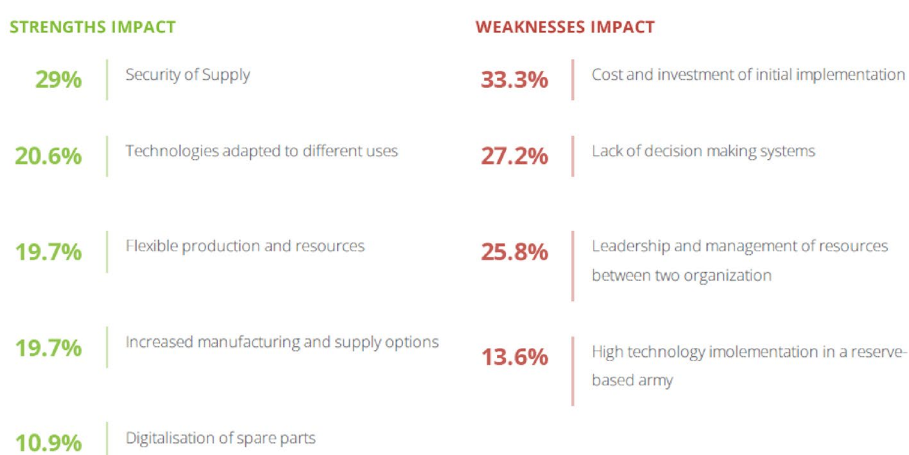
4 Discussion

The Capability Framework in the Finnish Defence Forces identifies the stakeholder's role through aspects of the capability development model. These perspectives are:

- Effectiveness—"What are the desired effects"?
- Ability—"What abilities are needed for the desired effects"?
- Solution—"How and with what solutions they desired abilities are ensured"?
- Life cycle—"When is the capability ready to be utilized and what are its effects on the costs"?

To fulfill the needs of all the relevant stakeholders needs within deep partnerships and hybrid organizations, consistent and structured capability development is needed. In the respect of our research questions, some key observations need further study.

Fig. 6 Strengths with the biggest positive and weaknesses with the biggest negative impact on opportunities and threats



4.1 Can a military performance-driven DOTMLPFI process be used in a hybrid organization where a commercial operating logic also exists?

There are major similarities between commercial and military capability development processes. This comes from the fact that in both cases the situation can be described, analyzed, and developed by the means of Systems Theory and multivariate analysis. It comes as no big surprise that the different operating logics of the two organizations bring more variables to the analysis. For example, if there is a one-sided need to implement changes that require investments or there is a direct contradiction with the other parties' interests, either pre-existing mandatory procedure or a contractual process needs to be applied. This complicates the otherwise straightforward capability development process. Despite the major differences between the operating logics of the individual companies, commercial and military operating logics can co-exist.

4.2 Are the concepts of change drivers and the functional elements of the DOTMLPFI-model comparable? What are the key aspects of capability development in hybrid organizations?

The agility to counter or to adjust to the changes, i.e., change drivers for the change in the governing context, is a key to success both in military and commercial organizations. This requires a structural process in which all the factors of change are considered and if necessary revised under the changed governing context. This leads to a situation where firms base their long-term strategies on organizational capabilities instead of served markets [61]. The most interesting cases are formed when several interest groups with not fully coherent motives, such as hybrid organizations, are involved in the capability development process. The drivers for-and-of-change have a similar basis in both military and commercial contexts and that basis is within the organizational theory. From this point of view, any structural process based upon these can be used in both contexts. In addition, when the organizations mainly have the same basic building blocks, the hybrid organization has the same key aspects in capability development as any other organization.

4.3 What are the key aspects of implementing AM into a commercially backed military logistics system?

The key aspects of AM in a military context of the smaller armies, the adaptation of Additive Manufacturing as a part of Military Logistics is more than justified. For small armies, the ability to fight in relative isolation is crucial [62]. This demand is scalable from the single-unit level to the national level and partly comes from possible and probable limitations of the national and/or global logistical network. If the logistic network is, for any reason, disturbed this will affect the availability of essential consumables [63, 64]. When logistical resources are sparse, the flexibility becomes important the ability to make quick changes to the center of gravity can mean a difference between winning or losing.

The SWOT-analysis reveals the key aspects, both positive and negative, from the implementation of Additive Manufacturing as a part of a Military Logistics system. AM can bolster its capability especially in situations, where some level of isolation is apparent. In addition, the flexible use of production resources increases redundancy to the logistics system. On the other hand, in a context of a hybrid organization, there are some key aspects, that can be problematic. The profitability calculations of the business case, value, and distribution of the initial investments and the payback period, in other words, the business case, need to be clear.

The level of optimal implementation of AM can vary in different organizations. This depends on the organization's structure, leadership, management, and technical processes. If the armed force is partly or mainly reserve-based, it can be more challenging, for example, to identify the person who can be trained as an operator. If the whole concept of the corps is built on commissioned core personnel, which is supplemented at the time of crisis, it is usually the crew level that is drafted. This poses a problem: if the operator-level personnel are draftees, how can they be adequately trained to use high-level technology? One solution could be to establish a reach back that could serve as a center of excellence for the critical AM know-how. This could consist mainly or entirely of commissioned personnel. This center of excellence can keep up the critical information and knowledge of AM and only the lowest level AM tasks are outsourced to the maintenance crew. In the FDF's situation, however, a commercially operated maintenance partner with existing production resources already exists.

Although the AM technologies, in general, were used as an example in this article, they are not the only ones to hold the improving potential to Military Logistics. There are other technologies with similar benefits such as form adding processes, incremental sheet forming, computer numerically controlled (CNC) machining (especially if those are already in the postprocessing stage for AM and material joining and coating processes), and indirect AM with sand and investment casting [65–68]. All or selection of those could improve the capabilities and responsiveness.

An unresolved discussion about change drivers within the military operating environment is one result of the classical debate of the relationship between technology and tactics. It could be argued that the available technology dictates the possibilities of tactics. On the other hand, the tactics can be the catalyst that incites the development of necessary technology [69]. In a reference to the governing context, however, this can be seen from either perspective, as a drive towards an adaptation to change. AM can provide advantages and improvements to the spare parts logistics and through this, to the overall Military Logistical System.

Author contributions Conceptualization IV, SR, and MS; methodology, IV and SR; validation, MS; resources, MS; data curation, IV; writing–original draft preparation, IV; writing–review and editing, MS and SR; visualization, IV; supervision, MS. All the authors have read and agreed to the published version of the manuscript.

Funding Open Access funding provided by Aalto University. The APC was funded by Aalto University.

Data availability Data availability is not applicable.

Declarations

Conflict of interest The authors declare no conflict of interest.

References

1. Learned E, Christensen C, Andrews K, Guth W (1969) Business policy: text and cases. Irwin, Hanoywood/III
2. Fligstein N (2021) Organizations: theoretical debates and the scope of organizational theory. Handbook of classical sociological theory. Berkley, CA, pp 487–506
3. Atakok G, Kam M, Koc HB (2021) A Review of mechanical and thermal properties of products printed with recycled filaments for use in 3d printers. Surf Rev Lett. https://doi.org/10.1142/S0218625X22300027
4. Kam M, Ipekçi A, Şengül Ö (2021) Investigation of the effect of FDM process parameters on mechanical properties of 3D printed PA12 samples using taguchi method. J Thermoplast Compos Mater. https://doi.org/10.1177/08927057211006459
5. Kam M, İpekci A, Saruhan H. (2017) Investigation of 3D printing filling structures effect on mechanical properties and surface roughness of PET-G material products, GAZİOSMANPAŞA BİLİMSEL ARAŞTIRMA DERGİSİ (GBAD). Gaziosmanpasa J Sci Res 6:114–121
6. Kam M, Saruhan H, Ipekçi A (2018) Investigation the effects of 3d printer system vibrations. Sigma J Eng Nat Sci 36:655–666
7. Meboldt M and Klahn C. (2018) Industrializing additive—Proceedings of additive manufacturing in products and applications—AMPA2017, Cham
8. Chua CK, Leong KF (2017) 3D printing and additive manufacturing–principles and applications. World Scientific Publishing Co Pte Ltd, Singapore
9. Garcia-Colomo A, Wood D, Martina F, Williams S (2020) A comparison framework to support the selection of the best additive manufacturing process for specific aerospace applications. Int J Rapid Manuf 9:194–211
10. Mäkitie A, Paloheimo K, Björkstrand R, Salmi M, Kontio R, Salo J, Yan Y, Paloheimo M, Tuomi J (2010) Medical applications of rapid prototyping–three-dimensional bodies for planning and implementation of treatment and for tissue replacement. Duodecim 126:143–151
11. Kestilä A, Nordling K, Miikkulainen V, Kaipio M, Tikka T, Salmi M, Auer A, Leskelä M, Ritala M (2018) Towards space-grade 3D-printed, ALD-coated small satellite propulsion components for fluidics. Addit Manuf 22:31–37
12. Salmi M, Akmal JS, Pei E, Wolff J, Jaribion A, Khajavi SH (2020) 3D printing in COVID-19: productivity estimation of the most promising open source solutions in emergency situations. Appl Sci 10:4004
13. Çevik Ü, Kam M (2020) A Review Study on Mechanical Properties of Obtained Products by FDM Method and Metal/Polymer Composite Filament Production. J Nanomater. https://doi.org/10.1155/2020/6187149
14. Chekurov S, Salmi M (2017) Additive manufacturing in offsite repair of consumer electronics. Phys Procedia 89:23–30
15. Verboeket V, Khajavi SH, Krikke H, Salmi M, Holmström J (2021) Additive manufacturing for localized medical parts production: a case study. IEEE Access 9:25818–25834
16. Chekurov S, Salmi M, Verboeket V, Puttonen T, Riipinen T, Vaajoki A (2021) Assessing industrial barriers of additively manufactured digital spare part implementation in the machine-building industry: a cross-organizational focus group interview study. J Manuf Technol Manag 32:909–931
17. Kretzschmar N, Chekurov S, Salmi M, Tuomi J (2018) Evaluating the readiness level of additively manufactured digital spare parts: an industrial perspective. Appl Sci 8:1837
18. Kämäri V (2010). Kumppanuusohjelman strateginen johtaminen- Monitapaustutkimus puolustushallinnossa, Lappeenrannan teknillinen yliopisto, Lappeenranta
19. Salmi M, Partanen J, Tuomi J, Chekurov S, Björkstrand R, Huotilainen E, Kukko K, Kretzschmar N, Akmal J, Jalava K, Koivisto S, Vartiainen M, Metsä-Kortelainen S, Puukko P, Jussila A, Riipinen T (2018) Digital spare parts, Tekes–the finnish funding agency for innovation. Aalto University, VTT Technical Research Centre of Finland Ltd, Espoo
20. Eren B, Chan Y (2015) A combined inventory and lateral resupply mode for repairable items–Part II: solution by generalized Benders' decomposition. Military logistics-research advances and future trends. Springer International Publishing, Switzerland, pp 89–104
21. Alexious S, Furusten S (2019) Managing hybrid organizations-governance, professionalism and regulation. Palgrave Macmillan, Cham
22. Nijs HD (2010) Concept developement and experimentation policy and process: how analysis provides rigour. North Atlantic Treaty Organisation, Norfolk
23. NATO. (2021) NATO CD and E Handbook A Concept Developers Toolbox 2.01, Norfolk: Allied Command Transformation, Deputy Chief of Staff for Policy and Plans. Concept Development Division
24. Anteroinen J. (2013) Enhancing the development of military capabilities by a systems approach. Diss, National Def Univ

25. Whelan-Berry KS, Somerville KA (2010) Linking change drivers and the organizational change process: a review and synthesis. J Change Manag 10:175–193
26. Torraco RJ (2005) Writing integrative litterature reviews: guidelines and examples. Human Res Dev Rev 4:356–367
27. Sterman JD (2002) All models are wrong: reflections on becoming a systems scientist. Syst Dyn Rev 18:501–531
28. Morecroft JDW (2015) Strategic modelling and business dynamics: a feedback systems approach. John Wiley and Sons, Cornwell
29. Wahlström B, Ollus M (2014) Systeemiteoria ennen ja nyt-systeemit muuttuvassa maailmassa. Aalto university, Espoo
30. Hayes RE. (2007) Concept development and experimentation. http://www.dodccrp.org/files/CDE%201-1%20Overview.pdf. Accessed 18 February 2021
31. Kilpinen P. (2013) Capability Development within the Multinational Corporation. Diss, Aalto Univ
32. Penrose E (1959) The theory of the growth of the firm. Oxford University Press, Oxford
33. Pikner I, Zuna P, Spisak J, Galatik V (2012) Military operating concepts development. SHOPMYBOOK, Puurs
34. NATO Standardization Office (NSO). (2018) NATO Glossary of Terms and Definitions. North Atlantic Treaty Organization NATO Standartization Office (NSO), Washington
35. Walden DD, Roedler GJ, Forsberg KJ, Hamelin DR, Shortell TM (2015), Systems Engineering Handbook. International Council on Systems Engineering, San diego CA
36. Yi-Hong T, Ching-Torng L (2008) Enhancing enterprise agility by deploying agile drivers, capabilities and providers. Elsevier, Chang-Hua
37. Pasivirta P, Kosola J (2004) Vaatimustenhallinan soveltaminen Puolustusvoimissa. Pääesikunta, Helsinki
38. Spisak J (2013). Military concepts-a background for future capabilities development. Econ Manag 119–125
39. Kivimaa A, Saarnio J (2018). Konseptit-Määritelmät ja Prosessit. Puolustusvoimien tutkimuslaitos, Ylöjärvi
40. McIvor R (2008) What is the right outsourcing strategy for your process. Eur Manag J 26:24–34
41. Prime Minister's Office. (2017) Government's defence report, prime Ministers's Office, Helsinki
42. Ministry of Defence. (2016) Suomen puolustuksen teknologisen ja teollisen perustan turvaaminen. Ministry of Defence, Helsinki
43. Finnish Defence Forces. (2018) POHJEK-PE Sotilaallisen suorituskyvyn käsitemalli HO46. Finnish Defence Forces, Helsinki
44. UsDoD (2019) Capability Portfolio Management. United States Department of Defence, Washington DC
45. NATO (2019) Consultation, command and control board (C3B), C3 taxonomy baseline 3.1. NATO, Norfolk
46. Pikner I. (2015) Concept developement and experimentation as tool for capability development. International conference KNOWLEDGE-BASED ORGANIZATION
47. Bridoux F, Coeurderoy R, Durand R (2017) Heterogeneous social motives and interactions: the three predictable paths of capability development. Strateg Manag J 38:1755–1773
48. Helfat C, Winter S (2011) Untangling dynamic and operational capabilities: Strategy for the (n)ever-changing world. Strateg Manag J 32:1243–1250
49. de Man A-P (2014) Alliances: an executive guide to designing succesful strategic partnerships. John Wiley and Sons, Incorporated
50. Bentley C (2012) The Concise Prince2. IT governance publishing, cambridgeshire, A Pocket Guide
51. Prime Minister's Office, "Finnish Security and Defence Policy 2012," Prime Minister's Office, Helsinki
52. NATO. (2018) Allied Joint Doctrine for Logistics. NATO Standardization Office (NSO), Washington DC
53. Holmström J, Partanen J, Tuomi J, Walther M (2010) Rapid manufacturing in the spare parts supply chain—alternative approaches to capacity deployment. J Manuf Technol Manag 21:687–697
54. Khajavi S, Partanen J, Holmström J (2014) Additive manufacturing in the spare parts supply chain. Computers Industry 65:50–63
55. Godina R, Ribeiro I, Matos F, Ferrreira BT, Carvalho H, Pecas P (2020) Impact assessment of additive manufacturing on sustainable business models in industry 4.0 context. Sustainability 12:7066
56. European defence agency (2018) Additive manufacturing feasibility study technology demonstration. European Defence Agency, Brussels
57. Petch M. (2017) 3D printing industry. https://3dprintingindustry.com/news/trends-additive-manufacturing-end-use-production-carbon-124651. Accessed 29 January 2021
58. National emergency supply agency. (2021) National emergency supply agency. https://www.huoltovarmuuskeskus.fi. Accessed 7 March 2021
59. Gibson I, Rosen D, Stucker B (2010) Additive manufacturing technologies; rapid prototyping to direct digital manufacturing. Springer, New York
60. Kauppila. (2021) all3dp.com. https://all3dp.com/1/3d-metal-3d-printer-metal-3d-printing/. Accessed 29 January 2021
61. Grant R (1996) Prospering in dynamically-competitive environments: organizational capability as knowledge integration. Organ Sci 7:375–387
62. Palokangas M, EXPLODING WILDERNESS—Guerrilla-type activities in the Finnish art of war. National Defence University, Helsinki
63. National emergency supply agency (2018) Huoltovarmuuden skenaariot 2030. National Emergency Supply Agency, Helsinki
64. Vesa J (2017) Kriittiset metallit ja huoltovarmuus. National Emergency Supply Agency, Helsinki
65. Lehtinen P, Väisänen T, Salmi M (2015) The effect of local heating by laser irradiation for aluminum, deep drawing steel and copper sheets in incremental sheet forming. Phys Procedia 78:312–319
66. Ashayeri J (2007) Development of computer-aided maintenance resources planning (CAMRP): a case of multiple CNC machining centers. Robotics Computer-Integr Manuf 23:614–623
67. Yongxian H, Zongliang L, Long W, Junjun S, dos Santos JF (2017) A new method of hybrid friction stir welding assisted by friction surfacing for joining dissimilar Ti/Al alloy. Mater Letters 15:172–175
68. Lynch P, Hasbrouck C, Wilck J, Kay M, Manogharan G (2020) Challenges and opportunities to integrate the oldest and newest manufacturing processes: metal casting and additive manufacturing. Rapid Prototyp J 6:1145–1154
69. Blasko DJ (2011) Technology determines tactics: the relationship between technology and doctrine in chinese military thinking. J Strateg Stud 34:355–381

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