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POLICY IMPLICATIONS FOR INTEGRATING ADDITIVE MANUFACTURING IN THE DEFENCE SUPPLY CHAIN

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INTRODUCTION

In the last year, the Assistance Deputy Minister for Data, Innovation and Analytics (ADM(DIA)) and the Royal Canadian Navy (RCN) respectively released their *Data Strategy* and *Digital Navy* policy documents. Both documents highlight and recognize that additive manufacturing (AM)[1] carries the potential to improve materiel sustainability across the defence enterprise. The supply chain is the backbone of the sustainment apparatus for the Canadian Armed Forces (CAF). Without a reliable and resilient supply chain, forces cannot sustain operations either in a domestic or expeditionary setting. To date, the Defence Supply Chain (DSC) has not faced major shortages of critical spare parts or supplies. Additionally, the CAF has been able to rely on a wide array of commercial suppliers as well as enjoy a comfortable level of redundancy for uninterrupted sources of materiel. However, supply chain disruption is a real issue and one that can very much impact military operations. The novel coronavirus pandemic is currently testing the limits of supply chains responsible to provide critical health care supplies. In some countries such as Italy, AM proved to be an *in extremis* logistics solutions when suppliers could not match supply to the demand for ventilator parts on time using conventional manufacturing. Much like the health care system, the CAF needs an agile and resilient supply chain that can sustain its forces under the most challenging situations. While it would be unconceivable and unrealistic for the CAF to manufacture all parts and supplies it requires, it could certainly bolster its supply chain by

[1] References to the terms *additive manufacturing* and *3D printing* will be used interchangeably throughout and are to be regarded as synonymous for the purpose of this paper.

integrating an AM capability into it. But how can AM be best integrated into the DSC, to what advantages and what will the policy implications be for a successful integration? To harness the true potential of AM, the DND will first need to recognize and accept that there are true advantages and a compelling case to integrate AM in the defence supply chain and design the roadmap to achieve such integration by considering the policy aspect required in the areas of supply chain management, data management, and workforce management. The focus of the paper will therefore be along two axes. The first part of the discussion will focus on AM integration in the DSC and some of the potential enhancements for the DND/CAF. Then, the second part of the paper will discuss some of the key policy implications which are of importance for the DND to maximize the benefits of further leveraging and integrating this technology within the next decade. Lastly, it is important to note that this paper does not intend on discussing, or otherwise delve into, any of the technical details associated with the various AM technologies.[2] Rather, the emphasis will be placed on the policy aspect of additive manufacturing in the context of supply chain integration.

ANALYSIS

The current State of Additive Manufacturing

There are numerous examples of allied armed forces currently experimenting with additive manufacturing. The United States, Britain and Australia are all investing time and resource towards this technology, albeit to differing degrees.[3] In all instances, AM is

[2] For a technical overview of AM technologies within the DND/CAF context, the author recommends reading the reports by Munro (2019) titled “Review of Structural Additive Manufacturing for Defence Applications: Current State of the Art” and Boukhtouta *et al*. (2018) titled *Additive Manufacturing and Repair: Support & Distribution*.

[3] Boukhtouta *et al.*, *Additive Manufacturing and Repair: Support & Distribution*, DRDC-RDDC-2017-R164, (Defence Research and Development Canada, 2018): 22–37.

viewed as a disruptive technology with great potential to enhance in the fields of support and logistics. From medical to maintenance applications, there are many opportunities. There has also been a significant amount of research done with regards to how AM can change the way supply chains delivery goods and how they fundamentally operate. A

Before discussing AM integration into the DSC, it is imperative to first understand the state of current capabilities and applications of AM within the DND/CAF. The fact and matter is, the DND/CAF are no strangers to the technology. The RCN developed an organic capability to additively manufacture parts back in 2012, when it stood up a Laser Additive Manufacturing (LAM) System Team at Fleet Maintenance Facility Cape Scott (FMF CS) in Halifax in addition to acquiring a 3D printer.[4] Since implementation, the team in Halifax has had many successes in manufacturing parts that can no longer be obtained through the original equipment manufacturer (OEM), as was the case a few years ago with the *Protecteur* Class of supply vessels.[5] Having entered service in the late 1960s early 1970s, it became incredibly difficult for the DSC to source parts for these steam-powered ships forty years after they were built. Many of the suppliers either no longer existed or the costs associated with conventionally manufacturing the parts were prohibitive. In addition, the LAM team at FMF CS has had success in repairing critical shipboard equipment using AM technology. In early 2016, FMF successfully repaired the capstan (an essential piece of shipboard fitted equipment

[4] "3D Printing Transforms the RCN," Navy News Video, 4:14. Posted by the Royal Canadian Navy, 26 February 2016, http://www.navy-marine.forces.gc.ca/en/news-operations/news-view.page?doc=3d-printing-transforms-the-rcn/il3c32xa.

[5] As a Naval Logistics Officer, the author has experienced this issue first hand. There have been many instances where manufacturing parts was the only option to source parts to maintain the fleet of supply ships operationally ready due to unavailability in the market, high manufacturing costs and unacceptable lead times for delivery. In some of the early instances, the parts were manufactured using traditional subtractive manufacturing methods. However, since acquiring a 3D printer, there have been several cases of successful additive manufacturing.

used to veer lines and cables under tension) on HMCS *Halifax*. Using an additive process, the LAM team was able to repair the piece of equipment using a better material than was used in the original design of the equipment, thus improving corrosion resistance and durability.[6] Most recently, the Naval Training Development Centre (Pacific) acquired a 3D printer to fabricate training aids to enhance student learning.

There is also evidence that the Canadian Army (CA) has been experimenting with AM. The Maintenance Section at Canadian Forces Base Wainwright recently procured a 3D printer and had success in repairing and refurbishing various parts that would have otherwise required complete replacement.[7] The current use of AM within the DND/CAF has already proven to be useful on many occasions, despite the fact it currently remains very limited in scope. The institution has already recognized the inherent advantages that having an AM capability, even one that is scattered both geographically and organizationally.

Also to date, it is relevant to call attention to the fact existing capabilities within the DND/CAF remain largely used and managed by the few organizations who acquired the technology. In most cases, the capability remains almost exclusively managed by and through the technical community (naval or land engineering). These concrete examples indicate clearly how AM has reduced pressure of *demand* on the supply chain, but also point to the fact that there is very little evidence that the topic has seen wider discussion within logistics circles. There is however, evidence in policy that some organizations

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[6] "3D Printing Transforms the RCN," Navy News Video, 4:14. Posted by the Royal Canadian Navy, 26 February 2016, http://www.navy-marine.forces.gc.ca/en/news-operations/news-view.page?doc=3d-printing-transforms-the-rcn/il3c32xa.

[7] Jessica Ross and Timothy Goldfinch, "Additive Manufacturing in LEMS – Repairing as Far Forward as Possible," *Land Equipment Management System Journal*, issue 3 (September 2019): 19.

within the CAF recognize that additive manufacturing will enhance readiness through increased materiel sustainability[8] and that implementation of new technologies will require engagement with "stakeholders so that factors related to training, material support, interoperability, security and other domains are considered early in the development cycle."[9] The latter is of particular importance in the context of expanding an existing capability like AM as it relates to its potential on sustainment. Supply chain management within the DND/CAF is built on a centralized corporate model, hence the reason why it is referred to as the *Defence Supply Chain*. Materiel sustainment for all the services is delivered through the operation of a supply chain that is joint in nature, but also *integrates* finance, acquisition and maintenance through the Defence Resource Management Information System (DRMIS) which acts as the official system of record. For an AM capability to truly expand and flourish within the DND/CAF, it will therefore require true integration with the supply chain and other disciplines which are critical enablers to maintaining overall materiel readiness. An article on 3D printing collaboration released last year highlights that there are indeed teams within the DND/CAF looking at expanding the use of 3D printing technology, but it also acknowledges the fact that they are "each approaching it from a different perspective and with different goals."[10]

AM and Supply Chain Management

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[8] Department of National Defence, *Digital Navy: A Strategy to Enable Canada's Naval Team for the Digital Age*, (Ottawa: DND Canada, 2020), 12.

[9] *Ibid*., 8.

[10] John Faurbo, "Collaboration is the Key to Enabling 3D Printing," *Land Equipment Management System Journal*, issue 3 (September 2019): 21.

There is a wealth of information available in the literature on additive manufacturing and its many benefits in a military context. One that is prevalent in the literature is commonly referred to as "shortening the supply chain".[11] The basis of the concept is that the ability for parts to be manufactured *in situ* where a military force is operating significantly contribute to bridge the geographical gap to which supply chains are subjected, while making the logistics footprint potentially leaner. Another similar scenario would see manufacturing occurs closer to the end-user or customer. In a deployed operation context, it can translate into higher serviceability rates, less strain on supply chain transportation assets, lower shipping costs and lesser requirements for warehousing infrastructure. Also, an additive manufacturing capability can also translate into more flexibility to push parts forward to line units without compromising the availability of parts in supply depots across the DSC.

The CAF currently employs a supply chain model which preconizes stocking spare parts in warehouses with predetermined levels that are sufficient to meet the demand. In cases where it is not possible or deemed not advantageous to stock parts, the items are procured based on a just-in-time (JIT) approach. Integrating AM within the DSC could increase the availability for certain line items, while alleviating the requirement to increase inventory levels or possibly lowering them. Leaner inventories cost less to maintain and can save space in warehouses and central depots. From a naval logistics perspective, this is all the more relevant. Warships have limited storage capacity, so the ability to carry copious amounts of spare parts in case of breakdowns is diminished. Space being at a premium, the RCN must carefully select which parts should

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[11] Connor M. McNulty *et al*., "Toward the Printed World: Additive Manufacturing and Implications for National Security," *Defense Horizons* no. 73 (September 2012): 6.

be kept on inventory based on criticality of systems to be maintained and the probability of failure of certain parts or systems. Compounding this issue is the fact that, at present, demand forecasting for spare parts is far from optimal. Indeed, the CAF technical community has little data available to forecast equipment failures with any form of real accuracy besides past consumption levels recorded in DRMIS. In turn, this means RCN ships carry a number of parts they may never have a need for.[12] Conversely, there are often parts that are required but cannot be held on inventory due to stock shortages. Depending on the criticality of the part, stock unavailability often triggers the release of a high priority requisition (HPR)[13] to request that a part be sent from a depot or procured if none is available in the national inventory. The CA and Royal Canadian Air Force (RCAF) arguably face similar challenges when operating away from their home base on domestic and expeditionary operations. The number of parts that can be reasonably carried and warehoused to support vehicles and aircrafts is limited. In all instances, the lack of parts can significantly hinder the CAF's operational readiness. In addition, one must also consider that procurement of parts is usually done in bulk, meaning they are typically manufactured in batches of tens or hundreds while the actual need may only have been for a fraction of the quantity. The remainder of the parts remain on inventory until they are requisitioned which adds to the mounting costs for keeping them on inventory. Shipping costs are also a consideration. Using a JIT approach to procurement

[12] Upon offloading all equipment and parts from shipboard warehouses off of Halifax Class frigates in preparation for their mid-life refit in the early 2010s, the data showed that a sizable number of spare parts held on the inventory had never been requisitioned since the ships had been commissioned in the early 1990s.

[13] Department of National Defence, A-LM-007-100/AG-001, *Supply Administration Manual* (Ottawa: DND Canada, 2019), 160.

in the context of HPRs incurs increased costs for premium shipping of parts that are difficult or too expensive to source and maintain on inventory.

As past trends indicate, the DND/CAF tend to use major platforms for periods of time that far exceed their intended life span. Examples such as the CF-18s and CP-140s aircrafts as well as the 1990s era Halifax Class frigates which are scheduled to remain in service until 2050 come to mind. With every passing year, sourcing spare parts becomes increasingly difficult as systems become obsolete and their sources of supply dry out or for which manufacturing has been discontinued. A marked benefit of AM is the ability to fight obsolescence by providing a level of autonomy and self-sufficiency in guaranteeing long-term access to parts and components that are essential to keep fleets of ships and aircrafts operating over the course of several decades.

Customization and prototyping is another benefit. AM has been used extensively to produce early prototypes for a variety of products, which is a relatively quick and low-cost way to conduct tests and trials. There is also an opportunity for the CAF to use AM in a similar capacity to test new pieces of equipment or field attempts to customize existing ones to enhance and improve their performance. The latter option could prove cost-efficient in that improving an existing piece of kit can be a more suitable option than trying to procure a new one altogether.

However, leveraging the benefits and opportunities that AM has to offer will have to be rooted in the development of a policy framework that will support integration of the technology into the DSC. Creation of a Centre of Collaboration for AM under the Materiel Group was done in 2018 in an attempt to regroup responsibilities under one umbrella with the aim of unifying existing capabilities, then foster deliberate growth.[14] While the initiative has created a forum for discussion and provided a voice to champion AM, it has not yet produced any form of policy document to provide guidance on how to further operationalize the technology.

Policy Implications of Am Integration

AM applications have been largely studied by scientific and technical experts. While there is an abundance of literature on manufacturing methods and the development of the technology, there is a relative paucity of research available on the policy implications of integrating AM in military logistics. But why is it so important to understand policy implications for integration into the supply chain? A key aspect that must be considered, is the fact that AM is not only technologically *disruptive*, it is also complex in nature. For such a technology to integrate fully on a departmental scale, the DND/CAF will need a policy that provides a clear framework so that a strategy can be devised to move toward integration in the supply chain. This is all the more important considering that fundamentally, expansion of AM capabilities means the DND/CAF are effectively contemplating entry into the realm of manufacturing, an activity that has never been a core business of the institution. In that sense, AM integration is akin to entering *uncharted territory* and as such success will hinge on developing policy instruments that will guide efforts across the defence enterprise.

One thing that must be recognized from the onset is that not all parts can or should be additively manufactured.[15] As such, one of the first policy development that

[14] John Faurbo, "Collaboration is the Key to Enabling 3D Printing," *Land Equipment Management System Journal*, issue 3 (September 2019): 21.
[15] Kidd *et al*., "Additive Manufacturing: Shaping the Sustainment Battlespace," *Joint Force Quarterly: JFQ* no. 91 (Fourth, 2018): 45.

should be considered is the design of a roadmap to conduct the CAF inventory review. Such a task should be undertaken based on the list of predetermined criteria to identify line items for which AM is both suitable and desirable. Still, a total review of the DND/CAF inventory would arguably take an inordinate amount of time and personnel to complete. Considering the limited resources, the DND/CAF has at its disposal, the use of AM must strike a balance between cost and benefits. Identifying key criteria based upon which line items in the DSC can be selected for their potential to be manufactured organically will be an important step that will lay the foundation for supply chain integration of AM. In their article from 2018, Kidd *et al*. propose a list of nine possible criteria to use in determining suitability for additive manufacturing.[16] A potential starting point, the proposed criteria are particularly relevant in the context of military manufacturing.

Integrating a disruptive manufacturing technology capability to the defence enterprise, even one defined and limited in scope, will pose some challenges for policy makers. In that regard, quality assurance and part certification procedures and policies comes to mind as recurring theme in the literature on AM. It is widely recognized that although AM allows rapid production of parts, there is an ever-present requirement to validate their quality and performance due a lack of widely accepted and recognized set of standards.[17] This becomes particularly important when the failure of a part could have catastrophic consequences (i.e.: aircraft components, weapons systems parts, etc.). The

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[16] Kidd *et al*., "Additive Manufacturing: Shaping the Sustainment Battlespace," *Joint Force Quarterly: JFQ* no. 91 (Fourth, 2018): 46.

[17] M. D. Monzón et al., "Standardization in Additive Manufacturing: Activities Carried out by International Organizations and Projects," *The International Journal of Advanced Manufacturing Technology* 76, no. 5–8 (February 2015): 1112.

United States Department of Defense's experience with AM has already recognized that the part certification process can often be "lengthy and cumbersome". [18] This challenge typically materializes with additively manufacturing parts used in equipment or platforms that are either sensitive or carry a high risk of injury to personnel should failure occur (i.e.: aircrafts, weapons systems, communication equipment, etc.). In such cases, technical authorities for the equipment or platform in question must certify that the part meets all performance and safety standards prior to entering service. Research and testing have already shown that additively manufactured parts can vary widely in physical characteristics even if they were fabricated using the same 3D printing device, computer-aided design (CAD) file, raw materials, and following the same procedures.[19] Consequently, the development of stringent policies and procedures for addressing presents itself as a necessary precondition to achieve optimal AM integration. The *prima facie* problem here is that setting manufacturing standards is not a defined DND/CAF responsibility, but instead typically falls on internationally recognized organizations such as the *American Society for Testing and Materials*[20] or the *International Organization for Standardization.*[21] Consequently, developing a comprehensive policy to address this gap appears as a huge undertaking that could potentially take many years to come to fruition, thus representing an obstacle to AM integration. In contrast, a report produced for the

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[18] Kidd *et al*., "Additive Manufacturing: Shaping the Sustainment Battlespace," *Joint Force Quarterly: JFQ* no. 91 (Fourth, 2018): 42.

[19] M. D. Monzón et al., "Standardization in Additive Manufacturing: Activities Carried out by International Organizations and Projects," *The International Journal of Advanced Manufacturing Technology* 76, no. 5–8 (February 2015): 1113.

[20] American Society for Testing and Materials, "Additive Manufacturing Technology Standards," last accessed 6 May 2020, https://www.astm.org/Standards/additive-manufacturing-technology-standards.html.

[21] International Standardization Organization, "ISO/TC 261 - Additive Manufacturing," last accessed 6 May 2020, https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/committee/62/90/629086.html.

United States Department of Defense released in 2016 revealed that policies to additively manufacture parts associated with low-risk systems tend to be less complex and faster to produce due to quality assurance and control requirements being less stringent.[22] In addition, there is evidence showing that conventional manufacturing standards have been successfully applied to additively manufacture parts.[23] Nonetheless, the key takeaway with regards to additive manufacturing standards is that developing a guiding policy is prerequisite to coherently support supply chain integration. There are different ways to approach this issue. Roca *et al*. make a good argument for a flexible methodology which consists of developing standards and documenting processes using an experiential learning approach.[24] An example of a policy model following a similar approach is the United States Marine Corps' current AM Guidance.[25] It provides adequate leeway to allow the use of AM technologies to produce parts for which established manufacturing standards exist, while also outlining the process when a lack of standard would preclude fabrication. While developing a manufacturing standard policy is essential in the context of integrating AM into the DSC, due consideration must also be given to identifying what can or should be additively manufactured.

From a policy standpoint, the DND/CAF will also have to determine which parts and components can or should be considered to be suitable for additive manufacturing. As

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[22] Department of Defense, *Final Report – Department of Defense Additive Manufacturing Roadmap* (Washington, DC, 2016), 17.

[23] M. D. Monzón et al., "Standardization in Additive Manufacturing: Activities Carried out by International Organizations and Projects," *The International Journal of Advanced Manufacturing Technology* 76, no. 5–8 (February 2015): 1114.

[24] Jaime B. Roca *et al*., "Policy Needed for Additive Manufacturing," *Nature Materials*, vol. 15 (August 2016): 817.

[25] Department of the Navy, MARADMINS 594/17, *Headquarters Marine Corps Procedural Guidance Update on the Management and Employment of Additive Manufacturing* (Washington, DC, 2017).

was mentioned earlier, it would arguably be neither realistic nor desirable for the DND/CAF to additively manufacture a vast array of items from its national inventory. In order to go beyond the stage of experimentation and into an integration of AM in the supply chain, it is imperative to clearly outline the scope of enterprise manufacturing the DND/CAF are willing to undertake. Identification of critical spares suitable for additive manufacturing is one but important step on the road to integration.

Adopting AM is believed to not only carry the potential to enhance supply chains, but also to alter the way they operate.[26] This indicates that AM integration into the DSC will likely require several amendments to the departmental policy document governing supply chain management: the Supply Administration Manual (SAM).[27] With the exception of a few paragraphs providing broad strokes on supply chain management across the DND/CAF enterprise, the SAM in its current state is arguably inadequate in supporting any form of AM integration.[28] In addition, the SAM contains only limited details in terms of procedures regarding internally manufactured parts and how inventory management should be done in that regard.[29] An AM policy from a supply chain management perspective should be embedded into a larger DSC policy. At the very minimum, a standalone AM policy with a supply chain focus should be written as an interim solution to bridge the gap so as to foster integration in a consistent and deliberate manner.

Concluding sentence: Need to summarize that integration of AM in the supply chain will, in many regards, consist in an effort to merge policy aspect related to the business of

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[26] Katrin Oettmeier and Erik Hofmann, "Impact of Additive Manufacturing Technology Adoption on Supply Chain Management Processes and Components," *Journal of Manufacturing Technology Management* 27, no. 7 (September 2016): 945.

[27] Department of National Defence, A-LM-007-100/AG-001, *Supply Administration Manual* (Ottawa: DND Canada, 2019).

[28] *Ibid*., 18.

[29] *Ibid*., 416.

manufacturing on the one hand, and managing the digital data that is the source of every additively manufactured parts.

The DND/CAF Data Strategy acknowledges the fact that the institution has been (and will continue) experimenting with data-driven technologies such as AM. But, how will this data be managed within the context of the new technology within an integrated supply chain? Evidently, manufacturing parts additively will not be possible without robust means of storing and maintaining the part design data that 3D printers use to fabricate the items. Parts and components fabricated using AM will sometimes be subject to changes in design by the original equipment manufacturer (OEM).[30] In such cases, the change may simply be a slight improvement in design or the correction of a previously identified flaw which can impact the performance or safe use of a part or piece of equipment. Leveraging the potential of AM will therefore require storing and maintaining thousands of CAD files. Change management would not be a CAF responsibility per se, but ensuring that OEM part design data can be tracked for changes and obtained so that any additively manufactured parts are fabricated according to the latest build will be important. But perhaps more importantly, the fact that AM relies on digital data to fabricate object calls for a need further develop data management guidelines and policies that specifically address this issue. Without the necessary framework to manage the data, achieving a suitable level of integration of AM in the supply chain will be arduous at best. The management of that information will require data infrastructure systems and associated policies that are not currently available within the DND/CAF

[30] Kidd *et al.*, "Additive Manufacturing: Shaping the Sustainment Battlespace," *Joint Force Quarterly: JFQ* no. 91 (Fourth, 2018): 43.

AM integration in the DSC may, in certain cases, require a shift from procurement of parts to procurement of part designs in data form. In many cases, IP will be sensitive data requiring systems of records and virtual storage providing an adequate level of cybersecurity to protect its integrity. From a policy standpoint, there is a requirement to standardize procedures when it comes to IP and patented parts and components in order to avoid any potential legal ramifications with manufacturing OEM parts. In an article from the Canadian Army published in 2019, it was explained that a maintenance platoon was able to create a new design for a fuel pump using the measurements from the OEM part. The purpose of redesigning the part by making alterations to the original specifications allowed for two things: making improvements to the overall part, but more importantly, avoiding any potential breach of IP.[31] While the approach taken might technically not encroach IP rights, it does however seem to skirt dangerously close to a threshold where an OEM could have a valid claim against the DND/CAF for wrongfully using a part design unless the IP was purchased as part of procuring the equipment. The ideal solution to avoid any IP infringement would be for the DND/CAF to acquire IP rights from the OEM. But purchasing IP rights can be complex business and there are important considerations to point out. First, the OEM may not be willing to sell property rights to maintain exclusivity and market competitiveness for part and components that are already in the DSC inventory. Second, the manufacturer may be willing to sell, but at a high price that could effectively make the investment in support of AM unappealing or outright unsustainable over the long-term. Third, and perhaps most relevant in the case

[31] Jessica Ross and Timothy Goldfinch, “Additive Manufacturing in LEMS – Repairing as Far Forward as Possible,” *Land Equipment Management System Journal*, issue 3 (September 2019): 20.

for AM integration in the supply chain, future acquisition projects would have to include procurement of IP rights as part of the procurement from the onset. The purchase of IP or digital computer digital data is not currently common practice within defence acquisition and the level of experience in that respect within the procurement workforce is arguably low. With an increased need to procure IP or data as part of integrating AM, procurement policies and procedures would need to be expanded to include how to best handle their purchase through contractual instruments. Essentially, AM integration into the DSC will cause a paradigm shift from buying spare parts to buying designs in digital format. In that regard, a review on the current policy to move towards in-service support contract (ISSC) for manufacturers to provide spare parts and maintenance services for various fleets of land vehicles, aircrafts and ships will have to be considered. Given that AM will arguably not see large-scale integration across the supply chain, there is no compelling argument for a complete departure from the ISSC model. However, AM integration will arguably call for a review of current and future ISSC to find efficiencies and avoid unnecessary duplication of capability. Another salient policy implication of integrating regarding IP is the concept of liability. Zijm *et al*. highlight the liability issue and rightfully pose the question as to who bears responsibility for part failure: the company who manufactured it or the one who designed it? [32] In a DND/CAF context, who becomes legally liable for damages and in what proportion if a part designed using a CAD file purchased from the OEM fails after being additively manufactured? There is currently no standardized legal

[32] Henk Zijm *et al*., "Additive Manufacturing and Its Impact on the Supply Chain," in *Operations, Logistics and Supply Chain Management*, ed. Henk Zijm et al., Lecture Notes in Logistics (Cham: Springer International Publishing, 2019), 524.

framework addressing such a scenario.[33] Arguably, legal considerations will be of critical importance in the development of AM policies.

Introducing a new technology such as AM on a larger scale and integrating it into the supply chain will inevitably require a concerted effort to ensure those involved in the manufacturing of parts have the requisite education and training. In turn, such changes will call for changes to policies in terms of recruitment, force structure, as well as training and education. AM may require changes to the current workforce structure. Depending on desired level of integration into the DSC, the CAF may have to consider the modification of qualification standard plans (QSP) to existing occupations within the services or even consider the creation of a new occupation altogether. The technological nature of AM and the technical skills required for anyone to operate a 3D printing system points to a potential need for an occupational review of technical occupations across the CA, RCAF and the RCN. Indeed, there is evidence suggesting that AM integration in private sector supply chains requires changes to employee "skill profiles and work structures".[34] A quick glance at a few of the existing occupations such as vehicle technicians and materials technicians (land), marine technicians (sea) or aircraft structures technicians (air), indicates that making changes to the QSP to include formal education and training on additive manufacturing technologies may prove to be a suitable strategy upon the initial implementation stage. However, a more holistic approach to

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[33] *Ibid*.

[34] Katrin Oettmeier and Erik Hofmann, "Impact of Additive Manufacturing Technology Adoption on Supply Chain Management Processes and Components," *Journal of Manufacturing Technology Management* 27, no. 7 (September 2016): 958.

develop a training policy with a long-term vision for AM will be required to sustain supply chain integration.

Integrating AM into the DSC will also require investment in education for the current workforce (both DND civilian and military personnel). In the mid to long term, the educational background for those trades that may have to use AM technology will have to be considered prior to workforce intake so that DND is hiring personnel with the skills to sustain the capability. As was mentioned earlier, part certification, quality assurance and quality control are essential aspects for integrating AM. Developing a policy that covers qualification standards and technical specifications is an essential step to reap the tangible benefits of AM. Consequently, policy compliance with technical standards for manufactured parts will demand a workforce that is trained to conduct those quality assurance and control activities. Given the complexity of these activities, implementation of an impromptu training program will arguably be both insufficient and inadequate to meet the required level of technical rigour. The requirement will be for a more holistic approach to build a formal training policy that incorporates the relevant knowledge and educational outcomes for military and civilian personnel who will act as technical authorities to certify additively manufactured parts.

There are also indications suggesting that the complex nature and fast evolving pace of AM technologies will be necessary from a defence acquisition standpoint. Indeed, a report released in 2018 by Defence Research and Development Canada under The Technical Cooperation Program umbrella concluded that military organization adopting AM will need to revisit the way they train their workforce in sourcing suppliers and evaluating contracts.[35] It is also important to recognize that AM integration in supply chain management will also bring a new dimension to procurement by introducing the acquisition of digital goods in addition to physical ones. Considering that procurement of digital media and software primarily falls under the purview of an organization external to the DND (Shared Services Canada), early adoption of AM in supply chain management by the DND/CAF will arguably suffer from a lack of functional expertise for acquiring digital goods such as CADs. In addition, research done on AM supply chain integration in the business sector indicates that success in implementation is highly dependent on an organization's ability to develop an increase in the technical knowledge pertaining to AM equipment and raw materials amongst its procurement workforce.[36]

CONCLUSION

There are clearly a lot of effort put forth within the DND/CAF to further explore AM, advance its use beyond the current *ad hoc* capabilities entrenched in *service silos*.[37] On the other hand, it is less clear how the department intends on ensuring these efforts converge to integrate the technology coherently within the context of the DSC in order to elevate it past the status of what is often regarded as a high-cost/low-yield niche capability. The premise of this paper was that there is a significant number of published research papers and technical studies focusing on broadly describing AM technologies and their potential military applications in a military supply chain, but very little attention has been paid to how they the technology would integrate in the DSC and the policy

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[35] Boukhtouta *et al.*, *Additive Manufacturing and Repair: Support & Distribution…*, 16.

[36] Katrin Oettmeier and Erik Hofmann, "Impact of Additive Manufacturing Technology Adoption on Supply Chain Management Processes and Components," *Journal of Manufacturing Technology Management* 27, no. 7 (September 2016): 956.

[37] Boukhtouta *et al.*, *Additive Manufacturing and Repair: Support & Distribution…*, 41.

implications of such an endeavour. AM integration into the Defence Supply Chain will call on the collaboration of various stakeholders from different branches and services of the DND/CAF (scientific, engineering, technical, and logistics). The multidisciplinary character of the issue will require a policy approach that is both joint and pan-departmental in nature. The aspiration of this paper was not to provide a detailed way ahead on whether there should be multiple separate policies addressing various aspects of AM integration vice one single overarching document encapsulating all the relevant aspects. Rather, it aimed to demonstrate that the path to harnessing the full potential of AM will be through supply chain integration through the development of policies that capture important facets outside of the technical realm in the areas of supply chain management, data management, and workforce management.

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