National Defence Défense nationale

Canadian Forces College

Collège des Forces Canadiennes

3D PRINTING MANDATES A SUPPLY CHAIN PARADIGM SHIFT

Major Chris Read

JCSP 45

Service Paper

Disclaimer

Opinions expressed remain those of the author and do not represent Department of National Defence or Canadian Forces policy. This paper may not be used without written permission.

PCEMI 45

Étude militaire

Avertissement

Les opinons exprimées n'engagent que leurs auteurs et ne reflètent aucunement des politiques du Ministère de la Défense nationale ou des Forces canadiennes. Ce papier ne peut être reproduit sans autorisation écrite

Canada

CANADIAN FORCES COLLEGE/COLLÈGE DES FORCES CANADIENNES
JCSP 45/PCEMI 45
15 OCT 2018

DS545 COMPONENT CAPABILITIES

3D PRINTING MANDATES A SUPPLY CHAIN PARADIGM SHIFT

By / Par le Major Chris Read

Word Count: 2,615

Nombre de mots : 2,615

3D PRINTING MANDATES A SUPPLY CHAIN PARADIGM SHIFT

AIM

1. The aim of this service paper is to identify factors unique to three-dimensional printing (3DP) technology that will disrupt the current supply chain paradigm. These factors will generate required adaptations for the supply chain and its implementation into Canadian Armed Forces (CAF) operations.

INTRODUCTION

2. 3DP, formally referred to as additive manufacturing (AM), is a disruptive technology that will cause a paradigm shift in how industry and defence departments manage materiel.[1] "The most significant benefits for defence forces relates to on demand manufacturing of spare parts very close [to] the point of need in the battlefield or at high sea."[2] The Technical Cooperation Program (TTCP) identified 13 benefits of AM pertaining to militaries; of significance to the CAF supply chain in the coming horizon are: "cost reduction in manufacturing and transport… reducing lead time and increasing land systems operational availability…on demand logistics sustainment… [and] reduced inventory management."[3] This widely accepted background for validating the practicality of AM will be used to treat the question: *how will 3DP technology affect the supply chain and supply chain management?*

3. The *Technology Innovation Management Review* journal published an article that consolidated the aims of 116 recent AM articles; most writings are focussed on key resources and activities. The research also found that supply chain discussions were limited and without tangible implications or recommendations.[4] TTCP research has consolidated AM challenges identified by various defence departments.[5] To interpret this breadth of data into a recommendation pertinent to this horizon (next 10 years), factors relevant to the supply chain have been grouped into three categories: risk, control measures and implementation.

DISCUSSION

4. Leveraging 3DP has associated risks if implemented in this horizon. These risks include product quality, product certification, production throughput and product security. These risks are inherent with the current state of the art and for the most part are predicted to be resolved over the coming decade.[6] The obvious mitigation of waiting-out the maturation of AM to avoid these concerns is not viable for three significant reasons outside the pragmatic technical realm. First, the federal 2017 budget lists AM as a priority targeted innovation field for the Government

---

[1] B. Colosimo, et al, "Opportunities and Challenges of Quality Engineering for Additive Manufacturing," *Journal of Quality Technology* 50, no. 3 (2018): 233.

[2] A. Boukhtouta, et al, *Additive Manufacturing and Repair, Support & Distribution*. Scientific Report. DRDC-RDDC-2017-R164 (Defence Research and Development Canada, 2018): 11.

[3] *Ibid*., 14.

[4] C. Öberg, et al, "Additive Manufacturing and Business Models: Current Knowledge and Missing Perspectives," *Technology Innovation Management Review* 8, no. 6 (2018): 19-20.

[5] A. Boukhtouta, et al, *Additive Manufacturing and Repair, Support & Distribution*. Scientific Report. DRDC-RDDC-2017-R164 (Defence Research and Development Canada, 2018): 22-40.

[6] *Ibid*., 6.

of Canada.[7] Second, a Gartner report makes the reasonable assertion that "the early adopters of 3DP will gain an important innovation advantage over their rivals".[8] Third, Cohen (political scientist with the state department) and Gooch (professor of international history) in their book *Military Misfortunes: The Anatomy of Failure in War* have determined

> that there are three basic kinds of [military] failure: failure to learn, failure to anticipate, and failure to adapt. They add that when two types of failure occur together, an "aggregate" failure will result, and then when three types of failure occur together, a "catastrophic" failure will result.[9]

These reasons, coupled with the time it will take to integrate this technology throughout the supply chain, dictate that the CAF cannot merely observe and wait for the field to mature before it orients, decides and adapts.

5. Product quality risk refers to AM processes which do not result in products with consistent material stress ratings, tensile strengths, fatigue resistance or accuracy. Some processes and materials result in defects such as pores, cracks and rough surfaces.[10] There are two options to mitigate quality risk. The first could be achieved by restricting the production of AM printed materials that commonly result in defects, or by only printing parts that have insignificant impacts upon part failure. This option reduces the number of parts that are eligible for AM. The second option is to create a product certification process to verify the quality of the item once printed. Depending on the product and its purpose, this can be as simple as a visual inspection using readily available optics technology. In cases where product failure will have impact on life or critical second order effects, a more vehement product certification process is needed.

6. Product certification risk for items with critical consequence potential must be mitigated by verifying geometric properties as well as internal material properties without compromising the item. This means leveraging existing non-destructive testing techniques. Unfortunately, non-destructive testing can be more complicated than AM. The question becomes at what point does it make sense for the supply system to opt to procure/stock/distribute the item vice print the item. Sometimes the item may not be available for procurement or prohibitively expensive due to obsolescence and/or scarcity. If this is the case, perhaps a limited number of third-line or fourth-line organizations are required to have AM and non-destructive testing capabilities to feed the supply chain below third-line. Likewise, deployed and second-line organizations could be restricted to items that can be reliably printed and certified.

7. Production throughput risk refers to the potential overreliance on AM resulting from items deliberately not being stocked. AM "is generally slow when compared to subtractive manufacturing. Currently, AM is better suited for low-volume production… commercial

[7] *Ibid*., 37.

[8] *Ibid*., 2.

[9] Military Misfortunes: The Anatomy of Failure in War 45

[10] B. Colosimo, et al, "Opportunities and Challenges of Quality Engineering for Additive Manufacturing," *Journal of Quality Technology* 50, no. 3 (2018): 236.

deployment of fast 3D machines is yet to be seen in the market."[11] This fact is of particular concern during operations with high consumption rates when the supply chain is already stressed. While the AM field matures, this can be mitigated by increased quantities of deployed printers; however, a printer farm increases the logistics footprint and reduces mobility. To mitigate, select Operational Support Hubs could have a permanent or temporary AM capability and even non-destructive testing equipment with technical personnel to shorten the supply chain and reduce reach back timelines. Given the high electricity loads and sensitivity of bulk production equipment this could mitigate large forward footprints and address surge requirements when forward AM suites become bottlenecks in the supply chain.

8. The final risk to AM is product security from a shield perspective. After interviewing AM researchers, Charles Choi, a science reporter, states that "3D printers will become attractive targets for cyberattacks because 3D-printed objects and parts are finding more and more use in critical infrastructures around the world."[12] It is easier and more discrete to sabotage a digital design (a computer file) than parts physically in the supply chain. A step further is the possibility of inserting files for parts that are not safe to print or for which the CAF does not own patent rights causing political turmoil. Should the CAF accept risk and operate AM software and hardware on unclassified systems or should this become a capability operated on classified systems adding to the complexity of implementation? Currently, almost all the CAF's holdings are on DWAN with minimal concern of adversarial tampering. If the CAF begins internal production of items, supply chain digital security will need to be balanced between ease of access and vulnerability.

9. Control measures addressing AM risks and legal considerations need to be integrated into the materiel management and distribution system. This additional governance must address quality assurance and quality control (QA/QC), categorising of printable items and design rights for those items (copyrights, patents, intellectual property, etc.).

10. QA/QC is a priority at the forefront of this disruptive technology's research and development.[13] This is because

> Proprietary polymers usually used for AM are weaker (sometimes also lacking uniform strength) than those used in conventional manufacturing. Metal objects fabricated by AM can lack the full density which can compromise toughness and fatigue properties of the AM metal object.[14]

[11] A. Boukhtouta, et al, *Additive Manufacturing and Repair, Support & Distribution*. Scientific Report. DRDC-RDDC-2017-R164 (Defence Research and Development Canada, 2018): 16.

[12] C. Choi, "Defending 3D Printers from Hackers," *Manufacturing Tomorrow*, August 18, 2017, https://www.manufacturingtomorrow.com/story/2017/08/ defending-3d-printers-from-hackers/10136/.

[13] B. Colosimo, et al, "Opportunities and Challenges of Quality Engineering for Additive Manufacturing," *Journal of Quality Technology* 50, no. 3 (2018): 234.

[14] A. Boukhtouta, et al, *Additive Manufacturing and Repair, Support & Distribution*. Scientific Report. DRDC-RDDC-2017-R164 (Defence Research and Development Canada, 2018): 17.

In the interim, materiel management controls can safeguard against AM items being employed beyond their capacity.[15] This can be done by restricting production of certain items. The support mechanism already exists; for example, adding metadata to the item in DRMIS or creating a stock code for printable items. A step further could be to have the AM print file linked to the item in DRMIS. Suffice to say, this is something that can be addressed in the information management realm if made a priority. The real complexity lies in determining which items can be printed given the number of variables that must be considered. The common industry philosophy for determining what should be AM printed is referred to as *non-critical, low risk* items. That is, items that if they do fail have an insignificant effect and the probability of them failing is low. In addition to this philosophy, AM is also restricted by the item's composition or material; not all materials can be AM printed. Another variable is whether it is cost-effective, taking into consideration unit value, scaling, warehousing and distribution costs. Furthermore, consumption rates of the item and availability may force the CAF to AM print the item regardless of cost-effectiveness. Given the vast number of items in DRMIS, it is necessary to translate these variables into an objective metric. Also, items need to be prioritised as these metrics need technical human input to determine if the item is printable, if it is cost-effective or if the item must be printed due to availability. Priority for this analysis should be placed on obsolescent items, discontinued spare parts, severely back-ordered items and "items with sporadic and slow-moving demand patterns"[16] Priority for production, once the metric has been satisfied, can be a print-on-demand option or a scaled option for fast-moving items.

11. An additional variable that must be included in the metric is legality. Legality encompasses copyright law, patent procurement, intellectual property protection and liability. If the CAF does not own the design or have permission to print an item, there are copyright ramifications. Determining if the CAF has the right to print an item must be part of the printing eligibility metric. If the CAF does not have permissions to print the item, then obtaining permission (through procurement and/or legal mechanisms) needs to be prioritised using the same logic as that proposed for the eligibility analysis. Unfortunately, some platforms have proprietary components which are not easy to obtain printing permissions for. To address this issue going forward, rights to AM print designs could be integrated into the initial statements of requirement and contracts. Taking this a step further, multiple articles assert that manufacturers have, and will increasingly, integrate AM into initial production lines; this means the analysis of which items can be AM printed will already have been completed. [17] The CAF can leverage this ground work if able to procure permissions during the contracting process or later in the life cycle if necessary.

12. Once a *print eligibility metric* is in place, the next challenge is procedure development to guide the implementation of AM within the supply chain. Print eligibility will influence inventory scaling at each level within the supply chain and therefore distribution writ large. It is reasonable to conclude that the list of eligible items will grow as both the technology and supply

---

[15] P. Zelinski, "From Functional Parts to Lots of Functional Parts, AM is Advancing into Production," *Additive Manufacturing*, September 26, 2018. https://www.additivemanufacturing.media/columns/from-functional-parts-to-lots-of-functional-parts-am-is-advancing-into-production.

[16] *Ibid*., 23.

[17] Prodways Technologies, "Prodways Group Presents its New Rapid Additive Forging Technology for the 3D Metal Printing of Large Parts," *Manufacturing Tomorrow*, June 16, 2017, 1.

chain mature. To embrace this inevitability, AM procedures need to include personnel/equipment requirements and concepts for when and where to employ AM throughout the chain.

13. From a supply chain perspective, the equipment will be managed using existing materiel control mechanisms. The material (i.e. powders) used for AM will be *consumable stock* as it would be cumbersome to issue and control print materials by mass or volume. In some circumstances, it may be prudent to control print material issue due to its value. For example, gold is an excellent conductor and is an AM printable material that could be used for circuits. It is also reasonable to assume that as AM matures that it will include more and more lucrative material types. Based on an assessment of each AM material, the supply chain will need to increase controls on some materials; albeit, most common materials will be comparatively low value polymers and metals. Likewise, once the item has been manufactured, it needs to be taken on charge and based on the stock code assigned to the item in DRMIS; materiel managed accordingly using a process similar to the local procurement mechanism. Some items, such as parts, are returned to the supply system; however, if a broken item has been printed in the system, is there any point in controlling it in the same manner? Arguably, if the item is printable, there is no point in refurbishing it and it should be written-off. These eventualities can be controlled using a stock code in DRMIS or an additional item *AM Code* that informs the technician how to respond to these situations without the need for deliberation each time a part is printed. This AM Code could also specify copyright restrictions for the digital design file identified above.

14. This added complexity to the supply chain not only requires engineering input and integration of design rights into procurement, it also places more emphasis on the technicians. The CAF must decide which trade(s) or new trade is responsible for the physical printing of items. The technology is not mature enough to assume that a supply technician can simply push a button on a printer and get an item without technical expertise. Supply technicians will need to be trained on changes to the materiel management system such as stocking of AM print material, but it is unreasonable to expect that they will have the manufacturing aptitude for item/parts certification until such time that the AM has developed into a highly reliable and user-friendly process. The requirement for AM trained personnel does not necessarily mean more burden on uniformed trades. As mentioned earlier, obtaining printing rights can be addressed by a DND employee. Similarly, an item could be centrally designed by a contractor and emailed to a unit, ship or theatre for printing. A benefit of AM not commonly discussed is the ability to decentralise the process with connectivity as the only risk. That is to say, the print file can be designed or procured anywhere and digitally distributed to a print location. This implies that only deployed print locations would need to be uniformed personnel. The Operational Support Hub print location option could also leverage civilian employees or contractors. Maintenance and supply organizations throughout the CAF would still need trained print personnel to maintain a deployable experienced and qualified cadre. Integrating DND employees and contractors into AM procedures might even allow the AM printing and certification skillset to be a qualification vice a new trade. This qualification could even be open to various trades and ranks from signallers to engineers to supply technicians. This would also allow DND to recruit civilian specialists for a technical role without the training bill of uniformed personnel.

CONCLUSION

15. AM is a technology that has matured to the point where it behooves the CAF to learn the technology, anticipate its challenges and adapt in order to avoid failure. AM is a disruptive technology requiring adaptations to the supply paradigm.[18] The idea that the supply chain can manufacture items internally and that these items are subject to both adversarial and process compromise requires both item and design shield. The spread of item manufacturing will require adaptations to materiel management and DRMIS to control the process from raw materials to inventory scaling to taking on charge of finished items. Technical personnel requirements means striking a balance in AM specialties amongst employees, members and contractors as well as AM suite locations throughout the supply chain. This technology should be decentralised throughout the supply chain based on required expertise and logistics footprint leveraging existing infrastructure such as Hubs, procurement and maintenance organizations. Not all locations require the same level and breadth of AM capability. Higher level procurement, blueprinting and legal organizations will focus on designs and copyrights. High risk items requiring complex certification will not be printable at all locations. Item complexity and demand will determine print location and expertise requirements. Until such time that limitations of AM are overcome, eligible print items should be focussed on obsolescent, severely back-ordered and slow-moving items. To mitgate risks and implement control measures, the CAF must adapt existing systems to build a capability comprised of various expertise sets, policy and equipment catered to the local need.

RECOMMENDATION

16. It is recommended that priority items for AM printing be identified and metrics developed to determine eligibility for printing. The results of this analysis should be integrated into the items' metadata in DRMIS. This knowledge will drive the specific types of AM technology for procurement. The CAF should then leverage industry training to develop a cadre of qualified personnel as well as hire or contract technical expertise that is beyond internal capacity. AM policies, coupled with available expertise and equipment, will determine throughput and in turn drive capability positioning and inform inventory scaling.

---

[18] B. Colosimo, et al, "Opportunities and Challenges of Quality Engineering for Additive Manufacturing," *Journal of Quality Technology* 50, no. 3 (2018): 233.

BIBLIOGRAPHY

Boukhtouta, A., J. Berger, S. Baker, D. Mitchell, B. Short, and J. Wilson. *Additive Manufacturing and Repair, Support & Distribution*, Scientific Report, DRDC-RDDC-2017-R164, Defence Research and Development Canada, March 2018.

Choi, Charles. "Defending 3D Printers from Hackers." *Manufacturing Tomorrow*, August 18, 2017. https://www.manufacturingtomorrow.com/story/2017/08/ defending-3d-printers-from-hackers/10136/.

Cohen, Eliot A. and John Gooch. *Military Misfortunes: The Anatomy of Failure in War*. 1st Free Press pbk. ed. New York: Free Press, 2006.

Colosimo, Bianca M., Qiang Huang, Tirthankar Dasgupta, and Fugee Tsung. "Opportunities and Challenges of Quality Engineering for Additive Manufacturing." *Journal of Quality Technology* 50, no. 3 (2018): 233-252.

Marr, Bernard. "7 Amazing Real-World Examples of 3D Printing in 2018." *Forbes*, June 16, 2017. https://www.forbes.com/sites/bernardmarr/2018/08/22/7-amazing-real-world-examples-of-3d-printing-in-2018/#6297b3586585.

Öberg, Christina, Tawfiq Shams, and Nader Asnafi. "Additive Manufacturing and Business Models: Current Knowledge and Missing Perspectives." *Technology Innovation Management Review* 8, no. 6 (2018): 15-33.

Prodways Technologies. "Prodways Group Presents its New Rapid Additive Forging Technology for the 3D Metal Printing of Large Parts." *Manufacturing Tomorrow*, June 16, 2017. https://www.manufacturingtomorrow.com/story/2017/06/ prodways-group-presents-its-new-rapid-additive-forging-technology-for-the-3d-metal-printing-of-large-parts/9843/.

Zelinski, Peter. "From Functional Parts to Lots of Functional Parts, AM is Advancing into Production." *Additive Manufacturing*, September 26, 2018. https://www.additivemanufacturing.media/columns/from-functional-parts-to-lots-of-functional-parts-am-is-advancing-into-production.