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ADDITIVE PRINTING AND THE CANADIAN FORCES SUPPLY CHAIN: REDUCING REACH-BACK AND OPERATIONAL RESPONSIVENESS

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Service Paper

ADDITIVE PRINTING AND THE CANADIAN FORCES SUPPLY CHAIN: REDUCING REACH-BACK AND OPERATIONAL RESPONSIVENESS

By Major D.W. McCarthy

ADDITIVE MANUFACTURING AND THE CANADIAN ARMED FORCES

AIM

1. The aim of this paper is to outline the future viability of harnessing additive printing technology to address logistical challenges facing the Canadian Armed Forces (CAF) Logistics Branch. It will focus on the Additive Manufacturing (AM) process and how it can affect the supply chain within the CAF and its management. This will be conducted by discussing a variety of critical considerations (cost savings, reduction in delays, physical holdings, etc.) that need to be reviewed before amending existing CAF supply chain practices. Throughout, an ongoing discussion regarding how AM could be employed in a deployed environment will be addressed and how AM can reduce reach-back, shorten delay times and stock holdings. In concluding a recommendation will be provided on the way forward for the CAF as it relates to AM.

INTRODUCTION

2. Technologies today are advancing at a pace faster than ever observed in history. As with many militaries around the world, the CAF is not excluded from budgetary restraints, balancing of resources support systems and kinetic capabilities and the requirement to remain at the forefront of operational readiness and responsiveness. Any advantages that can be leveraged to reallocate resources in an operationally sound manner, while improving the overall defence support system should be actively pursued. AM has demonstrated that it has the potential to provide answers to many of these present-day challenges.

3. AM can be defined as a process that creates an object by joining material from the bottom-up, rendering a three dimensional object.[1] This process is fundamentally different from the commonly used practices of Subtractive Manufacturing (SM) where an item is generated from shaping of a solid piece of material into a finished commercially ready product. Already after a review of the definitions of AM and SM, one can immediately identify that there will be a savings related to wastage of material between the two processes. [2]

3. As the industry continues to advance the limitations of this technology, it is becoming more obvious that using these methods to augment our supply chain management has undeniable benefits within the CAF. These benefits can be used for both regular as well as deployed operations sustainment. Lending credibility to the AM processing movement, notable companies are investing into AM including; GE, NASA, Lockheed Martin, Boeing and Aurora Flight Sciences (unmanned aerial vehicles).[3] With leading edge industrial influencers adopting AM, it is not a matter of if it will become mainstream, but when (demonstrated in fig 1.1 below). Future

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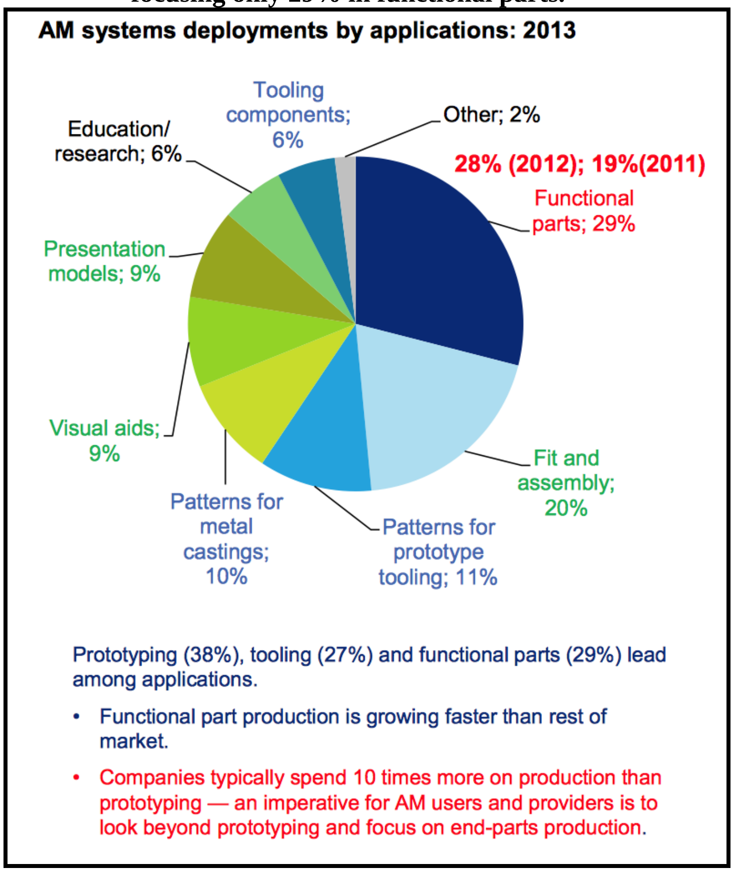
[1] A. Busach, J. Erkoyuncu, P. Colegrove, R. Drake, C. Watts, and S. Wilding. "Additive Manufacturing applications in Defence Support Services: Current Practices and Framework for Implications." *International Journal of System Assurance Engineering and Management, Vol 9, Issue 3,* (June 2018).

[2] Connor M. McNultry, Neyla Arnas, and Thomas A. Campbell. "Toward the Printed World: Additive Manufacturing and Implications for National Securtiy." *Defense Horizons*, Journal No. 73, (2012).

[3] Timothy A. Moore, Timothy, "Evaluating the Augmentation of Army Resupply with Additive Manufacturing in a Deployed Environment." *North Carolina State University Graduate Thesis*, 2018.

benefits of AM include decreased inventory levels, reduced delay times, and increased efficiency of labour resources and lower operating costs. CAFs early adopting and embracing of the future of supply chain management would demonstrate forward thinking, implementation of leading edge sustainment technologies and maximization of available resources.

Figure1.1. Illustrating where the AM technology focusing only 29% in functional parts.



Dr. M. J. Cotteleer, "3D Opportunity: Additive Manufacturing Paths to Performance, Innovation and Growth." Additive Manufacturing Symposium, *Deloitte Services*, 2014.

DISCUSSION

4. The CAF currently holds a large portion of the Federal material holdings of which a sizable portion of these holdings rest within warehouses for platforms and their spare parts components. Infrastructure to manage the material support demands requires a significant allocation of the defence budget and as such prevents a greater focus on other departments within the CAF. However, CAFs ability to manage these resources has been under scrutiny recently by the Federal Government. As identified by the Auditor General "National Defence did not adequately manage the resources used to support military equipment in a cost-effective manner, to meet operational and training requirements."[4] These findings can be directly tied to the

[4] Kevin Sorenson, "Report 7, Operating and Maintenance Support for Military Equipment – National Defence, of the Fall 2016 Reports of the Auditor General of Canada." *Canada, House of Commons*, (June 2017). http://publications.gc.ca/collections/collection_2017/parl/xc16-1/XC16-1-1-421-29-eng.pdf

challenges that are inherent within the existing supply system and its struggle to meet the operational demands of the military. CAF has demonstrated that we as an organization "overestimated equipment use, underestimated support costs, and under-resourced personnel requirements, which led to higher costs and reduced equipment availability."[5] It is imperative that we address these findings and harness new technologies such as the recently adopted SAP based DRMIS program and advancing technologies similar to AM.

5. **Supply Chain Integration and Stock Levels.**

a. As the CAF looks to streamline and improve the efficiency of its supply chain and support practices, the greatest savings of resources will inevitably come from improved inventory management. Inventory is considered an ill-structured cost, where capital is tied up in line items that are unused.[6] In order to meet the immediate operational demands of the CAF, stockpiling is required and the establishment of warehousing levels is based on historical information generated from the unpredictability of demand.[7] While these items remain on shelves they continue to deteriorate and eventually become obsolete, generating a disposal requirement and additional labor to remove items from inventory and make adjustments in the system. [8] Human error costs DND millions of dollars annually, adjusting inventory levels based on inaccurate data. AM represents a new customizable technology where automation can reduce these errors and improve cost efficiency.[9] There is a significant cost to the management and warehousing of slow moving items that will be covered in a follow-on section. Through the use of AM, there can be a reduction to the number of overall line items within warehouses, which will improve accuracy of stocktaking and material accountability. The ability to self-manufacture items traditionally stored within a warehouse will eliminate these ill-structured costs associated with the line items being self-manufactured. The potential of integrating AM into a spare parts warehouse as outlined in Tab.1. below.

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[5] A. Busach, J. Erkoyuncu, P. Colegrove, R. Drake, C. Watts, and S. Wilding. "Additive Manufacturing applications in Defence Support Services: Current Practices and Framework for Implications." *International Journal of System Assurance Engineering and Management, Vol 9, Issue 3*, (2018). 14.

[6] Ibid.

[7] Yao Li Guozhu, Yang Cheng, and Yuchen Hu. "Additive Manufacturing Technology in Spare Parts Supply Chain: A Comparative Study." *International Journal of Production Research*, (2016).

[8] Timothy A. Moore, Timothy, "Evaluating the Augmentation of Army Resupply with Additive Manufacturing in a Deployed Environment." *North Carolina State University Graduate Thesis*, 2018.

[9] Ibid.

Tab. 1. Value range of spare part attributes that indicate improvement potential with AM technology

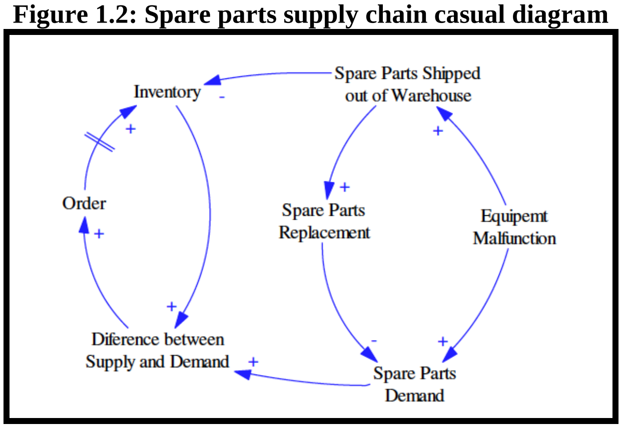
		Improvement potential						
		Reduce manufacturing/ order costs	Reduce direct part usage costs	Reduce safety stock costs	Improve supply chain responsiveness	Postponement	Temporary fix	Reduce effect of supply disruptions
Spare part attributes	Demand rate	Low		Low		Low		
	Resupply lead time			Long	Long	Long	Long	
	Agreed response time			Short	Short		Short	
	Remaining usage period		Long					
	Manufacturing/ order costs	High						
	Safety stock costs			High		High		
	Number of supply options	Few			Few			Few
	Supply risk				High			High

Read: If spare part attribute 'x' belongs to value level 'y' then this indicates improvement potential 'z'.

Knofius, N., M.C. van der Heijden, and W.H.M. Zijm. "Selecting parts for Additive Manufacturing in Service Logistics. (working paper)." *University of Twente*, (September 2016).

b. The integration of AM technology will reduce the steps resident within the supply chain and improve material availability to maintain operations.[10] (Traditional spare parts replenishment system outlined below Fig 1.2) Having a self-manufacturing capability eliminates will immediate need to hold thousands of items in domestic and deployed warehouses and can replace them with the required raw materials. Additionally, having an AM capability fully operational within a deployed operation reduces the reach-back requirements for the organization. Integration of this technology within the CAF will require first a greater acceptance by industry, rigorous testing and an initial identification of components to be integrated. This process will be lengthy and given the current capabilities of the AM industry, is a strong indicator that although the technology will be revolutionary, the CAF should monitor and foster its advances but not move to implement at this early stage.

Figure 1.2: Spare parts supply chain casual diagram



Guozhu, Yao Li, Yang Cheng, and Yuchen Hu. "Additive Manufacturing Technology in Spare Parts Supply Chain: A Comparative Study." International Journal of Production Research, (2016).

[10] Yao Li Guozhu, Yang Cheng, and Yuchen Hu. "Additive Manufacturing Technology in Spare Parts Supply Chain: A Comparative Study." *International Journal of Production Research*, (2016). 3.

6. **Time to Support and Transportation.**

a. Today the CAF provides logistical support using a Just-In-Time (JIT) delivery model, where goods and materials are delivered as stockholding levels become depleted. This model enables reduced levels to be held within warehouses, but assumes increased risk as warehouses become operationally strained. AM technology addresses this concern and shifts the model to a JIT manufacturing model. This shift creates a leaner supply chain with lower costs and increased responsiveness.[11] Additionally, supply moves from a back-end structure to front-end structure eliminating/reducing administrative and manufacturing delays to logistics support. [12] Fewer steps along the way reduced chance of delay and disruptions.[13] This becomes especially important when operating in a contested environment; where lines of support can be compromised and the ability to address battle damage is limited.

b. Long standing challenges to move material from a stored location to a customer's location has been the continued struggle of military logisticians. Strategic Lines of Communications (SLOC) are established to provide material support but these SLOCs range from very costly for airlift options to very slow if a sea support option is selected. An example of this can be seen from the deployment of material in support of Canada's contribution to MINUSMA in MALI where airlift was utilized almost exclusively costing in excess of $20M to project and establish approximately 250 soldiers into the Area of Operations (AOR). Using AM technology, long lines of support can now reduced and material can be provided immediately on site within a deployed location almost immediately. The financial savings associated with this new capability can now be diverted elsewhere to support kinetic action or soldier survivability initiatives.

7. **Reliability.**

a. "Cost is usually the key point for decision-making, with break-even points for different manufacturing technologies being the dominant information for decision-makers."[14] This statement holds true with commercial industry; however, with the development of any new technology within a military, safety remains the paramount concern, especially as it relates to component parts for aircraft, and weapons system. Flight safety programs ensure the airworthiness of

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[11] Timothy A. Moore, Timothy, "Evaluating the Augmentation of Army Resupply with Additive Manufacturing in a Deployed Environment." *North Carolina State University Graduate Thesis*, 2018.

[12] A. Busach, J. Erkoyuncu, P. Colegrove, R. Drake, C. Watts, and S. Wilding. "Additive Manufacturing applications in Defence Support Services: Current Practices and Framework for Implications." *International Journal of System Assurance Engineering and Management, Vol 9, Issue 3*, (June 2018).

[13] Timothy A. Moore, Timothy, "Evaluating the Augmentation of Army Resupply with Additive Manufacturing in a Deployed Environment." *North Carolina State University Graduate Thesis*, 2018.

[14] Yao Li Guozhu, Yang Cheng, and Yuchen Hu. "Additive Manufacturing Technology in Spare Parts Supply Chain: A Comparative Study." *International Journal of Production Research*, (2016).

aircraft and the provision of an alternative method to attain spare parts has to meet or exceed the requirements currently established by the various safety programs within the CAF. There is an ever present concern relating to the quality control capabilities of a particular component part produced via AM. AM sampling is challenging because quality control and parts certification generated by AM are productions runs of one.[15] However, SM or traditional manufacturing quality control can be tested on a batch of items to determine if they meet the component specifications. "Once components are identified geometrics need to be processed in real life to understand how the AM technology can print this component"[16]

b. A key component for CAF consideration is the availability of obsolete parts. As DND routinely maintains various platforms well beyond normal life-cycle estimates, the availability of parts increasingly becomes problematic. AM technology provides the means to manufacture parts that are no longer commercially available or available with long wait times due to specialized manufacturing requirements. Having the ability to manufacture these parts ensures that operational downtime is minimized and that damaged platform Vehicle Off Road (VOR) rates are reduced.[17]

8. **Contracting and Financial Impacts.**

a. Operating within a climate of reduced funding, financial managers continually searching for and encouraging initiatives to develop leaner organizations. This section will be divided into two sections, Contracting and Procurement and Adoption Cost Savings.

(1) <u>Contracting and Procurement</u>.

(a) Before any adoption of AM can be incorporated with the CAF structure there needs to be a shift of industry thinking to contracting for availability; where an awarded contract is established to provide sustainment for a platform or capability over an extended period of time. Similar to the Performance Based Logistics (PBL) model where contractors are paid based on measurable performance targets. Contracting for availability seeks to sustain a capability at an agreed upon level of readiness over an extended period of time. These models are significant deviations from traditional contract arrangements where suppliers are typically paid according to the throughput of 'spares and repairs'.

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[15] Ryan Crean, "Benchmarking DoD Use of Additive Manufacturing and Quantifying Costs." Air Force Institute of Technology AFIT Scholar, (2017).

[16] A. Busach, J. Erkoyuncu, P. Colegrove, R. Drake, C. Watts, and S. Wilding. "Additive Manufacturing applications in Defence Support Services: Current Practices and Framework for Implications." *International Journal of System Assurance Engineering and Management, Vol 9, Issue 3*, (June 2018).

[17] Ibid.

[18] More than 75% of all DND platform lifecycle costs are committed to the maintenance and spares parts components associated with its support throughout the items amortized life cycle.[19] Significant negotiation would have to occur with industry when procuring support packages and there would have to be a provision of intellectual property programed within the contract that provides an ability to use the technology. Industry may not be capable of meeting these requirements in its current capacity for DND supply chain requirements.

(b) Regardless of contracting domestically or abroad, there is no denying that the Canadian procurement cycle is cumbersome. At times this system is unable to meet the fast paced demands of the CAF. Finding alternative ways to reduce the procurement cycles, reduce the logistical tail to support operations will only optimize the CAFs responsiveness and effectiveness. An example of where AM technological benefits could be employed would be within the CAF initiative to establish seven Operational Support Hubs (OSH) globally. These OSHs are strategic logistical locations that would enable the support to operations to commence with minimal delays. Currently, these OSHs consist of stockpiling of materials of difference classes with contracting mechanisms established to bridge the gaps until additional material could be delivered. These actions could be addressed through the staging of AM equipment and the required production raw materials. Leveraging AM technology could reduce the requirement to warehouse/procure tens of thousands of line items where multiple contracts would have to be raised. "AM-based supply chains are indeed superior to the conventional one in terms of total cost variable."[20]

(2) Adoption Cost Savings.

(a) There is a cost to holding line items and support organizations scale their requirements well above an optimum level to ensure that the unknown circumstances are accounted for in an attempt to reduce operational down time. This is not a fiscally responsible model and is not the most effective use of resources. Cost for

[18] Erkoyuncu, J.A., R. Roy, E. Shehab, and P. Wardle. "Uncertainty challenges in service cost estimation for product-service systems in the aerospace and defence industries."*Cransfield University CERES*. (2009).

[19] Ibid.

[20] Guozhu, Yao Li, Yang Cheng, and Yuchen Hu. "Additive Manufacturing Technology in Spare Parts Supply Chain: A Comparative Study." International Journal of Production Research, (2016).

production can be reduced as procurement planning can easily be integrated into DND FY budgeting structure.[21]

(b) Resource availability continues to become scarce and DND needs to be maximizing environmentally responsible options when awarding contracts.

(c) Current technology is not low cost enough to replace current traditional manufacturing.[22] US Army Logistics Innovation Agency – Concluded that while using AM to produce an item could cost 3-28 times more than using traditional methods, AM could reduce wait time by 6%-99%.[23] Of note, complexity is free and modifications to an existing design can be altered at no additional cost.[24] This new design could strengthen the component that would not normally be possible.[25]

CONCLUSION

9. AM is not the answer to improving the CAF supply system and is still in its infancy with respect to its capabilities; however, early access into to adopting of this technology as it advances will ensure that the CAF remains an active player in support logistics and focused on establishing a lean capable support organization. Early adoption of this budding technology will ensure that as the technology advances and industry evolves, support experts will consider AM in future contracts. These contracts can then push defence contractors to integrate this capability into their business models. Training and early exposure to these technologies will foster a climate of reducing existing holdings for alternative support solutions.

RECOMMENDATION

10. It is recommended that the CAF deliberately become involved with the integration and development of future capabilities regarding AM. Nearly all academics agree that AM will serve best as a complement to machining rather than outright replacement.[26] This integration should

[21] Ryan Crean, "Benchmarking DoD Use of Additive Manufacturing and Quantifying Costs." Air Force Institute of Technology AFIT Scholar, (2017).

[22] Timothy A. Moore, Timothy, "Evaluating the Augmentation of Army Resupply with Additive Manufacturing in a Deployed Environment." *North Carolina State University Graduate Thesis*, 2018.

[23] Ryan Crean, "Benchmarking DoD Use of Additive Manufacturing and Quantifying Costs." Air Force Institute of Technology AFIT Scholar, (2017).14.

[24] Connor M. McNultry, Neyla Arnas, and Thomas A. Campbell. "Toward the Printed World: Additive Manufacturing and Implications for National Securtiy." *Defense Horizons*, Journal No. 73, (2012).

[25] Ryan Crean, "Benchmarking DoD Use of Additive Manufacturing and Quantifying Costs." Air Force Institute of Technology AFIT Scholar, (2017).

[26] M. Bogers, Hadar, R., and Billberg, A. "Additive Manufacturing for Consumer-centric business Models: Implications for Supply Chains in the Consumer Goods Market. Technological Forecasting and Social Change, 225-239.

initially be conducted on a limited capacity, ensuring that as industry advances there is a small element that remains current on advancing trends. Early access into this sector generating a nucleus of experts will allow for quick integration of the technology once it reaches operational supportability.

11. Harnessing the advancing technology of AM as early as possible will not only permit a progressive introduction of this capability into the CAF but it will allow for the training and institutional transformation to occur from decades old models of scaling large warehouses to a more responsive and on demand system. Stepping to this technological table early regarding additive printing could enable the CAF to be a world leader in logistical support modeling and simultaneously enabling our forces to maximize ever reducing budgets.

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