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ENABLING FUTURE OPERATIONAL SUSTAINMENT: 3D PRINTING IN THE JOINT OPERATIONAL SUPPLY CHAIN

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AIM

1. Additive Manufacturing, otherwise known as 3D printing, has the potential to alter defence organizations in areas such as automation, logistics delivery and supply chain management.[1] The market for 3D printing has evolved at a rapid pace over the past decade to an estimated USD 800 Million in 2018 with an estimated growth to USD 4,594.4 Million by 2025.[2] This service paper is written for Chief of Staff Operational Support (COS Sp) at Canadian Joint Operational Command (CJOC) HQ. It's aim is to provide a detailed summary to explain the current capabilities with respect to advances in 3D printing technology, both now and in the future. It will offer suggestions as to how this technology could potentially be leveraged in a joint operational setting while considering challenges and timelines associated with any potential implementation.

INTRODUCTION

2. In its simplest term, 3D printing should be considered as the ability to manufacture a custom requirement in a rapid fashion at the press of a button. The opposite of subtractive manufacturing, i.e. machining, this is a form of additive manufacturing which endeavours to create physical objects by adding several layers of thin material together, under the direction/program of a digital design.[3] This process provides several advantages that could be leveraged to great effect within a military operational context, specifically with respect to supply chain management. There are some excellent examples of 3D printing technologies already in use by foreign military that will be referred to later in this paper that will assist in understanding the potential utility of this process.

3. The discussion will first delve into specific potential capabilities of 3D printing in an operational context within the Canadian Armed Forces (CAF). It will focus on current practices while discussing how 3D printing technology could provide a positive and effective impact to joint supply chain management. The second theme will focus on the distinct and numerous challenges associated with the implementation of 3D printing technologies. It will consider areas such as realistic timelines, costs, intellectual property (IP) and quality assurance. Finally, the paper will offer a clear recommendation to allow the CAF to pursue 3D printing technology in a systematic and logical approach with an emphasis on supporting current and future operations across the globe.

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[1] Boukhtouta, A, J. Berger, S. Baker, D. Mitchell, B. Short, J. Wilson. "Additive Manufacturing and Repair". Defence Research and Development Canada, March 2018.

[2] PR Newswire. "Military 3D Printing Market Worth 4,594.4 Million USD by 2025". PR Newswire Association LLC 4 May 2018. https://search.proquest.com/docview/2034314510/fulltext/7AFCCBC4AE1C4EB4PQ/1?accountid=9867

[3] Veronneau, Simon, Geoffrey Torrington and Jakub P. Hlavka. 3D Printing: Downstream Production Transforming the Supply Chain. RAND Corporation, 2017.

DISCUSSION

4. For the purpose of this paper, the focus will be on perhaps the most immediate and technologically feasible usage of 3D printing: the ability to manufacture and repair equipment components geographically close to the area where they are immediately needed.[4] This concept alone has the potential to change our support doctrine, whether this be for land, sea or air operations in a meaningful way. There are risks associated with the implementation of such a rapidly growing technology sector, specifically in the area of metal 3D printing, where the process is not as developed as it is for plastics.[5] Highly complex metal processes are not projected to be available in the mainstream in the next few years, however, plastic composite printers that could be used to manufacture some spare parts appear close to mass production.[6]

Capabilities of 3D printing

5. In order to understand the potential benefits to the CAF operational supply chain, we will examine the general benefits that could be achieved through the proper implementation of 3D printing technology.[7]

a. Cost Reduction in Manufacturing and Transport. 3D printing could reduce manufacturing and transport costs by allowing for the production of parts in situ with generic bulk material, vice the stocking and shipping of specific replacement parts.

b. "Mass" Customization. The ability to manufacture multiple objects from a single 3D printer, allows for a great deal of flexibility with a relatively small footprint.

c. Reducing Lead Time and Increasing Equipment Operational Availability. The ability to repair a part within a theatre of operations in relatively short order will significantly reduce the amount of equipment downtime, directly improving combat effectiveness for deployed Commanders.

d. On Demand Logistics Sustainment. Future equipment procurement strategies should consider the ability to 3D print replacement parts. Specifically goods/products that come in multiple sizes and take up valuable storage space would make excellent candidates for on-demand sustainment. Weapons printing is one area that the U.S. Army is currently investigating, having already successfully printed and tested some small arms.

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[4] Dundon, Robert, Quality Engineering Test Establishment. "Director General Land Equipment Program Management Report on Additive Manufacturing Capability Development" 202 Workshop Depot, May 2017.

[5] ibid

[6] Veronneau, Simon, Geoffrey Torrington and Jakub P. Hlavka. 3D Printing: Downstream Production Transforming the Supply Chain. RAND Corporation, 2017.

[7] Boukhtouta, A, J. Berger, S. Baker, D. Mitchell, B. Short, J. Wilson. "Additive Manufacturing and Repair". Defence Research and Development Canada, March 2018.

e. Reduced Inventory Management. As alluded to above, the concept of on-demand logistics sustainment could drastically reduce the footprint requirements of theatre level support bases. This would not only save money in infrastructure savings, but would also realize 2nd and 3rd order savings such as reduced Force Protection requirements.

f. Robotics. 3D printing could enable the manufacturing of small robotic systems on operations. For example, the U.S. and Australian Defence forces are in development of 3D printing of UAVs and drones to assist with intelligence gathering on the battlefield.[8]

g. Enhanced Training Experience. Common to plastics 3D printing is the ability to produce models and replicas for the purpose of enhancing the realism of training scenarios. The creation of life-like targetry for kinetic ranges is also possible.

h. Surveillance & Rescue Operations. As with robotics above, the capability to print micro-UAV on demand directly leads to an increase in situational awareness for soldiers on the battlefield. In addition, the rapid and precise modelling (printed) of an area of operations would assist Commanders' decision making process.

i. Coordination in a Multi-Ethnic/Multinational Environment. When considering joint international and humanitarian operations, the ability to produce on demand (and unforeseen) requirements to assist others in need, cannot be understated and would only benefit the image of the CAF and Canada in the international community.

j. Faster & Challenging Mission Planning. The potential benefits of rapid resupply must not only be considered in the friendly forces estimate, but it also must be considered that future adversaries will also have access to the same technology.

k. Macro Printing. There have been examples of 3D printing being leveraged to create infrastructure such as bridges and houses. Although this is a much more advanced usage of the technology, the potential benefits to support humanitarian disasters or the creation of affordable housing in third world nations cannot be understated.

l. Food Printing. This is in very early stages, but the concept is to use 3D printing technology to customize meals for each soldier based on nutritional requirements.

6. While many of the capabilities listed above are not widely available and many of their processes are arguably too early for wide scale implementation, there are examples of foreign militaries who are currently exploring these capabilities in limited fashion.

[8] ibid

One recent example is the U.S. Navy who had some sailors reverse engineer and 3D print a replacement cooling fan motor for $1.39 per fan, compared to a $375 replacement purchase price.[9] At the same event the keynote speaker, Dr. John Burrow, deputy assistant secretary of the Navy for research and development stated "additive manufacturing is a potential game-changing technology for naval warfare. It accelerates capability development and will increase our readiness by reducing obsolescence or long lead time issues."[10] In a resource constrained environment, such as the CAF, access to a capability such as 3D printing could help us achieve an advantage over our adversaries on operations.

Limitations of 3D Printing

7. Due to inherent limitations, 3D printing has mostly been utilized in the manufacturing of prototypes, scale models, one-of-a-kind products and even some short production runs.[11] There is risk with early entry in a rapidly evolving technology and conversely there is also potential risk in waiting too long. In order for the CAF to consider a large investment into 3D printing technology, it is essential that these limitations are known and attempts are made to mitigate them where possible. Some key limitations include:[12]

a. <u>Throughput</u>. 3D printing is a slow process when compared to traditional manufacturing or machining methods. Currently this means that 3D printing is limited and scope to specific low-volume manufacturing. Technology improvements will likely address this limitation in the future.

b. <u>Production Cost</u>. Both the acquisition cost of the 3D printer and the bulk material must be considered. A rough order of magnitude on cost is $300K to $1.5M for the printer and upwards of $200/kg for raw material. There will be a practicality to a cost-benefit analysis versus traditional manufacturing methods in support of CAF operations.

c. <u>Material Properties</u>. There are current limitations to the material available in 3D printing. Plastic material is generally weaker in strength and 3D metals can lack the toughness and fatigue properties of traditional manufacturing materials. The process for producing multi-material objects is still in development and 3D printing of transparent material such as glass is currently not possible. Advances in technology continue to try and bridge these gaps.

d. <u>Change in Work Balance</u>. As the technology becomes mainstream, it will create operator and IT style positions, while eliminating manual labour

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[9] Joyce, John. "Navy and Marine Corps Showcase 3D Printing Innovations and Impact at Pentagon Expo". CHIPS Magazine, Jan-Mar2017.

[10] ibid

[11] Rogers, Helen, Norbert Baricz, Kulwant Pawar. "3D printing services: classification, supply chain implications and research agenda". International Journal of Physical Distribution & Logisttics Management, Bradford Vol. 46, Iss. 10. 2016.

[12] Boukhtouta, A, J. Berger, S. Baker, D. Mitchell, B. Short, J. Wilson. "Additive Manufacturing and Repair". Defence Research and Development Canada, March 2018.

manufacturing positions and warehouse related jobs. From a CAF perspective, this would likely result in amendments/adjustments to manning structures, to reflect the new reality.

e. Trained Personnel. Personnel must be qualified to operate and maintain the equipment. Within the CAF this could fall to existing Military Occupational Structure ID's (MOSIDs) such as Material Technician (MAT Tech) in the Canadian Army (CA), who are qualified welders and machinists. As the technology evolves and printing becomes less technical, there is potential for expansion of other MOSIDs to operate the equipment. Additional post-secondary training requirements may also need to be considered for responsible MOSIDs.

f. Quality Control and Parts Certification. 3D printed parts may not exhibit the same strength requirements as original equipment manufacturing (OEM) replacement parts. There are no internationally designated product standards currently available, which makes mass production via 3D printing a challenge. Unauthenticated or "fake" parts may also start to make their way into warehouses and eventually onto CAF equipment, which could pose a safety risk to our soldiers.

g. Law and Order. Intellectual property considerations with respect to 3D printing are enormous and challenging to address. With the ease and availability via the internet to obtain engineering drawings/models, copyright infringement through the use of 3D printing at a cheaper cost is inevitable. In order to maintain a legal approach, the CAF should consider provisions for intellectual property rights for 3D printing of components, perhaps in limited scenarios i.e. authorized to do so on operations only, or specific scenarios, in future contract awards.

h. Security Management. 3D printing has the ability to create additional security concerns due to the potential ease of access of dangerous materials across a wider spectrum. i.e. weapons. From a military perspective, this has implications on Force Protection, along with potential exploits offensively to increase our own weapons proliferation on operations.

i. In-Theatre Energy Use. This problem considers that the best location to employ 3D printing capabilities i.e. isolated areas, may present large challenges themselves in terms of energy provision to operate the equipment. Initial deployments of 3D printers will likely be limited to theatre sustainment bases, or ships.

j. 3D printing Safety. Most 3D printers emit nanoparticles, which, in high concentrations could have adverse effects on the health of persons working in the manufacturing process. Health and safety must remain a top priority when considering the implementation of 3D manufacturing.

8. While there are several limitations to the technology at this point, there are ways to mitigate and overcome some of these challenges. For example, in order to determine

when best to employ a 3D printing capability, a 3D printing matrix could be developed. This matrix would be similar in many ways to a prescriptive flow chart that assists to determine whether or not 3D printing is the most viable option. For example, in one scenario where a replacement part is needed to return equipment to service, the matrix could be used to determine:

a. Is the part readily available in the current supply system (OEM)?

b. If so, can it be received in the timeframe required by the Commander to restore the equipment to operational status?

c. If not, is the material the object is to be printed on is readily available?

d. Does this material meet the QA/QC requirements? i.e. can the part be safely produced for the application?

e. Do we have the legal rights to print the object?

f. Are funds available and approved?

The part would only be printed once satisfactory conditions are reached by using the matrix. This is only a simple example for illustration; however, it is one way that the limitations/risks could potentially be mitigated.

CONCLUSION

9. 3D printing technology is rapidly maturing. The RAND corporation states: "Our research leads us to conclude that the level of capability, stability and maturity of these technologies is ready for the development of cost-efficient military and civilian applications."[13] Although there are a significant amount of hurdles to overcome with the current state of the technology, the CAF cannot afford to wait to gain entry into this game changing sector of the defence industry. Our allies and potential adversaries are already integrating this technology into their operations. A detailed plan and methodical approach must be taken with the involvement of all CAF environments to fully implement this technology into the CAF. As the initial and immediate benefits of 3D printing technology are clearly in support of deployed operations, CJOC should lead the charge in advocating the requirement for this technology in the CAF.

RECOMMENDATION

10. Below is a list of proposed recommendations (in no particular order):

a. The initial focus for 3D printing capability should be to support deployed operations to limit warehousing footprint and more importantly increase operational capability;

[13] Veronneau, Simon, Geoffrey Torrington and Jakub P. Hlavka. 3D Printing: Downstream Production Transforming the Supply Chain. RAND Corporation, 2017.

b. CJOC should lead the charge in the re-write of support doctrine, adding provisions for the usage of 3D printing to enhance supply lines;

c. A cost-benefit analysis for a deployed 3D printing capability should be completed for a current CAF mission to provide a baseline study and identify initial areas to exploit the technology;

d. CJOC should chair a 3D printing working group (operational themed) with all L1s and key stakeholders. The purpose would be to collectively identify the current needs/interests of each environment in the technology, leading to focused priorities for the CAF;

e. Given the challenges associated with 3D metal printers at this time, a working group should be commissioned to determine the practicality and employability of a polymer (plastics) 3D printer to immediately support a deployed operation;

f. Future CAF contracts, especially ones that may affect deployed operations should contain clauses to allow the CAF to 3D print replacement components/parts while on operations;

g. As an interim measure, CJOC should direct that Canadian Material Support Group (CMSG) ensures that only legitimate OEM parts are sent to operational theatres; and

h. Health and Safety experts should be consulted during all stages of planning, to include measurement/exposure collection activities to ensure we fully understand the health implications of those working alongside this new technology.

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