Implications of Additive Manufacturing Deployed at the Tactical Edge

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Abstract

Additive manufacturing (AM) has the potential to provide game-changing capability to deployed Special Operations Forces (SOF). AM is an alternative method of producing objects in which material is deposited (added) to create the finished product. Traditional or “subtractive” manufacturing removes material from a larger product (Drushal, 2013). Recent research about AM, particularly in support of Department of Defense activities, has not considered the use of AM in a tactical setting, but instead has focused on applying AM in lieu of traditional manufacturing and supply chain management. This research paper identifies the most likely missions and environments in which SOF personnel would utilize an additive manufacturing capability, reports the results of a market survey to identify potentially effective material solutions, then assesses potential implementation constraints. The survey was administered to more than 100 diverse SOF warfighters across a variety of military career fields. The survey results support the use of AM in a tactical environment, identify a preferred fielding level, and highlight a target commodity for initial implementation. Several limitations were identified in the course of this research, leading to a list of recommendations for further research. This research needs to be expanded to evaluate AM material solutions’ effectiveness within the environment (dust, humidity, temperature, and vibration) of a SOF tactical mission. Additional research is required to develop procedures to integrate parts libraries, currently available from a variety of sources, with custom requirements identified by the SOF operator in the tactical environment. The research conducted indicates that AM has the potential to increase the capability of the tactically deployed SOF warfighter.

Chapter 1 – Introduction

Background

Additive manufacturing (AM) has the potential to provide revolutionary capability to support deployed Special Operations Forces (SOF), but very little research has been conducted to explore and evaluate limitations and opportunities to use AM in tactically deployed conditions. Senior SOF leaders, such as LTG John Mulholland, former deputy commander, U.S. Special Operations Command, have expressed interest in taking advantage of AM in support of deployed units (personal communication, June 2014). Army *Field Manual 3-18* details how SOF units are employed. It reports that "Special Forces possess qualities and capabilities to mix nonlethal and lethal activities designed to shape the environment, deter conflict, prevail in war, or successfully conduct a wide range of contingency operations," and it defines the organizational structure used to conduct these missions (U.S. Army Headquarters, 2014). This reference, combined with information provided by research surveys, is used to define the "tactical edge"—where AM can be effectively deployed in support of SOF operations. This research paper explores the most advantageous applications and defines operational limitations to employment of AM at the tactical edge as identified by the user surveys.

Problem Statement

This research paper identifies the most likely missions and environments in which SOF personnel would use an AM capability, reports the results of a market survey to identify potentially effective material solutions, then assesses potential implementation constraints. This paper explores the following benefits of AM described by McNulty, Arnas, and Campbell (2012): remote, mobile fabrication; rapid response to changing mission; and use of local materials. Finally, further research into developing processes and procedures to maximize the utility of AM in the tactical environment are recommended.

Significance of This Research

Through the research developed in this paper, SOF personnel will be better equipped to take advantage of AM in support of national security missions. Current research in AM for the Department of Defense (DoD) has focused on traditional supply-chain management and intellectual property concerns (Drushal, 2013; Kurfess & Cass, 2014). It is my hypothesis that AM can provide a substantial advantage to the SOF warfighter by local manufacture of limited-use items. Historically, deployed SOF have used local procurement or improvised to acquire material that reduced visibility of military operations. Examples include procurement of local cell phones, utilization of vegetation and debris to create hide sites, and use of duct tape and zip ties for restraint/attachment requirements. These improvised or commercially available solutions do not always provide the exact material solution sought by the warfighter. Through the use of AM, a deployed team could print out a cell phone case that could be used to mask their encrypted communication device, providing exactly the desired solution to maintain operations security while performing the mission. They could also manufacture camouflage devices to completely blend into their environment, increasing their ability to complete their mission effectively. The findings from this research would be implemented through updates to unit tactics, techniques, and procedures, and be integrated into operator training at the U.S. Army John F. Kennedy Special Warfare Center and School.

Drushal (2013) explored the implications of AM for the Army Organic Industrial Base, but did not explore the implementation of AM beyond the current employment. My research explores the potential to expand AM beyond a support capacity and into a tactical advantage.

However, since my proposal focuses on limited-use manufacture of items for unique niche employment, this paper does not address the intellectual property concerns discussed by Kurfess and Cass (2014).

Overview of the Research Methodology

A literature search was conducted seeking research in the area of additive manufacturing capabilities, particularly in support of military applications. In addition, a survey was developed and conducted gathering insights from a variety of active-duty SOF personnel. The purpose of the survey was to gain insight into typical environmental conditions experienced in a deployed mission scenario. In addition, SOF operators were asked to identify current capability gaps that could be addressed through the use of deployed AM systems.

Research Question

What factors have the greatest impact on fielding AM capability at the SOF small-unit level?

Research Hypothesis

If realistic procedures are developed and implemented, SOF units will be able to use AM effectively to provide operational support in austere deployment environments.

Objectives and Outcomes

I anticipate that with appropriate processes, AM can provide substantial operational utility in support of SOF operational units. I anticipate that constraints on size, weight, power, and environmental conditions will be the primary limitations to more complete employment of AM. After the constraints are established, I anticipate that this research will be used in the development of operational plans employing AM at the tactical-unit level. Exactly what constitutes the tactical-unit level will be defined in terms of Army *Field Manual 13-8* as a result of my research and surveys (U.S. Army Headquarters, 2014).

Limitations of the Study

This research focuses on support of Army SOF operational units. While there may be some broader utilization for general purpose military forces, the survey inputs and environmental conditions were oriented to the deployed SOF unit. There may be greater utility in applying this research to other SOF operational units such as Air Force Special Tactics Teams; Navy Sea, Air, and Land troops; or Marine Recon units.

In addition to the user limitation, this research is limited to the state of technology in the fall of 2014. Advances in materials and equipment are likely to continue, which might remove some constraints identified in this study.

Validity of the Research

User input was based on a survey sent to approximately 100 SOF operators from six units. Exact numbers are not available because initial survey recipients forwarded the survey to other participants per my request. Survey participants were anticipated to range in rank from E6 to E8, with limited responses from junior officers (O2–O3). I anticipated five Military Occupational Specialty (MOS) series to be represented in the survey respondents. Actual survey respondent results varied from my assumptions. Only 18 surveys were completed. The majority of the respondents did range from E6 to E8 in rank, but there were two responses from mid-grade officers (O4 and O5). As anticipated, the majority of the respondents reported an 18 series MOS, which is the general Special Forces MOS, and responses were received from five distinct units (Tice, 2005). A detailed breakout of the survey demographics appears in chapter 3. Given the high degree of commonality among the respondents and the small sample size, there is a high probability of some bias in the survey results.

Reliability of the Responses

Within the foreseeable timeframe of the study, it is realistic to expect similar results from another assessment. However, a different set of survey demographics could have an effect on results. For example, although the survey was sent to representatives from all SOF units, the only surveys returned came from personnel assigned to Special Forces Command, shown in Figure 1. The lack of information from SOF operators in the fields of Civil Affairs, Military Information Support Operations, Rangers, and Aviation means that the information in this study may not be applicable across the range of Army SOF Tactical Operations.

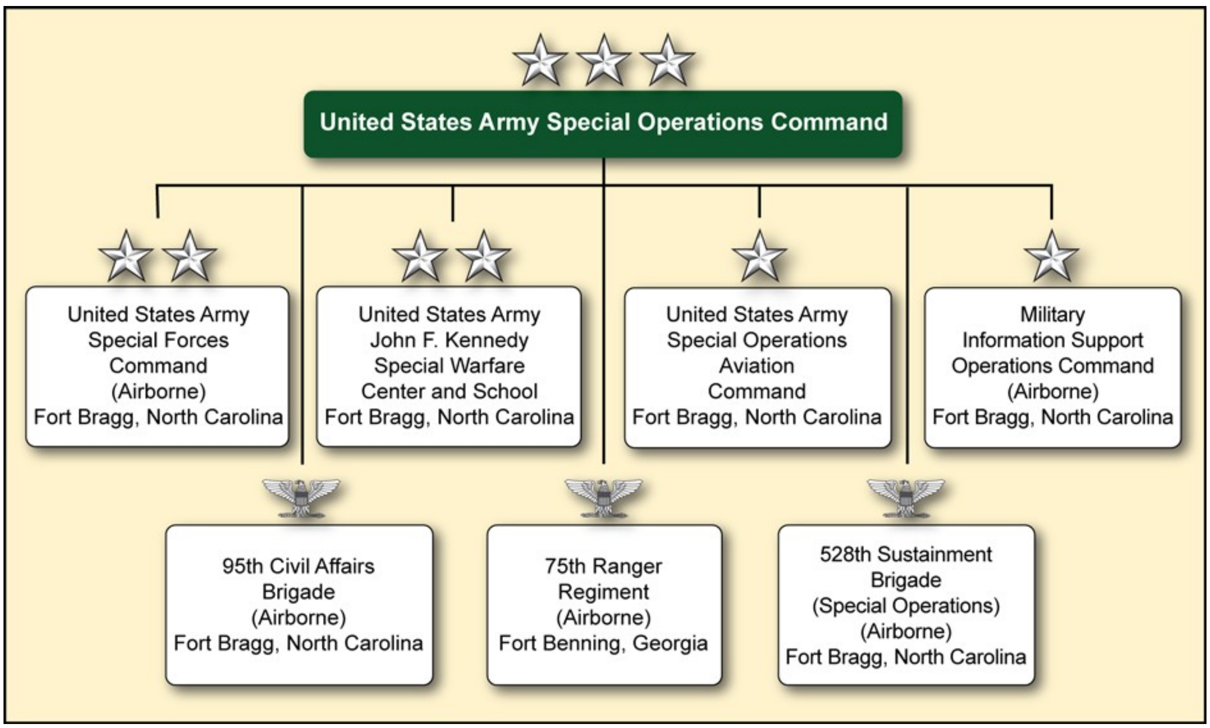

Figure 1 – U.S. Army Special Operations Command Organizational Structure
(Source: U.S. Army Headquarters, 2014)

Chapter 2 – Literature Review

Research Project Requirements

Existing research about AM has not considered implementation in a tactical setting as defined for this research. Several researchers have addressed AM and its impact on the Army supply system (Drushal, 2013; Smith, 2014; Smith & Vogt, 2014). Gourley (2014) and Kohlmann (2013) considered deployment opportunities for AM, but limited this to the organizational level, not the tactical unit. Substantial general research exists about the broader implications of AM for conventional manufacturing, supply chain management, and intellectual property (IP; Desai & Magliocca, 2014; Hornick & Roland, 2013; O'Mahony, 2014; Peck, 2014; Torruella, 2014). My research will add information to AM implications at the tactical-unit level, as defined later in this section, and focus primarily on limited-use items rather than material expected to be sustained within the Army logistics infrastructure.

Definition of Additive Manufacturing

AM, also known as 3D (three-dimensional) printing has almost become a household term. As an example, the Holiday 2014 issue of SkyMall catalog featured the 3D Doodler, available for purchase at $99.99 (SkyMall, 2014). The wide availability of inexpensive tools has created a great deal of sensation around the field of AM, resulting in misconceptions about it. AM has three distinct phases: design, manufacture, and employment. The employment or use phase of AM is open-ended and best defined on a case-by-case basis. The research presented in this study focuses on AM-use cases by tactically deployed SOF operators. Specific use-case conditions are discussed in chapters 3 and 4.

The concept of AM was introduced in the 1970s, but it could not be effectively implemented until computing power became more readily available (McNulty et al., 2012). In the mid-to-late 1980s, two AM industry pioneers developed and produced their products: 3D Systems and Stratasys (McNulty et al., 2012). These systems were typically used for prototype development, not final products. 3D printers capable of producing metal prototypes were developed in the late 1980s (Kurfess & Cass, 2014). Metal typically results in products with more precise tolerances and greater ability to withstand environmental variables, but at an increased cost (Tadjdeh, 2014).

With the increased power of personal computing and reduced cost of electronics that have developed since the turn of the century, AM use is increasing in numbers and diversity of purpose. Brown (2014) predicts nearly a five-fold increase in units sold from 2012 to 2015 (approximately 38,000 units in 2012 vs. a predicted 195,000 units in 2015). AM prototyping is moving toward greater complexity and larger sizes, while AM manufacturing is growing at a substantial rate (Brown). Brown reports that in 2004, end items accounted for 4% of the total AM revenues. This number rose to 28% of AM revenues in 2012. Reasons for this include reduced weight, greater part complexity, the new ability to change materials within a part, and increased use by schools (Brown). Given this rapid increase in capability, it is critical to develop effective methods of using this technology in support of the SOF tactical warfighter.

Additive Manufacturing Design

Before a product can be manufactured or used for its intended purpose, someone must convert the idea into a design. This portion of the AM process is highly controversial, because this is where the issue of IP and patent infringement often arises. Historically, design data have not been easily transferrable, often requiring detailed process knowledge and specialized tooling (Kurfess & Cass, 2014). But with AM technology, it is fairly simple to gain this detailed knowledge through a digital scan of an existing product. The real issue arises because this creates the potential of counterfeiting, when someone manufactures a part which cannot be distinguished from the original design. Kurfess and Cass (2014), as well as Desai and Magliocca (2014), highlight the potential impact of counterfeit parts. They also emphasize that the ability to customize items for personalized use is of great benefit to the consumer.

Desai and Magliocca (2014) recommend that IP regulations be enforced for “personal use” cases and that a reasonable threshold should be established for any patent infringement claims. If this recommendation were adopted, the implementation of AM as defined in this research would fall within these thresholds and would therefore not be subject to IP limitations. In this study, no further research was conducted with regard to IP concerns.

The final aspect of design that must be considered involves the method by which a tactical operator can translate an operational need to a design file to enable the part to be manufactured, either through AM or other means. The Army’s Rapid Equipping Force (REF) has been chartered with the establishment and support of a government-wide, 3D-design-sharing database that would host a variety of product data package files (Ewell, 2015). This database could serve as the design information backbone that supports the employment of AM by tactically deployed SOF units. The work of Smith and Vogt (2014) is discussed in this research as it relates to the engineering process. Their research proposed a virtual development process (Figure 2), which could be used to provide engineering support related to AM challenges experienced by the tactical operator. User survey results indicated that some type of reach-back capability would be needed in order to address technical concerns that are beyond the capability of the tactical unit. It is my recommendation that a virtual process such as the one shown in Figure 2 could address this need without creating excessive delays or unnecessary bureaucracy. The combination of standard design files, provided by the REF, with the virtual development process offers a means to fulfill a crucial requirement to enable the employment of AM at the tactical edge.

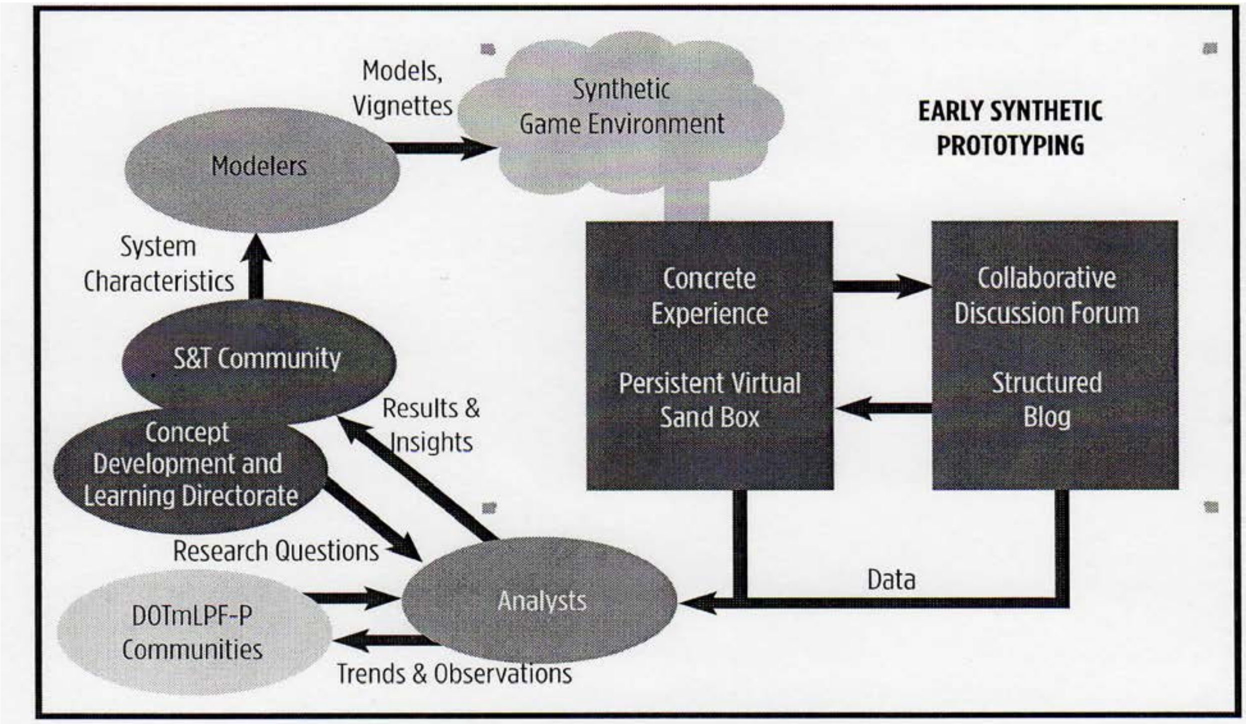

Figure 2 – Potential Virtual Development Process
(Source: Smith & Vogt, 2014)

Manufacture Phase

Manufacturing in the AM use case contrasts sharply with traditional manufacturing. In AM, the product is created through the application of material in a layer-by-layer approach rather than by removing excess material, which is the method used by traditional manufacturing (Drushal, 2013). This layered application is what requires the unique design method described in the previous section. Various types of material and machines are used to create these layers. Methods for plastic AM include Fused Filament Fabrication, Fused Deposition Modeling and Selective Layer Sintering (Tadjdeh, 2014). There are literally hundreds of choices of printers using varieties of this technology (Castle Island, 2014), with many industrial quality printers available for less than $10,000 (Brown, 2014).

The works of Drushal (2013), Smith (2014), Gourley (2014), Kohlmann (2013), and Toruella (2014) discuss potential implementation of AM in support of military operations. They focus on depot/organizational level or supply replacement (Gourley, 2014; Kohlmann, 2013; Torruella, 2014) rather than tactical-unit support. As such, their research is not expanded further in this study because they all focus on AM implementation at levels higher than the battalion level as defined in the next section. User survey data recommended that effective AM deployment would need to occur at the company level or below. More discussion regarding this is included in chapters 4 and 5.

Definition of Tactical-Unit Level

The tactical-unit level is best defined in terms of Army *Field Manual 31-8, Special Forces Operations* (U.S. Army Headquarters, 2014). Figure 1 shows the highest organizational level of U.S. Army Special Operations. Since the survey responses for this study were all provided by members of the Special Forces Command organization, that organizational construct will be used for the remainder of the study. There are five active duty and two National Guard Special Operations Groups within Special Forces Command (U.S. Army Headquarters, 2014). Each consists of multiple battalions which are between the Special Forces Command level identified in Figure 1 and the company level identified in Figure 3. User survey data recommended employment of AM at the company level, at one of the major activities shown in Figure 3. There are three potential employment levels for AM at the tactical edge: company level, operational detachment–alpha (ODA), and operational detachment–bravo (ODB).

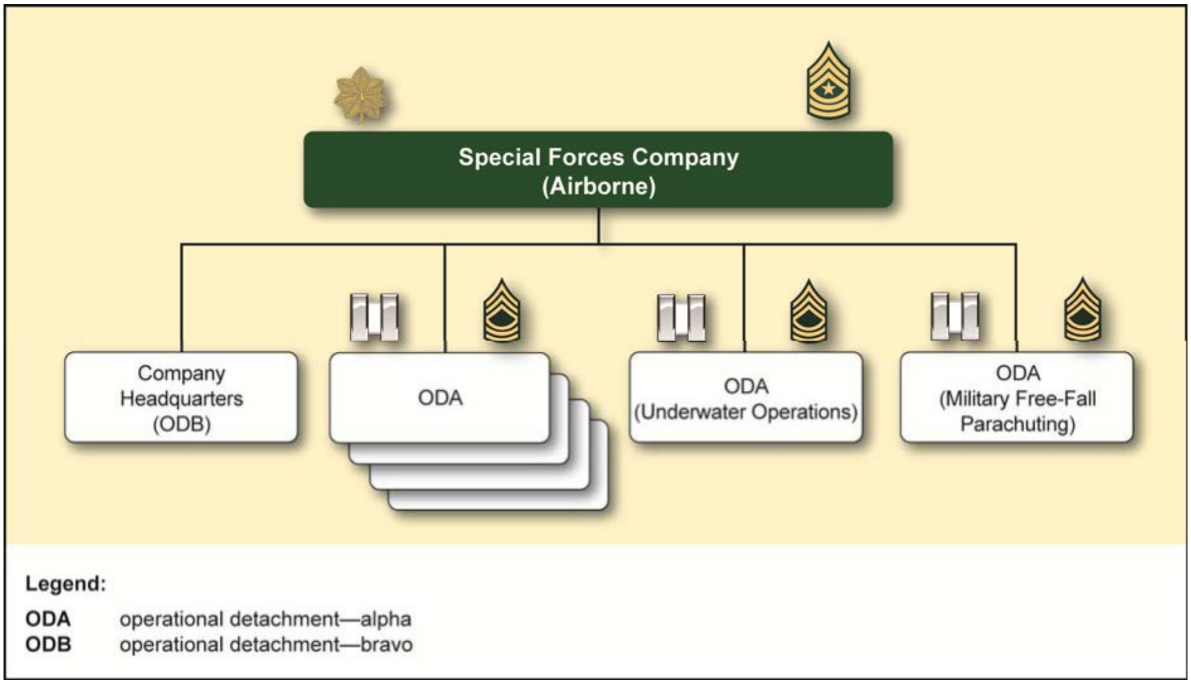

Figure 3 – Special Forces Company (Airborne) Organization
(Source: U.S. Army Headquarters, May 2014)

The literature review provided a substantial background on the strengths and weaknesses of AM, the current state of AM technology, information regarding the IP concerns with regard to AM, and detailed information regarding Army SOF organizational structure. The literature review was unable to locate any research focused on implementation of AM outside of a controlled environment, such as an office, school, or laboratory. Examples of remote implementation of AM include the REF's expeditionary lab (Drushal, 2013), AM employment on Navy vessels (Kohlmann, 2013), and employment on the International Space Station (Webster, 2015). Although these appear to be remote conditions, the AM systems are located in work spaces maintained at comfortable environmental levels with stable power sources, limited temperature extremes, and minimal dust and vibration conditions. SOF operations below company level are typically conducted in extreme environmental conditions. Further research into the impact of environmental conditions such as, but not limited to, temperature, humidity, dust, vibration, and power surges would be required before field implementation of AM in a tactical unit.

The literature review also did not provide any information regarding potential use cases for AM that would be of value to the SOF tactical units. User surveys were employed to gather this information. Further research with a broader base of SOF operators would increase the validity of this research.

Chapter 3 – Research Methodology

Through use of a market survey and literature search, this research paper identifies the most likely missions and environments in which SOF personnel would use an AM capability. It recommends implementation strategies and identifies potential implementation constraints.

Research Hypothesis

For this research project, the null hypothesis (Ho) is that if realistic procedures are developed and implemented, SOF units will be able to use AM effectively to provide operational support in austere deployment environments.

Research Process

The literature search primarily provided background information about AM capabilities and methods, IP considerations, and reference material about Army SOF organizational structure. The user survey provided grassroots assessments of several focus topics. These included the types of material required during typical tactical missions, recommendations about the implementation/fielding site for AM, potential AM use cases, and mission vignettes. Since this report focuses on AM in support of tactical SOF units, results from the user survey are weighted more heavily in the recommendations than information from the literature search.

Survey Structure and Results

The user survey was developed in coordination with two senior noncommissioned officers (NCOs) assigned to the Tactical Assessment Unit at U.S. Army Special Operations Command (USASOC) headquarters. After development the survey was emailed to 44 NCOs and Warrant Officers throughout all USASOC organizations. This survey was an anonymous instrument, conducted through the use of SurveyMonkey, an online survey tool utilized by Defense Acquisition University. The initial email requested that the survey be forwarded throughout the SOF user community. It is unknown how many survey invitations were actually distributed, but given the average unit size and number of units represented in the responses, at least 100 survey invitations were issued. Despite the broad canvas, only 18 surveys were completed, and all responses were provided by personnel within the U.S. Army Special Forces Command organization (see Figure 1). As a result of the small, cohesive sample size, it is possible that the survey results may not have broad applicability across the larger Army SOF community.

The survey consists of 23 questions and contains a standard voluntary, informed consent release. The survey is divided into demographics, familiarization with AM, deployment material usage (seven questions), deployment material sourcing (five questions), potential AM implementation criteria (two questions), and open-ended questions related to mission vignettes and comments about AM. A complete list of survey questions appears in Appendix A.

Demographic information was gathered to evaluate any bias in the users' responses. A single question regarding the respondents' familiarity with AM assesses how widely AM is understood at the tactical-unit level. The 12 questions regarding material sourcing and usage in the tactical unit provide a baseline understanding of what type of situations commonly occur that could be addressed through the use of AM deployed at the tactical edge. The two questions about implementation location sought the user's input on the best definition of "tactical edge" from an operational perspective. The user viewpoint is critical to developing a practical recommendation in this paper, since I have never deployed and do not have first-hand knowledge of the potential benefits and drawbacks for a given operational implementation level for AM. Finally, the three open-ended questions enable respondents to provide insights in the following areas: pros and cons for a given implementation level, mission vignettes where AM could add value, and general comments about the use of AM in support of the tactical SOF operator.

After receiving the user survey results, I used that information to seek more information from literature in two areas: reference material on SOF unit structure and personnel categorization, and research regarding the development and fielding of AM templates or libraries that could be used by tactical operators.

While the demographics of the respondents were limited in terms of the reporting headquarters organization, the MOS breakout was fairly diverse. Responses were received from areas including medical, intelligence, communications, engineering, infantry, and weapons. Respondent rank was bunched tightly, with the majority of respondents reporting to be E6 through E8. E7 was the most common rank of respondents. Two responses were received from officers. The amount of SOF experience was the demographic with the greatest diversity: responses ranged from less than 3 years to greater than 15 years of SOF experience. Detailed information is provided in chapter 4.

The lack of existing research related to AM at the tactical level, combined with the limited survey responses, does affect the reliability and validity of this research. Near the end of the survey response window, I received an email from a participant who asked for an endorsement memo so that the participant could send the survey out to their unit. Given the time limitations, I elected not to seek formal endorsement, which resulted in fewer user survey responses than I had originally anticipated. Recommendations regarding follow-on actions are included in chapter 5.

Chapter 4 – Findings

The objective of this research was to identify whether AM can provide substantial operational utility in support of SOF operational units. In addition, this research identifies potential implementation strategies to employ AM effectively. The following tables and figures reflect the results of the user survey discussed in chapter 3: demographic data, material shortage data (quantity and category), material sourcing data, candidate AM use cases, and deployment locations. Survey questions and user responses are copied directly from the survey, which occasionally results in grammatical inconsistencies. I made minor spelling corrections, and occasionally added clarification within brackets where required to convey the respondent's intent.

Survey Responses

User survey respondent demographic information is shown in Table 1 and Figure 4, with responses to contextual survey questions displayed in Figures 5 through 10. Demographic data were separated into a table and a figure to prevent identification of specific survey respondents based upon the limited distribution of senior NCOs in any given unit. As reported in chapter 3, a total of 18 surveys were completed. As shown in the data, some questions were not answered by all respondents. Fixed-choice questions were answered by between 12 and 18 respondents, while open-ended questions were answered by three to five respondents. Candidate vignettes were given by three respondents.

Table 1 provides a visual representation of three survey questions (questions 2, 3, and 5):

- What is your Rank? Respondents selected from the following fixed choices: E5, E6, E7, and E8. A free-text box was provided for respondents outside the free- text choices.

- How long have you been part of Special Forces? Respondents selected from the following fixed-choice options: 0–3 years, 4–7 years, 8–10 years, 11–15 years, and over 15 years.
- What is your MOS? Responses were collected through use of a free-text box.

Table 1 – User Survey Demographic Data

Respondent[a]	MOS	Rank	SOF Experience (in Years)
1	91Z	E8	8–10
2	18E	E7	8–10
3	11M	E9	8–10
4	18Z	E8	Over 15
5	18E	E7	8–10
6	18Z	E8	Over 15
8	25W	E7	11–15
10	18B	E6	8–10
11	18A	O5	Over 15
12	35M	E6	0–3
14	35P	E7	11–15
15	18A	O4	11–15
16	18C	E7	4–7
17	18Z	E7	4–7
18	11C	E7	11–15
19	11B	E7	8–10
20	91X	E7	8–10
21	18D	E7	Over 15

Note: data shown reflect user survey questions 2, 3, and 5.

[a] *Numbers are not consecutive due to incomplete surveys.*

Figure 4 reflects demographic data in response to user survey question 4:

- What is your unit? Responses were collected through use of a free-text box.

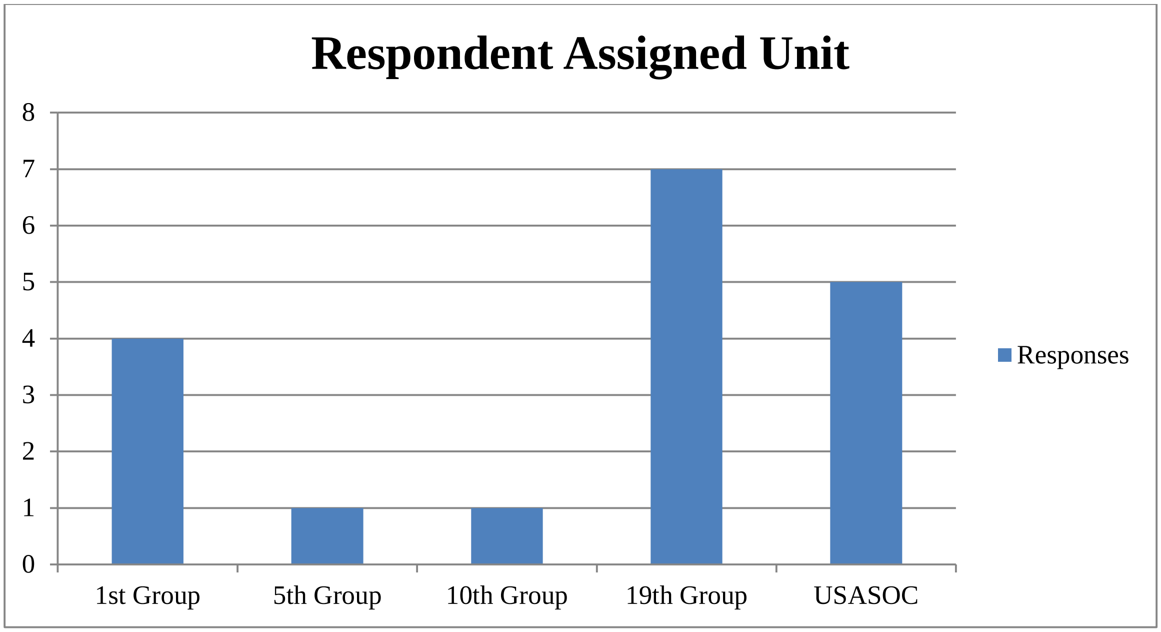

Figure 4 – Respondent Unit Demographics

As discussed in chapter 3, the user survey questions determine the breadth and depth of the need for AM by SOF units during deployment. Respondents' knowledge of AM is displayed in Figure 5 based upon their response to survey question 6 (How familiar are you with 3D Printing (Additive Manufacturing)?). Respondents selected from the following fixed choices:

- Never heard of it
- Somewhat Familiar (read an article, heard people talk about it)
- Familiar (Seen it used for prototypes, seen/participated in a demonstration
- Very Familiar (Actually made parts or used parts made at your request)

Based upon these results, the respondents have at least a working knowledge of AM, adding validity to their responses to the remainder of the survey.

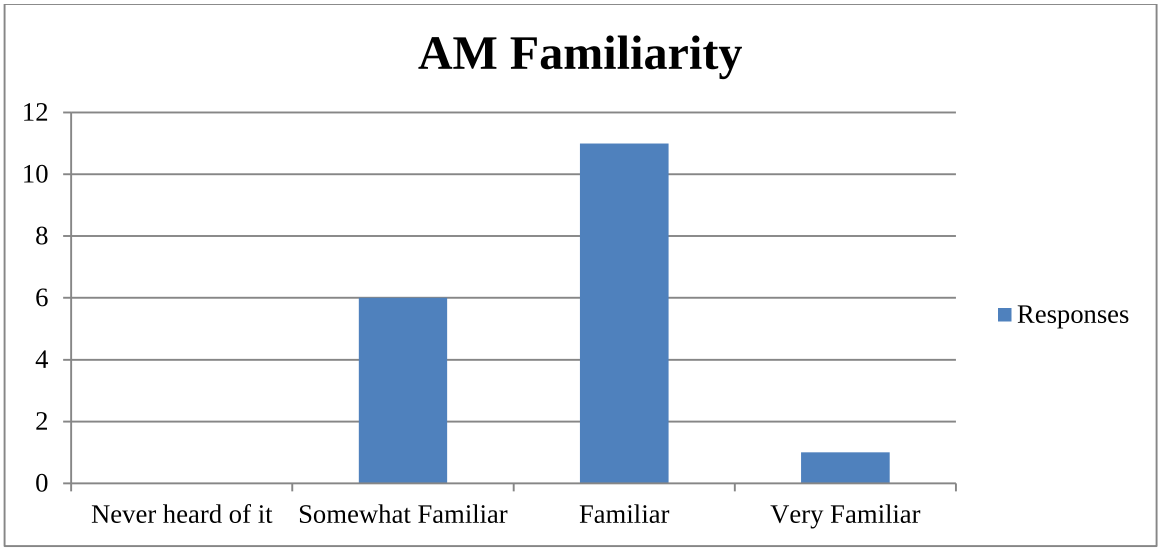

Figure 5 – Respondent AM Familiarity

The remaining questions are organized in categories of material usage, material sourcing, and deployment criteria. The material usage section of the survey began by asking about the frequency of material shortages experienced by the respondents. Figure 6 visually displays the results of survey question 7 (During a typical deployment, how often have you personally had to fix or make/buy an item in the field to complete your mission?). Respondents selected from the following fixed choices:

- Rarely (0–10%)
- Occasionally (10–30%)
- Sometimes (30–60%)
- Often (60–90%)
- Almost Always (90–100%)

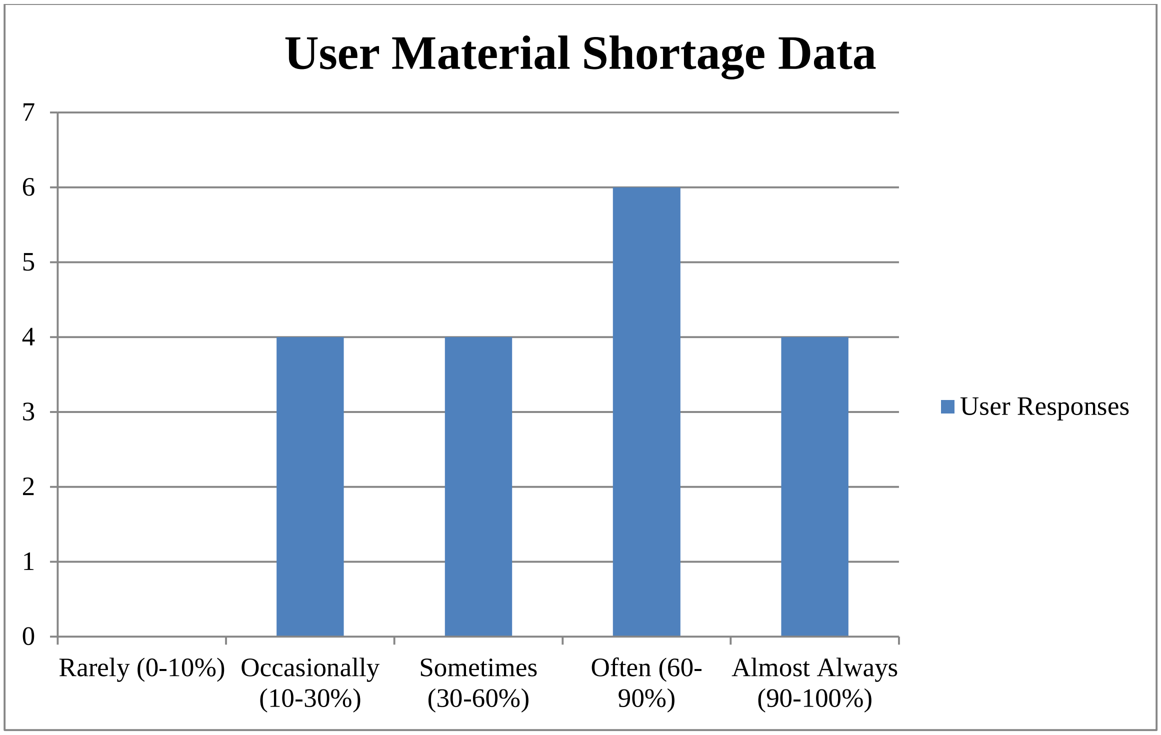

Figure 6 – User Survey Material Shortage Data

These data confirm my initial assumption that SOF operators do have material shortages that occur during tactical operations. Given the limited survey response rate, this result may not be broadly applicable across the larger Army SOF community.

The next series of questions provides greater detail regarding the type of material shortages that occur. Questions 8–12 ask respondents to identify how frequently on a typical deployment they would have to fix or make/buy an item of this type in the field. This does not include consumables such as batteries or wear items such as weapon barrels. Question 12, Force Protection Items, requested additional details regarding the type of material required. Users were provided the same fixed-choice options from question 7 (rarely, occasionally, sometimes, often, and almost always) for each of the following five commodity areas:

- Concealment/camouflage items such as cover plates, hide sites, etc.

- Vehicle accessories such as brackets, mounts, storage, etc. Do not include structural or armor modifications.
- Mission Kit Accessories such as mounts for weapons sights, NVD helmet mounts, etc. Do not include structural items.
- Local interaction such as items for civil affairs, village stability ops, etc.
- Force Protection (If this category is used, please select a frequency and also check "type of item" then clarify in comments).

Figure 7 shows user responses for this series of questions. Four free-text responses were provided for question 12. The responses were gates and camera mounts, HESCO [brand name movable barrier commonly employed by DoD] barriers, labor, and mounts for security cameras. Labor cannot be accomplished through the use of additive manufacturing.

A free-text box in Question 13 allowed users to add any other commodity not addressed in questions 8–12. User responses are listed below:

- Comms Antennas and mounts
- Comfort items. Being able to relax between ops is crucial to mission success.
- Not know the strength or durability that would be produced, commonly as a signal soldier I would have to "invent" methods to mount anteannas to vehicles and buildings in non-standard ways from the deployed kits. The same applies to mounting security cameras. Also, if the technology allowed, finding appropriate cable connectors to create coax cables, modify connections, etc are difficult to procure locally in many locations and are consumed at a rapid rate during deployment.
- Concealment Devices
- Hostile Forces Tagging, Tracking, and Locating (HFTTL)

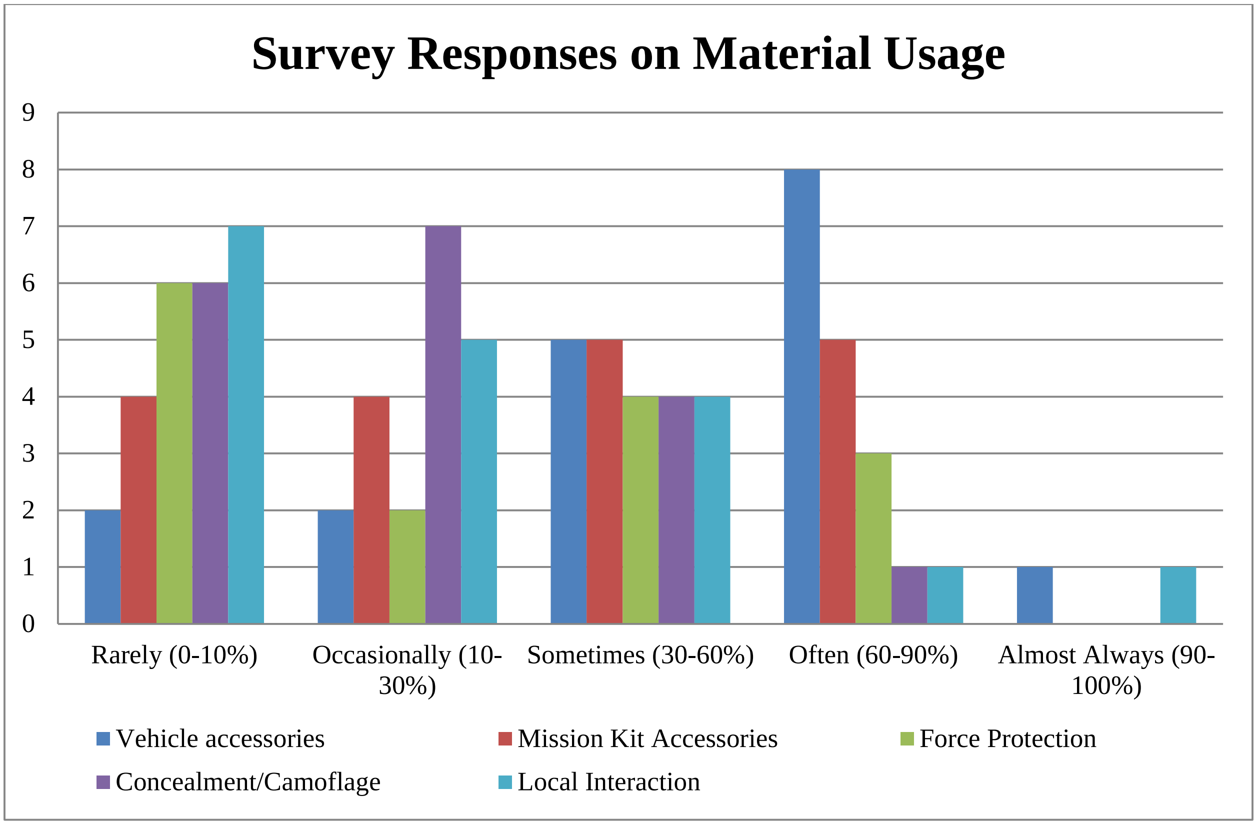

Figure 7 – User Survey Material Usage Data

The next questions identify where respondents sourced the material displayed in Figure 7. These data are displayed visually in Figure 8. Respondents were asked, "On a typical deployment, identify where you get the material discussed in questions 8–13 using the scale provided." Users were provided the same scale used previously (rarely, occasionally, sometimes, often, and almost always) for the sources of supply listed below. They also had a free-text option to identify sources of supply not listed.

- From unit supply (i.e., support battalion)
- Buy it from the local economy
- Make it yourself (duct tape, zip ties, etc.)

- Buy some supplies, then make exactly what you need
- Other (free-text box provided for details)

There were five free-text responses from question 18, “Other.” Responses included take what we are issued and modify to fit the need we have; we fabricated a lot of items, usually from metal and wood; repurposing equipment to a new use; mission dependent; and tape.

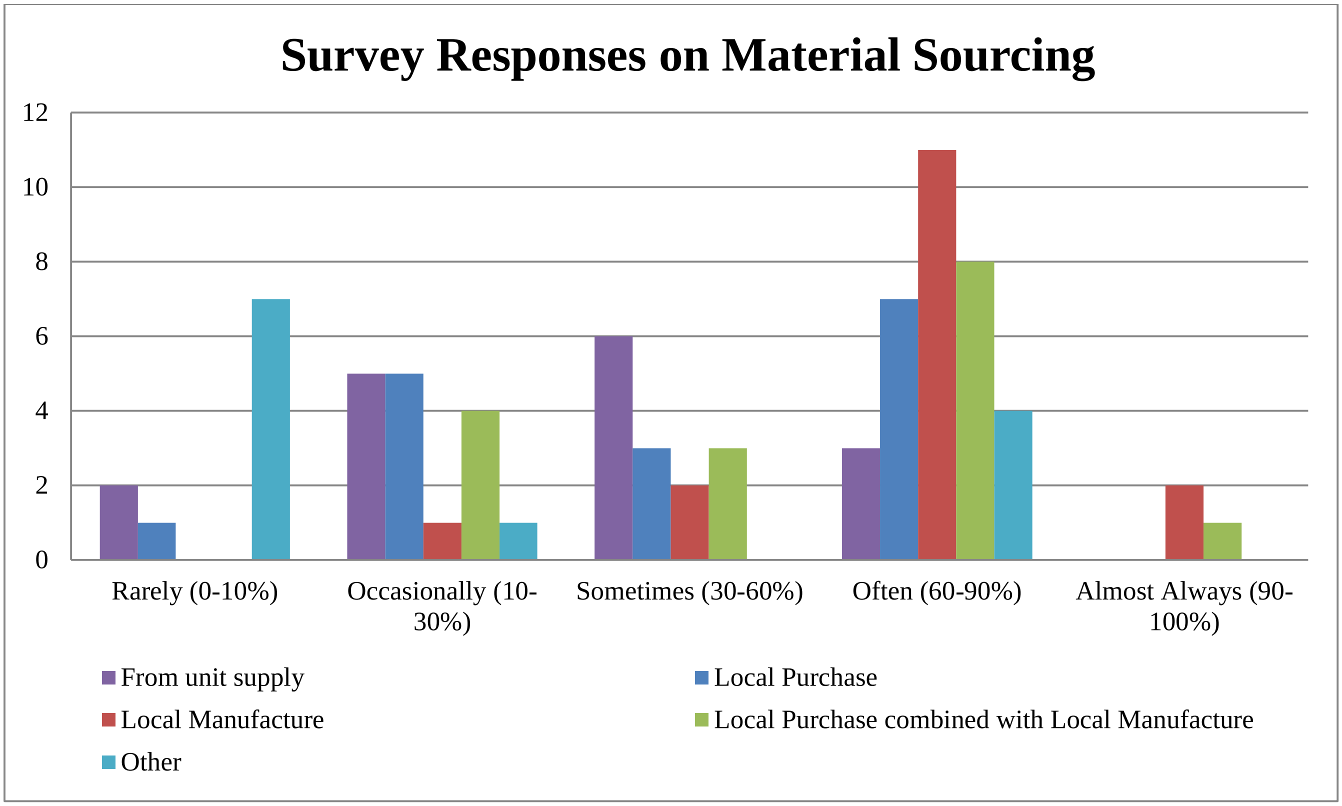

Figure 8 – User Survey Material Sourcing Data

In order to validate the responses from the material shortage and usage section, the survey then asked respondents to identify which categories of shortages could be filled through AM at the tactical level. Responses to the following question are displayed: “What items are you likely to make with a 3D printer?” Users selected from the following categories:

concealment/camouflage items, vehicle accessories, mission kit accessories, local interaction items, force protection, and a free-text option.

Figure 9 shows the survey results. Free-text responses associated with "other" were "tracking and marking devices, HFTTL concealments, and items of import to the local population." Because these responses fit within the category of concealment devices and local interaction, they were added to the totals for these categories. No new categories of use were identified via the free text.

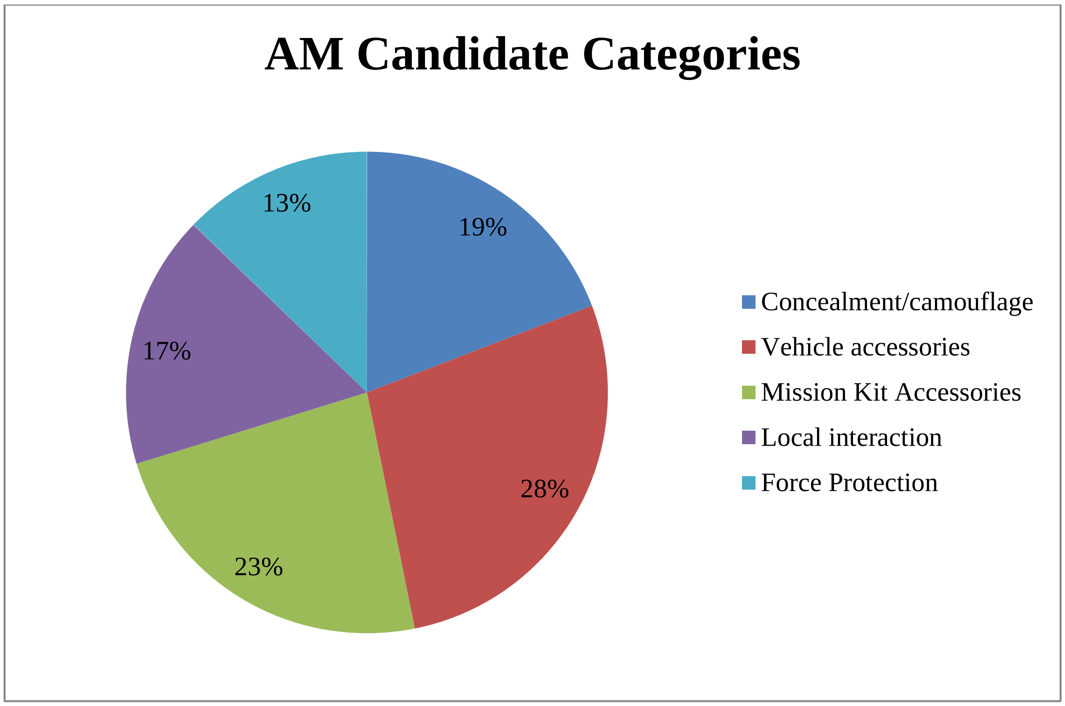

Figure 9 – User Identified AM Candidate Categories

The last section of the user survey focused on the fielding level. The following two questions evaluate the recommended fielding level:

1. Select the locations you think should be equipped with a 3D printer. Choose as many locations as you feel would be of value. Use the other category for locations not listed.

2. Select the locations you think should NOT be equipped with a 3D printer. Use the other category for locations not listed.

The same list of fixed-choice options was provided for both categories:

- At the headquarters support company (with maintenance or supply)
- At the FOB [forward operating base], assigned to each company
- At the company ODB (move to the AOB [advanced operational base] if necessary)
- With each ODA team (deployed for mounted operations)
- Other (please specify)

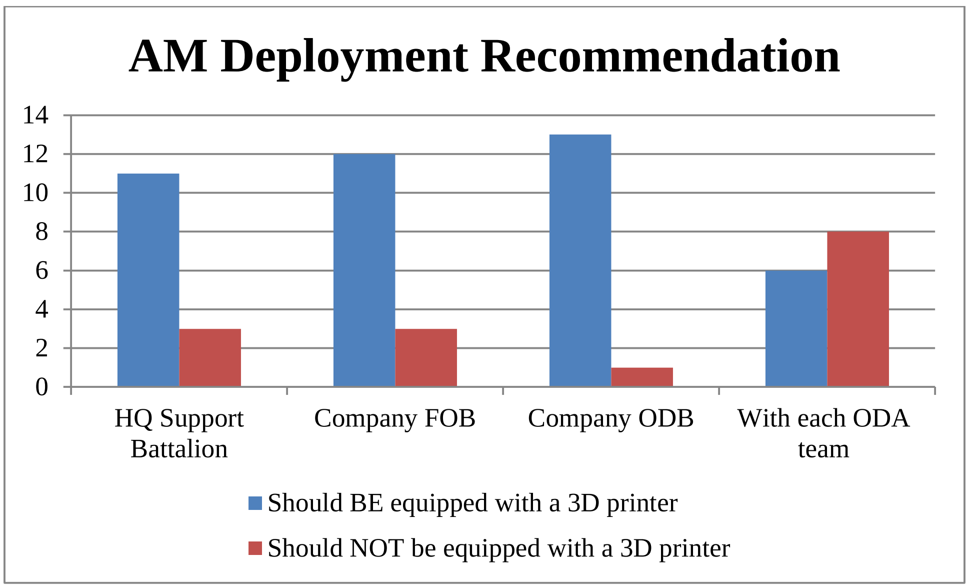

Figure 10 – User Survey AMD Deployment Recommendation

The single free-text input reported that the fielded level should be tailored for each mission. An optional free-text box (question 22) identifies the limitations and/or benefits to any location selected in question 20 or 21. Five respondents provided the responses listed below.

- Having one at each level will aid in the use and time till available. A large more capable system could be at HSC. [Based on the author's experience, HSC likely refers to Headquarters, Support Company. This equates to the Headquarters, Support Battalion listed in Figure 10.]

- This technology like all others will be issued based on operational need vs cost.
- Limitations and specifically benefits are limited only by the user's imagination.
- The only problem with having 3D printers at each and every location listed is the propensity of the higher headquarters elements to hoard raw material for the printer. Maybe if they don't have a printer they'll actually send raw materials down to those that do.
- A 3D Printer is not a stand-alone option. Unless you have a library of CAD [computer-aided design] files for common items, the end user would have to know a CAD program. Also for other items you would need a 3D scanner to copy an item for reproduction.

Two additional free-text boxes (questions 23 and 24) provide respondent input to the following questions:

1. If desired, please describe a vignette where the ability to custom manufacture something using a 3D printer would have made a difference in achieving the mission. The example could be a case where the mission was negatively impacted because of the lack of this capability, or a case where you were able to adapt.
2. Please provide any additional thoughts you have regarding use of 3D Printers in support of SOF deployed operations. If you are interested in a follow up discussion, please provide your contact information (NIPR [Nonsecure Internet Protocol Router] email and/or commercial phone number).

User responses are listed below. Contact information has been removed to protect operator identity. Responses are shown as submitted by the survey respondents. The following vignettes were offered for question 23:

- A Sat. com [Satellite Communications] antenna needed to have the ability to be stored and used while on the move. We used zipties and other pouches to secure it to an assault pack where a simple mount could have been made. Our technique worked but required constant adjustment.
- I needed to mount a specialized antenna to an MATV [Mine-Resistant Ambush Protected All Terrain Vehicle] and did not have a purpose built mount for it. In order to meet mission requirements I had to repurpose an antenna mast from another system, rendering it useless for its original purpose. In addition I had to use bolts, wire, and 550 cord [common parachute cord] to mount the antenna to the mast. A 3D printed part would have allowed me to solve both problems without destroying equipment and would have allowed the antenna to be both mounted and dismounted quickly, enhancing mission capability and force protection.
- The ability to create a durable mount for antennas for the fixture to be applied would be invaluable. I have had to figure out how to mount to existing host nation towers, tops of buildings, vehicles, both military and civilian, HESCO [brand name movable barrier commonly employed by DoD] walls, etc.

These additional comments responded to question 24:

- The initial desire of this will probably be low until more of the capabilities and ideas of things that can be created and used is more well known.
- Just another tool.

- Most of the 3D printers I have seen work in plastic that does not have a very high tensile strength. A 3D printer in the operational environment would need to work in high-strength plastics or metal. Also, it would need to be able to produce parts with a high resolution, higher than some I have seen, in order for 3D parts to profitably interface with existing systems.
- I feel that the sophistication of the user will drive the application of the printer.

Summary

User survey data indicate a consistent need for material to be manufactured at the tactical level. Survey data indicated that SOF operators are fabricating, repurposing, modifying, and procuring items in the tactical environment to conduct their mission effectively. Vignette responses to survey questions 13 and 23 indicate that the most critical area of concern to the users involves brackets to mount communications accessories such as antennas and security cameras to vehicles and physical structures. Free-text responses to user survey question 13 also identify concealment and camouflage items as an area of interest.

The user survey did not provide consensus in deploying AM at the highest (battalion) and lowest (ODA) levels. However, there was consensus in deploying AM at the ODB (see Figures 1 and 3 for clarification of organizational structure). Based upon the survey data, my recommendations in chapter 5 are limited to implementing AM at the ODB level in order to provide mounting brackets for communications equipment.

Chapter 5 – Conclusions and Recommendations

The research conducted for this paper indicates a need for AM to be deployed tactically beyond the current levels supported today. Conclusions regarding the implications of this research summarize the research question, results of the literature study and user survey, and potential benefit to the tactical Special Operations community. This research is limited because of the small number of user survey responses, which may mean that results of this research may not be broadly applicable to the larger SOF community. This chapter provides an analysis of the survey results, identifies implementation actions required in order to field AM in a SOF tactical environment, and assesses implications for ongoing research.

Data Analysis

The data analysis focuses on three primary areas:

1. Are SOF missions being adversely affected by material shortages that could be improved through the fielding of AM at the tactical level?
2. Which commodity area(s) has/have the greatest impact on mission effectiveness?
3. At what organizational level should tactical AM fielding be implemented?

An analysis of survey question 7 (“During a typical deployment, how often have you personally had to fix or make/buy an item in the field to complete your mission?”) indicates that SOF users do experience material shortages that affect their ability to complete assigned missions. All survey respondents reported at least some level of impact, with 78% reporting that material shortages affect their mission more than 30% of the time. More than half of the respondents report a mission impact of 60% or greater.

Follow up questions 8–13 narrowed the focus to determine what commodities were most affecting tactical operations. Results of these questions are shown in Figure 7. To determine the items with the greatest impact, I apply a weighting factor of 1x for the category "never," 3x for the category "occasionally," 5x for the category "sometimes," 7x for the category "often," and 9x for the category "nearly always." This shows that the categories of vehicle accessories and mission accessories create the largest impact. The weighted results for these questions appear in Table 2.

Table 2 – Weighted Analysis of Commodities Affecting Tactical Operations

Category	Rarely	Occasionally	Sometimes	Often	Almost Always	Weighted Total
Weight	1	3	5	7	9	-
Vehicle Accessories	2	2	5	8	1	98
Mission Accessories	4	4	5	5	0	76
Force Protection	6	2	4	3	0	53
Concealment Camouflage	6	7	4	1	0	54
Local Interaction	7	5	4	1	1	58

The user vignettes provided in response to user survey question 23 also support this analysis. All three vignettes focus on interfacing communications and surveillance equipment either with vehicles or physical structures. Based on the free-text responses, camera mounts can be considered force protection items, or mission accessories.

I then moved on to determine how respondents are currently filling material shortfalls identified in the previous analysis. The data from questions 14–18 (Figure 8) show that while the necessary equipment sometimes can be found in their unit supply, respondents typically look outside the supply system to achieve mission success. This is reflected in the responses of "local manufacture," "local purchase combined with local manufacture," and "other." The weighted analysis for this question is shown in Table 3.

Table 3 – Weighted Analysis of Sources of Supply

Source of Supply	Rarely	Occasionally	Sometimes	Often	Almost Always	Weighted Total
Weight	1	3	5	7	9	-
Unit Supply	2	5	6	3	0	68
Local Purchase	4	5	3	7	0	80
Local Manufacture	0	1	2	11	2	108
Combine Pur & Mfg	0	0	3	8	1	90
Other	0	1	0	4	0	31

I then focused on assessing the user survey recommendations regarding the most effective fielding level to implement AM in support of SOF tactical operations. Survey results for questions 20 and 21 are reflected in Figure 10. There was no consistent agreement in the results for implementation at the lowest tactical level. Six respondents favored deployment at the ODA level, while eight respondents recommended against deployment at that level. However, there was strong consensus for employment at the ODB level, with 13 respondents in favor of this level of employment. One respondent recommended that AM not be deployed at this level. Free-text comments related to level of AM employment provided two relevant inputs that I considered in my analysis.

- The only problem with having 3D printers at each and every location listed is the propensity of the higher headquarters elements to hoard raw material for the printer. Maybe if they don't have a printer they'll actually send raw materials down to those that do.

- Having one at each level will aid in the use and time till available. A large more capable system could be at HSC.

Because my literature study indicated that the Army is providing AM capability at the Headquarters, Support Battalion level through the Rapid Equipping Force, this paper focuses on implementation strategies below that level (Kohlmann, 2013). The combination of survey results and literature study lead me to the conclusion that the initial AM fielding in support of SOF tactical operations should be conducted at the ODB level.

In summary, my analysis of research conducted during this study leads me to recommend the initial employment of AM in support of SOF tactical operations focus on fielding at the ODB level, with an initial use case emphasizing development of brackets and mounting accessories for security cameras and communications antennas. In order to effect this recommendation, the following actions should be completed.

Implementation Recommendations

Additional research should be conducted in the following areas:

- A sponsored user survey should be issued to the SOF tactical user community. The United States Special Operations Command (USSOCOM) Directorate of Science &Technology (S&T) is currently conducting a project to research methods to utilize AM effectively in support of SOF capability gaps. In a personal interview with the project officer, he stated that the objective of this project is “Empowered units and individuals solving problems and implementing solutions at the point of need” (personal communication, March 17, 2015). The type of survey used in this research paper aligns with the project goals and could leverage the organizations who are participating in the project, providing a formal method of documenting their insights.

The results of that survey should be combined with the recommendations from this research paper to focus and expand efforts for this ongoing project. Contact information and/or identification for the USSOCOM project officer can be made available from the author if required for official use.

- A thorough assessment of potential material solutions to provide AM capability should be conducted as a part of the ongoing USSOCOM S&T AM project. This assessment should consider a variety of printer types and manufacturers including models based on thermoplastic extrusion, fused deposition modeling, melted and extrusion modeling, and jetted polymers (Castle Island, 2014). A separate but related assessment of feedstock materials should also be conducted. There is existing research on the basic materials used for AM (Frost & Sullivan, 2015), but this research needs to be expanded to consider the environmental conditions that would be encountered in the SOF tactical environment. This assessment should consider dust, humidity, temperature, and vibration.

In addition to this research, there are a number of actions that must be completed before AM can be effectively implemented in support of SOF tactical operations. These include the following:

- Procedures should be developed and implemented to use the AM parts library provided by the Rapid Equipping Force (Ewell, 2015). These procedures should leverage the virtual systems engineering process developed by Smith and Vogt (2014) to enable on-demand updates. In addition, the procedures should identify those actions that must occur before deployment to support effective interface with the parts library. For example, before the unit deploys, they could develop a list of the parts most likely to require interface with an AM solution. Based on the user survey results, this would be security cameras and radio antennas. Before the deployment, the unit would interface with an appropriate engineering organization to scan these components into their library. These procedures should be developed in coordination with the USSOCOM S&T AM project either directly by the project officer, or in conjunction with the ongoing REF activities. Collaboration between these two organizations is already ongoing and should be expanded to address this capability gap.

- The USSOCOM S&T AM project officer should identify personnel within the ODB who are responsible for implementing the procedures developed above. Clarification and definition of the type of knowledge, skills, and abilities to implement the procedures should be coordinated through the development of tactics, techniques, and procedures (TTPs). In the SOF community, this type of assessment is performed at the U.S. Army John F. Kennedy Special Warfare Center and School (U.S. Army Special Operations Command, 2015).
- The USSOCOM S&T AM project officer should conduct an after-action review after the initial deployment of AM at the tactical level to determine how the process and TTPs can be improved. On the basis of this assessment, AM can then be expanded to other tactical units.

Impact on Ongoing Research

This research study does not have substantial impact on the continuing AM research since it focuses primarily on a niche capability within the SOF community. However, the recommendations above regarding environmental assessment in austere environmental conditions do have the potential to add value to the larger body of AM research. AM has the potential to provide capability in other austere environments such as disaster relief and archaeological excavations. A greater understanding of the impact of environmental conditions on AM capabilities would be valuable.

Conclusions

My research supports my initial hypothesis, that SOF units could use AM to provide operational support in austere deployment environments. This assessment is limited by the small number of respondents to the user survey. The research indicates that this would be most effective in the areas of mission kit and vehicle accessories manufactured at the ODB level. From the data, more than half of the respondents indicated a mission impact that could have been avoided through employment of AM. Based on this, as an expansion of the ongoing AM project, I recommend that USSOCOM S&T complete the action steps outlined above and conduct a field assessment within the next 12 months.

References

Brown, A. S. (2014). By the numbers: A big forecast for 3-D printers. *Mechanical Engineering, 136*(2), 28–29.

Castle Island. (2014, June 9). *Comparison chart of all 3D printers for $20,000 or less.* Retrieved from http://www.additive3d.com/3dpr_cht.htm

Desai, D. R., & Magliocca, G. N. (2014). Patents, meet napster: 3D printing and the digitization of things. *Georgetown Law Journal, 102*(6), 1691–1720.

Drushal, J. R. (2013). *Additive manufacturing: Implications to the Army organic industrial base in 2030* [Research paper]. Carlisle Barracks, PA: U.S. Army War College.

Ewell, K. (2015, February 12). Writing a 3D printing roadmap for Force 2025. *Belvoir Eagle.* Retrieved from http://www.belvoireagleonline.com/news/writing-a-d-printing-roadmap-for-force/article_0b966770-b2c0-11e4-a7f7-937cbddaeeb3.html

Frost & Sullivan. (2015). Research and markets; Impact assessment of 3D printing materials in key applications technical insights. *Journal of Transportation, 83*. Retrieved from http://search.proquest.com/docview/1641135513?accountid=40390

Gourley, S. R. (2014). 3-D printing adds new dimension to materiel command. *Army Magazine, 64*(5), 54–57.

Hornick, J., & Roland, D. (2013). 3D printing and intellectual property: Initial thoughts. *Licensing Journal, 33*(7), 12–16.

Kohlmann, B., USN. (2013). Forward deployed 3-D printers might be the next warfighter innovation. *Signal, 67*(9), 88.

Kurfess, T., & Cass, W. J. (2014). Rethinking additive manufacturing and intellectual property protection. *Research Technology Management, 57*(5), 35–42. doi:10.5437/08956308X5705256

McNulty, C. M., Arnas, N., & Campbell, T. A. (2012, September). Toward the printed world: Additive manufacturing and implications for national security. *Defense Horizons*, No. 73, 1–16. Retrieved from http://inss.ndu.edu/Portals/68/Documents/defensehorizon/DH-73.pdf

O'Mahony, J. (2014). Printing the 3D world. *Bloomberg Businessweek,* (4379), S1–S4. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=96086724&site=ehost-live

Peck, J. (2014). Building on 3d printing. *Journal of Commerce (15307557), 15*(17), 38–38.

SkyMall. (2014). Draw in 3D whenever the mood strikes. *SkyMall, Holiday*, p. 27.

Smith, M. D. (2014). Technologies to sustain the army of 2025 and beyond. *Army Sustainment,* 12–17. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=98622199&site=ehost-live

Smith, R. E., & Vogt, B. D. (2014). A proposed 2025 ground systems "systems engineering" process. *Defense Acquisition Research Journal, 21*(3), 750–772.

Tadjdeh, Y. (2014, March). 3D printing promises to revolutionize defense, aerospace industries. *National Defense,* pp. 20–23. Retrieved from http://www.nationaldefensemagazine.org/archive/2014/March/Pages/3DPrintingPromisestoRevolutionizeDefense.AerospaceIndustries.aspx

Tice, J. (2005, May 23). Military occupational specialties. *Army Times,* p. 32. Retrieved from http://search.proquest.com/docview/734358477?accountid=40390

Torruella, A. (2014, December 5). Make and mend: The revolutionary promise of 3-D printing. *Jane's International Defense Review, 47*(10). Retrieved from http://search.proquest.com/docview/1562300679?accountid=40390

U.S. Army Headquarters. (2014). *Field manual 3-18, Special Forces operations*. Washington D.C.: Author.

U.S. Army Special Operations Command. (2015). US Army special operations command headquarters fact sheet. Retrieved from http://www.soc.mil/USASOCHQ/USASOCHQFactSheet.html

Webster, S. A. (2015). International space station gets into 3D printing. *Manufacturing Engineering, 154*(1), 26–27.

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Glossary of Acronyms and Terms

3D...............................three dimensional

AOB ....advanced operational base

AM ....additive manufacturing

CAD ....computer-aided design

DoD............................Department of Defense

FOB............................forward operating base

HFTTL ....hostile forces tagging, tracking, and locating

HSC............................Headquarters, Support Company

IP ....intellectual property

MATV........................Mine-Resistant Ambush-Protected All-Terrain Vehicle

MOS...........................Military Occupational Speciality

NCO ....noncommissioned officer

NIPR ....Nonsecure Internet Protocol Router

ODA...........................operational detachment–alpha

ODB ....operational detachment–bravo

REF ....Rapid Equipping Force

S&T............................science and technology

SOF ....Special Operations Forces

TTP ....tactics, techniques, and procedures

USASOC....................United States Army Special Operations Command

USSOCOM ....United States Special Operations Command

Appendix A – User Survey Questions

INFORMED CONSENT AGREEMENT

As an adult 18 years of age or older, I agree to participate in this research about Implications of Additive Manufacturing Deployed at the Tactical Edge. This survey is being conducted to support research efforts being performed by Lisa Sanders, a student of the Senior Service College Fellowship Program of the Defense Acquisition University.

I understand that my participation is entirely voluntary; I can withdraw my consent at any time. By agreeing to participate in this study, I indicate that I understand the following:

1. The purpose of the research is to identify the most likely missions and environments in which SOF personnel would utilize an additive manufacturing capability. Should I choose to participate in the survey, I am aware that my feedback will be consolidated with other participants and the outcome will be briefed to Army leadership allowing them to potentially take action on my recommendations.

2. If I choose to participate in this research, I will be asked to complete an online questionnaire. The questionnaire will include items relating to deployed Special Operations Forces experiences. The questionnaire will take approximately 15 minutes to complete.

3. There is no incentive for participation.

4. All items in the questionnaire are important for analysis and my data input will be more meaningful if all questions are answered. However, I do not have to answer any that I prefer not to answer. I can discontinue my participation at any time without penalty by exiting out of the survey.

5. This research will not expose me to any discomfort or stress beyond that which might normally occur during a typical day. There are no right or wrong answers; thus, I need not be stressed about finding a correct answer.

6. There are no known risks associated with my participating in this study.

7. Data collected will be handled in a confidential manner. The data collected will remain anonymous.

8. The purpose of this research has been explained and my participation is entirely voluntary.

9. I understand that the research entails no known risks and by completing this survey, I am agreeing to participate in this research.

1. I have read the Informed Consent Agreement and will participate voluntarily.

- ○ Yes
- ○ No

2. What is your Rank?

- ○ E5
- ○ E6
- ○ E7
- ○ E8
- ○ Other (please specify)

3. How long have you been part of Special Forces?

- 0-3 yrs
- 4-7 yrs
- 8-10 yrs
- 11-15 yrs
- Over 15 yrs

4. What is your Unit?

5. What is your MOS?

6. How familiar are you with 3D Printing (Additive Manufacturing)?

- Never heard of it
- Somewhat Familiar (read an article, heard people talk about it)
- Familiar (Seen it used for prototypes, seen/participated in a demonstration
- Very Familiar (Actually made parts or used parts made at your request)

7. During a typical deployment, how often have you personally had to fix or make/buy an item in the field to complete your mission?

- Rarely (0-10%)
- Occasionally (10-30%)
- Sometimes (30-60%)
- Often (60-90%)
- Almost Always (90-100%)

For questions 8-13, please identify how frequently on a typical deployment you would have to fix or make/buy an item of this type in the field. This does not include consumables such as batteries or wear items such as weapon barrels.

8. Concealment/camouflage items such as cover plates, hide sites, etc.

○ Rarely (0-10%)

○ Occasionally (10-30%)

○ Sometimes (30-60%)

○ Often (60-90%)

○ Almost Always (90-100%)

9. Vehicle accessories such as brackets, mounts, storage, etc. Do not include structural or armor modifications.

○ Rarely (0-10%)

○ Occasionally (10-30%)

○ Sometimes (30-60%)

○ Often (60-90%)

○ Almost Always (90-100%)

10. Mission Kit Accessories such as mounts for weapons sights, NVD helmet mounts, etc. Do not include structural items.

○ Rarely (0-10%)

○ Occasionally (10-30%)

○ Sometimes (30-60%)

○ Often (60-90%)

○ Almost Always (90-100%)

11. Local interaction such as items for civil affairs, village stability ops, etc.

○ Rarely (0-10%)

○ Occasionally (10-30%)

○ Sometimes (30-60%)

○ Often (60-90%)

○ Almost Always (90-100%)

12. Force Protection (If this category is used, please select a frequency and also check "type of item" then clarify in comments).

☐ Rarely (0-10%)

☐ Occasionally (10-30%)

☐ Sometimes (30-60%)

☐ Often (60-90%)

☐ Almost Always (90-100%)

☐ Type of item listed below

13. Please identify any other category of item you have to repair or make/buy during a typical deployment. Please limit this list to items which could realistically be manufactured by a 3D printer.

On a typical deployment, identify where you get the material discussed in questions 8-13 using the scale provided.

14. From unit supply (i.e. support battalion)

○ Rarely (0-10%)

○ Occasionally (10-30%)

- Sometimes (30-60%)
- Often (60-90%)
- Almost Always (90-100%)

15. Buy it from the local economy

- Rarely (0-10%)
- Occasionally (10-30%)
- Sometimes (30-60%)
- Often (60-90%)
- Almost Always (90-100%)

16. Make it yourself (duct tape, zip ties, etc.)

- Rarely (0-10%)
- Occasionally (10-30%)
- Sometimes (30-60%)
- Often (60-90%)

○ Almost Always (90-100%)

17. Buy some supplies, then make exactly what you need

○ Rarely (0-10%)

○ Occasionally (10-30%)

○ Sometimes (30-60%)

○ Often (60-90%)

○ Almost Always (90-100%)

18. Other. Please mark the frequency, then check the "describe method" box and provide details in the comment box below.

☐ Rarely (0-10%)

☐ Occasionally (10-30%)

☐ Sometimes (30-60%)

☐ Often (60-90%)

☐ Almost Always (90-100%)

☐ Describe Method

For questions 19 - 21, assume that a 3D printer is able to easily make all the items discussed in this survey, and that it is as easy to operate as a desktop printer. Assume the items made by the 3D printer will last throughout a typical mission, but are not permanent.

Assume it will require a generator or local power, weigh no more than 30 pounds, and be no more than 2 cubic feet, and that it can operate in the deployed environment.

19. What items are you likely to make with a 3D printer? Select all that apply.

- ☐ Concealment/camouflage items such as cover plates, hide sites, etc.
- ☐ Vehicle accessories such as brackets, mounts, storage, etc.
- ☐ Mission Kit Accessories such as mounts for weapons sights, NVD helmet mounts, etc.
- ☐ Local interaction such as items for civil affairs, village stability ops, etc.
- ☐ Force Protection
- ☐ Other (please specify)

20. Select the locations you think should be equipped with a 3D printer. Choose as many locations as you feel would be of value. Use the other category for locations not listed.

- ☐ At the headquarters support company (with maintenance or supply)
- ☐ At the FOB, assigned to each company
- ☐ At the company ODB (move to the AOB if necessary)
- ☐ With each ODA team (deployed for mounted operations)
- ☐ Other (please specify)

21. Select the locations you think should NOT be equipped with a 3D printer. Use the other category for locations not listed.

- ☐ At the headquarters support company (with maintenance or supply)
- ☐ At the FOB, assigned to each company
- ☐ At the company ODB (move to the AOB if necessary)
- ☐ With each ODA team (deployed for mounted operations)
- ☐ Other (please specify)

22. If desired, please use this box to identify the limitations and/or benefits to any location selected in question 20 or 21.

23. If desired, please describe a vignette where the ability to custom manufacture something using a 3D printer would have made a difference in achieving the mission. The example could be a case where the mission was negatively impacted because of the lack of this capability, or a case where you were able to adapt.

24. Please provide any additional thoughts you have regarding use of 3D Printers in support of SOF deployed operations. If you are interested in a

follow up discussion, please provide your contact information (NIPR email and/or commercial phone number).