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Improving Logistics Agility Through Additive Manufacturing

by

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Improving Logistics Agility Through Additive Manufacturing

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Abstract

Can Advanced Manufacturing technologies improve the flexibility of Army logistics? Additive manufacturing, better known as Three-Dimensional (3D) printing, is an emerging advanced manufacturing technology that has the potential to revolutionize Army logistics and reduce the expense of stockpiled supplies. The current supply system of multiple Supply Support Activities (SSAs) embedded within tactical as well as strategic units is vulnerable, inefficient and expensive. Units attempt to stock the right combination and quantities of repair parts to meet unit requirements. However, demand analysis is complicated especially during unpredictable combat operations. Additive manufacturing technology can reduce this burden through on-site manufacturing. Reservations over the implementation of this capability range from a culture shift away from the role of an SSA to the reluctance of defense contractors and manufacturers releasing legal rights or patents over reproducing a part.

Improving Logistics Agility Through Additive Manufacturing

The Chief of Staff of the Army (CSA), General Mark Milley recently outlined the importance of focusing on the readiness of our current force while simultaneously looking to emerging technologies for the deeper future 2025 to 2050. He has recognized there are significant technologies likely to change the character of war.[1] Additive Manufacturing (AM) is an emerging technology that fits the CSA's focus and has the potential to significantly alter Army logistics in the future. However, this disruptive technology, although in its infancy, has proven applications today that achieve the CSA's near-term goal of improving current force readiness.

Rapid developments in the field of additive manufacturing, more commonly known as Three-Dimensional (3D) printing, have provided capabilities to resolve the challenges of unavailable repair parts as well as the ability to address unanticipated problems with field expedient solutions. Although a limited number of examples exist today of AM directly impacting unit readiness, the applications of the technology continue to expand opening new opportunities for greater use. The application of AM to reduce the current costly stockpiles of repair parts is one longer term use to effect the deeper future. The current Army supply system of Supply Support Activities (SSAs) embedded within tactical as well as strategic logistics units attempts to stockpile the right combination and quantities of repair parts to meet unit requirements. Despite lengthy and thorough analysis to establish the accurate stock objectives, at times, the SSA is required to turn to transportation and higher level supply systems to resolve a repair part shortage. This immediate non-availability of a repair part impacts the combat readiness of Army units.[2] Additionally, the parts that are available remain stagnant on a shelf until a requirement is recognized or eventually become obsolete requiring additional costs and handling.

Numerous initiatives to implement AM technology within the Department of Defense (DoD) have made initial explorations into substituting or replacing traditional manufacturing. Initially, many of these efforts were undertaken by individual agencies or military services. This decentralized approach and the recognized impact that AM will have on DoD prompted President Obama in 2012 to announce a funding plan and the creation of the National Network of Manufacturing Innovation (NNMI) to centralize efforts and share the benefits of innovation.[3]

Today, AM applications have accelerated with collaboration and advances in printing and 3D scanning technologies. Despite the numerous benefits provided by the technology and the immeasurable potential it possesses, there remain constraints that must be overcome to achieve greater implementation. Most, if not all, of the constraints, recognized today, are being addressed or are on the verge of resolution due to new techniques and improvements to AM methods.

Additive Manufacturing

Additive Manufacturing (AM), or more commonly known as Three Dimensional (3D) Printing, are manufacturing processes that use three-dimensional computer aided design (CAD) models sliced into layers. The information associated with each layer becomes the tool path to combine materials using a layer-upon-layer method of production.[4] Available printable materials continue to advance and develop which expand the applications of AM. Today, AM technology is using basic plastics, photosensitive resins, ceramics, cement, glass, metals and metal alloys as well as new thermoplastic composites with infused carbon nanotubes and fibers.[5] AM is a general name that encompasses a number of technologies to include: 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing, and additive fabrication.[6] The American Society for Testing and Materials (ASTM), an international standards development organization, has established seven categories for Additive Manufacturing processes:

- **Binder jetting** – A liquid bonding agent is selectively deposited to join powder materials.
- **Directed energy deposition** – Focused thermal energy, such as a laser, is used to fuse materials to form an object by melting as the materials are deposited.
- **Material extrusion** – Materials are heated and selectively dispensed through a nozzle or orifice.
- **Material jetting** – Materials, such as photopolymers or wax, are selectively deposited.
- **Powder bed fusion** – Thermal energy selectively fuses regions of a powder bed.
- **Vat Photopolymerization** – Certain types of light, such as lasers, are used to selectively solidify liquid photopolymers.
- **Sheet lamination** – Sheets of materials are bonded to form an object.[7]

To further define AM technology there are specific AM methods that delineate the above categories to include:[8]

Stereolithography (SL) – converts liquid plastic into solid objects by exposing a layer of photopolymer above a perforated platform. A UV laser then strikes the perforated platform to paint and cure the liquid plastic following the object pattern. This process is repeated layering the liquid plastic until the object is completely formed. Six to twelve hours are required to print depending on the size of the object. Larger objects can take days to manufacture.

Fused Deposition Modeling (FDM) – is a material extrusion process that uses a plastic filament or metal wire fed through an extrusion nozzle which heats the material, similar to a hot glue gun, and can turn the flow on and off. The nozzle moves in horizontal and vertical directions to layer the material into an object.

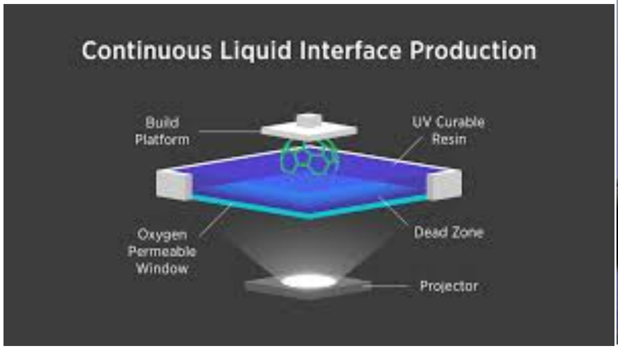
Multi-Jet Modeling (MJM) – operates similarly to an inkjet printer head that shuttles along a three dimensional – x,y, and z using hundreds of small jets to apply layers of thermopolymer material.

Selective Laser Sintering (SLS) - uses a high powered laser to fuse small particles of plastic, metal, ceramic or glass. Upon completion of each layer, the production table is lowered. A thin layer of material is applied, and the laser then fuses the next layer. This process is repeated until the final product is complete.

Direct Metal Deposition (DMD) – produces functional metal parts from CAD data by depositing metal powders using laser melting, and a control system to maintain production accuracy.[9]

LENS Technique – can process a range of metals to include: titanium, nickel-based superalloys, and stainless steel all of which are available in powder form.[10]

Continuous Liquid Interface Production (CLIP) – a breakthrough extrusion technology by carbon3D that grows parts vice printing layer by layer.[11] The process uses a reservoir of resin with a window that is transparent to light and permeable to oxygen (similar to a contact lens) at the bottom of the reservoir bath. A digital light projection system is used to cure the material at a rate 25 to 100 times faster than traditional manufacturing processes.[12]



The CLIP process is a promising technology within additive manufacturing that provides a more rapid process of manufacturing over the more traditional and recognized layer-by-layer 3D printing processes. This advancement is an example of how rapidly AM technology is progressing to identify more cost-efficient and rapid techniques.

Additive manufacturing is a disruptive technology with the potential to revolutionize manufacturing as well as military logistics and the traditional supply system. If fully recognized and applied, AM technology can replace traditional supply stockpiles with a more cost effective system of instantaneous inventory management.[13]

Army Supply System Policy and Costs

The Army supply system is a complex and costly supply chain system of depots, Supply Support Activities (SSAs), and unit repair part stocks electronically interconnected to manage inventory through the communication of item receipt, storage, and issue. Army Regulation (AR 710-2) Supply Policy Below the National Level outlines the requirements to maintain repair part stocks. The requirements include maintaining echelons of sustainment stocks that make up a network of available repair parts to support equipment and unit readiness. This expansive and redundant network includes repair parts maintained at the tactical unit level of operations to larger strategic contingency operations. The Army SSA is an essential element of this network with performance measurements centering on its ability to meet customer requirements. This metric is known as demand satisfaction or the net availability of items on the SSAs Authorized Stockage List (ASL). This leading performance measure, that strives for a 90% demand satisfaction rate, drives the depth of the ASL.[14] Additionally, performance measures include the SSAs ability to satisfy customer requests known as the fill rate and demand accommodation which determines the percentage of demands that match items on the ASL.[15]

The requirement to maintain consumable and reparable Class IX repair parts on an ASL, Prescribed Load List (PLL), Shop Stocks and Bench Stocks equates to a significant investment and holding of capital for a projected requirement. Tactical units at the corps, division and brigade level maintain repair parts within their ASL, PLL and bench stocks. The policy of maintaining multiple echelons of repair parts ensures the immediate availability of parts to meet readiness standards and ensures unit deployability and ability to sustain operations. Additionally, Army Prepositioned Stock (APS) sets are strategically positioned globally to rapidly project military power and reduce strategic lift requirements. APS sets are equipped to support every Unified Combatant Command (UCC) for major exercises, contingencies, Humanitarian Assistance and Disaster Relief (HADR) missions. Within each APS set, an ASL and shop stocks of Class IX repair parts are available to support the readiness of the APS fleet of equipment within the set.[16]

The multiple supply stocks distributed among tactical to strategic units equate to a high volume of repair parts. The volume of an individual part is further exacerbated to support the same vehicles and equipment distributed among different division and brigade units. Therefore, unit ASLs and PLLs maintain identical repair parts to support organizational equipment. This duplication of stockage lists, although necessary to sustain readiness, multiplies the number of repair parts and secondary items distributed throughout the Army.

Today's Army ASL lines of repair parts are managed within 271 SSAs located world-wide with over 420,000 line items valued at over $2.7 billion. Within the multiple echelons of units from strategic APS sets to tactical maneuver units, the repair parts maintained on ASLs, PLLs, shop and bench stocks include secondary items to include: nuts, bolts, and other simple items that make up a significant portion of Army supply stockage lists. One example of a secondary item repair part is the Nut, Self-Locking, Double Hexagon, (LIN: 5310-01-194-8489) which is a simple, high demand, and low-cost item maintained on many sustainment stocks for readiness.

Nut, Self-Locking, Double Hexagon

Considering that this part is maintained on multiple ASLs, Shop Stocks, and Bench Stocks the cost to decentralize the availability of Nut, Self-Locking, Double Hexagon is exponential. Also, considering the item must be maintained in varying quantities depending on the unit's fleet vehicle density requiring the part. Additionally, the Nut, Self-Locking, Double Hexagon is not universal among different vehicles and equipment. Therefore, multiple variants of the Nut with different sizes, thread counts and manufactured material are stocked to support the variety of platforms requiring this particular item.

As with any supply chain operation, the costs don't end with inventory alone. The average cost of a warehouse to store parts and support operations ranges between $12-16 million and advanced shelving and storage systems within the warehouse significantly add to this cost. Additionally, the manpower costs to conduct inventory, conduct receipt and storage activities are exponential.

In 2012, President Obama announced the Department of Defense's (DoD) partnership with the National Additive Manufacturing Innovation Institute (NAMII) as part of the "We Can't Wait" effort to strengthen America's manufacturing competitiveness.[17] With the announcement of this effort, a number of DoD organizations expanded or initiated programs to determine the applications and benefits of AM to their organizations.

Department of Defense (DoD) Initiatives in Additive Manufacturing

The Army Materiel Command (AMC) has a number of initiatives focused on implementing innovative technologies to include AM and 3D printing capabilities. AMC has recognized the potential of AM technology and has made proactive strides in maintaining an increasing awareness of progress in the ever developing AM field.

The Army Research, Development and Engineering Command (RDECOM), Aberdeen Proving Ground, Maryland strives to be a leader in research, development and engineering. RDECOM stated in an Oct. ’15 General Accountability Office (GAO) report:

> The U.S. Army RDECOM Armament Research, Development and Engineering Center (AMRDEC) plans to achieve performance improvements by developing an additively manufactured material solution for high demand items such as nuts and bolts, providing the engineering analysis and qualification data required to make these parts by means of additive manufacturing capability at the point of need in theater. This solution could potentially reduce the logistics burden on a unit and improve its mission readiness, thus enabling enhanced performance.[18]

Additionally, RDECOM’s Army Research Office (ARO), Durham, North Carolina is continuously collaborating with education institutions, nonprofit organizations and private industry leaders to research and exploit innovative advances to include Additive Manufacturing (AM). ARO leverages science and technology of academia and industry focusing on technologies that are vital to the Army’s future force.[19]

AMC also has established AM capabilities at the Joint Manufacturing and Technology Center (JMTC), Rock Island Arsenal, Illinois. JMTC collaborates with Quad City Manufacturing Laboratories to incorporate AM where feasible and economically to support JMTC’s mission. Today, AM is primarily used for prototyping and producing dies and molds for the casting process.[20] “The fabrication of new dies can cost up to $1.5M and have long lead times of 22-26 weeks.”[21]

The Army Materiel Command's Tobyhanna Army Depot, Tobyhanna, Pennsylvania currently has 3D scanning and printing capabilities primarily used for prototyping and manufacturing small plastic parts. Using this technology, Tobyhanna maintained its production schedule by manufacturing radio dust caps using AM within hours vice the weeks required to receive the parts from the vendor. Thus, avoiding significant delays in returning radios to supported units and subsequently maintaining the unit's readiness.[22] Tobyhanna recognizes additive manufacturing as a technology that will "redefine manufacturing" to include "reverse engineering simple to complex components and parts." The depot also acknowledges the potential for additive manufacturing to reduce costs and the time from design to production.[23]

The U.S. Air Force has recognized the game-changing degree of AM as recently stated by General Ellen Pawlikowski, Commander of the Air Force Materiel Command. "If you were to ask me what's the fourth game changer, in my mind it's additive manufacturing because it can truly change the calculus of how we sustain our systems."[24] The Air Force is investing heavily in AM through initiatives at the Air Force Research Laboratory (AFRL) focusing on flexible electronics, sensors, fuzes, and more with the overall goal to rapidly prototype advanced capabilities for the warfighter.[25]

The U.S. Navy has made significant strides in applying AM technology at the tactical level to support emergency repairs on the USS Essex and plans to add this capability to other carriers and ships in the near future. The Navy envisions AM to save time and costs as an "in-the-field solution" allowing equipment to be manufactured on demand and increasing flexibility.[26] Additionally, the Navy recognizes that AM's would "preclude the need to carry many spare parts that – ideally – never have to be used."[27]

An encouraging step made by the Navy's Rapid Innovation Cell (CRIC) was to prioritize the availability of AM technology to the tactical level allowing sailors to become comfortable and proficient with the technology before AM moves from its current state of infancy to maturity.[28]

The Defense Logistics Agency (DLA) has also recognized the potential benefits of AM by identifying candidate repair parts to manufacture using additive technology. Working to implement AM technology at the strategic Department of Defense (DoD) level, DLA's efforts would benefit all service components. Repair parts that are difficult to procure due to obsolescence, backorder, or long production lead times are the items targeted for DLA's Research and Development (R&D) effort.[29] DLA's AM initiatives seek to incorporate the technology to overcome long lead times and reduce production and set-up costs.[30] DLA has also identified candidate repair parts for 3D modeling to include bolts, fittings and ductwork.[31] DLA's vector is a multi-pronged approach:

- candidate part identification for DLA managed parts as well as service component parts
- Technical Data Package (TDP) refinement, storage, and security
- Vendor certification and qualification to manufacture parts to ensure quality assurance standards are met
- Print on demand initiatives[32]

DoD also partners and invests in America Makes, also known as the National Additive Manufacturing Innovation Institute (NAMII) to provide a consolidated and comprehensive source for AM efforts. America Makes launched in August 2012 with the primary purpose of bridging the gap between basic research and technology adoption. Established as a public-private partnership, America Makes collaborates with government agencies, private industry, and universities with oversight and management by the U.S. Air Force Research Laboratory.[33] America Makes goal is to leverage technical expertise to accelerate the implementation of additive manufacturing technologies.[34] Moreover, it serves as a collaborative source for DoD to share initiatives and avoid duplicating efforts.

Benefits of Additive Manufacturing vice Stockpiling Repair Parts

The construction, maintenance and operations associated with warehousing equipment repair parts is a significant cost to all DoD services. As AM technology continues to advance, secondary items like nuts and bolts can be removed from unit PLLs and ASLs and replaced with an AM on-site manufacturing capability. Eliminating secondary items will reduce warehouse space requirements and supply operation costs. As more complex repair parts are manufactured using AM technology, traditional warehouses and operations will be further reduced avoiding the costs of the current policy of maintaining repair parts.[35] Ideally, the traditional warehouse of stockpiled parts will be replaced with a small manufacturing operation providing immediate on-demand fulfillment for repair parts. Additionally, transitioning to an on-site manufacturing capability will eliminate the decentralized storage of surplus repair parts further recognizing the cost avoidance of repair part storage. The cost avoidance benefits achieved by reducing repair part stockpiles can be transferred to the further development and expansion of AM capabilities.

Employing AM can also benefit equipment readiness through the immediate demand satisfaction of a required repair part. Despite extensive demand analysis and planning, repair part non-availability impacts equipment readiness. Anticipating repair part requirements is an inexact science that becomes more complex during deployments and exercises. As repair parts are consumed and become unavailable the supply and transportation systems of the supply chain react to provide the required repair parts to maintain unit readiness. The supply chain process requires time to process and move the required part from point to point. In some cases, the simplest part, if unavailable on a stockage list, can deadline a vehicle. Implementing AM capabilities today can overcome simple, secondary item shortages that impact readiness. As AM technology continues to mature the ability to immediately change equipment readiness will become exponential. "The idea is to produce and deliver customized parts to customers as needed, instead of devoting acres of shelving to vast inventories. If we already live in a world of jut-in-time inventory management, we now see how JIT things can get. Welcome to instantaneous inventory management."[36]

Another beneficial application of AM is the reduction of obsolescence. The first benefit is the avoidance of obsolescence experienced with low-density equipment. Procuring repair parts may become costly due to high production run costs for a small number of parts. AM could avoid the high production run costs by manufacturing requirements on-demand. Also, repair parts for equipment at the end of its life-cycle become challenging and expensive to manage. Obsolete repair parts require intense management and extreme procurement efforts to maintain the associated equipment readiness. Again, employing AM capabilities to manufacture obsolete parts will avoid the high costs associated with procuring parts for aging equipment fleets. A final consideration related to obsolescence is the stockpiles of repair parts that remain after equipment is upgraded or replaced by a new variant. Outmoded equipment and vehicles are replaced with the new variants to improve capabilities and force protection. However, a stockpile of old variant repair parts persists. Additionally, parts become obsolete as vehicle platforms are modified in response to changing enemy tactics and techniques. These changes typically result in a significant change to the vehicles configuration making repair parts for previous models incompatible and obsolete. The Double-V Hull Stryker is one example of configuration changes in response to enemy tactics using Improvised Explosive Devices (IEDs).[37] The configuration change from the previous "flat bottom" Stryker resulted in numerous repair parts becoming incompatible with the newly designed double-V hull system. A transition from stockpiling repair parts to an on-demand additive manufacturing approach would provide a more adaptable supply system that is agile enough to react to short-term changes like the Stryker reconfiguration. A fully implemented additive manufacturing capability would eliminate the repair part stockpile and provide a more flexible, agile and responsive process to better support equipment modifications, upgrades and variations. Lastly, eliminating the traditional repair parts stockpile would avoid the costs associated with retrograde, demilitarization and disposal of obsolete repair parts after the transition to an upgraded vehicle or equipment.

A further benefit of replacing repair part stocks with an AM capability is the reduction of repair part damage and pilferage associated with traditional repair part stocks. Despite improvements in material handling equipment and advanced warehouse shelving systems, damage to repair parts occurs from human error and weather. Additionally, improvements in security systems and procedures have reduced pilferage. However, supply loss persists due to theft and damage. The postponement of manufacturing a part until the time of need will reduce material handling damage and pilferage.

Finally, reducing or eliminating repair part stockpiles will decrease strategic transportation requirements.[38] Although repair part transportation requirements would be replaced with AM raw materials requirements, the transportation of AM raw materials would recognize reduced cubic space over traditional repair parts. Therefore, benefits in reduced strategic transportation lift requirements and reduced costs would be recognized. Reducing the initial strategic transportation requirements is a primary purpose of Army Prepositioned Stocks (APS).[39] Employing AM capabilities would further support the transportation reductions APS policies were created to achieve.

Although there are numerous benefits of implementing additive manufacturing, there remain challenges and constraints to fully employ this rapidly developing technology. The challenges range from concerns over the responsiveness of the technology to more technical constraints requiring additional Research and Development (R&D).

Constraints to Greater Additive Manufacturing Implementation

The leading argument to implementing AM to produce repair parts is the process is too slow requiring hours and in some cases days to produce a basic item. Additive manufacturing is a rapidly growing technology, however, it’s a technology still in its infancy.[40] Next-generation technologies and developments are overcoming previous AM shortfalls and adding capabilities to include faster processes and multi-material manufacturing.[41] Advancing technology in the AM field to include CLIP technology are dramatically reducing processing times. As technology in this field continues to advance, the concern over the speed of production using AM will diminish expanding the applications of the technology.[42]

The cost of AM machines and high production costs are also of concern, especially metal printing capabilities. "The U.S. does not have a low cost metal 3D printer offering."[43] As with most new technologies the initial cost of equipment decreases over time as additional competitors enter the market increasing competition and consumer demand forces lower prices. AM technology will likely follow this trend making manufacturing equipment more economical allowing for broader implementation of the technology. Despite the cost of the equipment, timeliness and readiness benefits have already been recognized at Tobyhanna Army Depot "The cost of the 3D printer has quickly paid for itself after completing a couple of missions and more importantly saved significant time."[44] The cost of basic systems has already reduced from thousands to hundreds of dollars due the surge of interest and competition in the field of 3D printers.[45]

Additionally, production costs using AM are projected to decrease as technology improvements in increasing laser power, multiple laser adoption, and improved projection technology are realized and demand for better AM systems for lower prices increases.[46] General Electric's (GE) investment in AM has resulted in a "25% reduction in production time and cost savings, without sacrificing performance…"[47] Although the costs of AM equipment and production are expensive the costs to maintain the traditional global supply network of repair parts are even more significant. The sunk costs of the current Army repair part inventory alone that exceeds $80 billion is significant enough to off-set the expense of procuring AM capabilities.[48] In comparison, the procurement of equipment to establish an AM on-demand production capability from the Organic Industrial Base (OIB) to the tactical unit level to manufacture consumable repair parts could range in the low 100s of millions of dollars. However, once the initial investment in equipment is completed the operating costs and raw materials would be substantially less than maintaining redundant inventory. AM capability would also provide greater flexibility to respond to rapidly changing requirements and demands associated with varying enemy tactics improving readiness, adaptability and agility.

The U.S. Army Logistics Innovation Agency (USALIA) recently conducted a thorough Cost Benefit Analysis (C-BA) comparing the costs and requirements between conventional manufacturing and additive manufacturing in a military operational context. Their findings stated that AM will likely remain a higher cost than conventional manufacturing, but recognized the potential benefits to reduce wait-times and operational capabilities. The analysis also stated "AM could have a significant impact on the Army supply chain". It continued by recognizing that "Further research, especially quantitative research, is needed to better estimate how large-scale employment of AM would affect the supply chain" and that "second and third effects of AM, particularly its effect on total inventory levels" warrant greater exploration.[49]

Another significant hurdle is the availability of Technical Data Packages (TDPs) to provide the necessary three-dimensional data to accurately reproduce a part using AM capabilities. TDPs define the required design configuration and procedures necessary to produce a part and meet performance standards. It typically includes: drawings, specifications, standards, performance and quality assurance requirements.[50] TDPs are not routinely acquired by the military due to more cost beneficial manufacturer service packages. Fully implementing on-site AM capabilities would require the data rights to reproduce a part to standard and the necessary specifications. Reverse engineering a part is a feasible alternative to having TDP, but risks a lack of precision to meet part specifications and opens the potential for patent and copyright litigation from the original part manufacturers. Most of today's data on parts is typically two-dimensional data that wouldn't support additive manufacturing which requires 3D data. Therefore, future acquisition language must specify the requirement for a TDP with 3D data to support AM reproduction. Requiring full 3D data on a vehicle or equipment may prove to be too difficult, expensive, or controversial. Therefore, limiting the acquisition of 3D technical data for a vehicle's secondary items will allow for more immediate application of AM to repair parts with legitimate potential to benefit from the technology.[51]

The availability, consistency, and uniformity of raw materials to include metal powders (titanium, aluminum and stainless steel alloys) are additional constraints that require further technological advancements and development. Some metal powders required to manufacture parts using AM are highly flammable presenting limitations on storage of the materials and use of AM processes.[52] Additionally, metal powder raw materials require standardization and certification processes to ensure suitable materials are used to manufacture the repair parts. However, the daily advances in metal powder raw materials are significant and "are the fastest growing segment of 3D printing."[53] Therefore, advances in raw material technology can be expected to develop at a comparable rate as additive manufacturing 3D printing technology.

Also, design and manufacturing guidelines that provide uniform certification standards for AM raw materials and parts remains a limitation.[54] However, The National Institute of Standards and Technology (NIST) is leading and funding the research to establish quality assurance standards for AM parts.[55] Furthermore, NIST is collaborating with ASTM International, a global leader in the development and delivery of quality control standards, to establish AM standards.[56] Although establishing certification standards for raw materials and manufactured parts is complicated, these requirements can be achieved and are a priority effort for NIST, America Makes, and The Defense Advanced Research Projects Agency (DARPA). DARPA is focused on establishing enhanced manufacturing controls by applying rapid qualification technologies to increase confidence in additive manufactured products.[57] Given the attention and effort to establish standards to qualify materials and certify AM parts, the lack of current uniform certifications will be resolved with well-defined standards that ensure safety and performance.

Risk

Although greater agility and cost benefits are anticipated with the implementation of AM capabilities; the inherent challenges and risks of military operations cannot be eliminated. Transitioning to AM capabilities must include an assessment of the associated benefits and risks to ensure unit readiness is not impacted beyond the risks related with traditional supply and maintenance operations.

Raw material shortages, non-availability, or disruptions in the supply chain would be detrimental to the on-demand manufacturing of repair parts using AM technology. The availability of metal powders, bonding agents, and other AM process materials to support AM of repair parts would become a critical general supply class requiring detailed management. The requirement for supply management of special raw materials supporting AM would be offset by a reduction in requirements to manage Class IX repair parts. Therefore, raw material shortages and non-availability are equivalent challenges with comparable risks to today's traditional supply chain management of finished items. Additionally, supply chain disruptions are shared among all commodities during military operations. However, an inability to resupply raw materials for AM would likely have a greater negative impact on readiness than traditional forward positioned repair parts. Therefore, additive manufacturing of repair parts would have an inherently higher level of risk than traditional supply policies.

The incapacitation of an AM site within a theater of operations would have a similar result of significantly disrupting the supply chain. The loss of the manufacturing capability due to a printer maintenance issue or damage would impact the availability of the entire repair part supply chain. This disruption could be mitigated through secondary printers or back-up production plans between logistics units and locations. However, without adequate mitigation the use of AM equipment to produce repair parts would also assume a higher level of risk.

The use of AM will not eliminate transportation requirements, however, the overall requirements for repair part transportation would be reduced and replaced by raw material requirements that potentially would require less cubic space. Additionally, efficiencies in the transportation chain could be achieved if the raw materials are available for acquisition closer to the point of use. Any degree of transportation requirements reduction would have a correlating reduction in risk associated with strategic lift and tactical convoy operations.

The risk of manufacturing defects is a valid concern requiring further standardization of processes and materials to ensure repeatability and quality assurance of AM repair parts. Mitigation for this risk resides in the efforts of DLA, NIST, DARPA and other agencies to establish AM part certifications and standards.

Substituting traditional supply policies for an on-demand AM capability assumes risks, many of which can be mitigated through backup systems and planning. However, the associated risks of implementing an AM capability, especially in an operational or combat environment, must be fully analyzed and mitigated to avoid impacts to equipment readiness.

Conclusion

Additive manufacturing technology is rapidly developing and expanding into diverse areas to include medical applications, food production, repair parts and more. Although the technology is currently in its infancy, the progress in this field of manufacturing is rapidly maturing and overcoming existing constraints. DoD and service components are establishing programs and oversight to explore the advantages and possibilities of AM. These efforts are supported by AM's momentum in commercial industry and business. A recent Deloitte Consulting article stated, "24 percent of respondents from manufacturing firms report they are currently using 3D printing in some form; another 21 percent expect they will do so within the next three years."[58] It's encouraging that efforts within DoD are recognizing that AM technology has the potential to provide an on-demand repair part capability with the added benefit of reducing the expense of stockpiling basic repair parts. And that the technology is recognized as having the potential to provide near-term improvements to equipment readiness as well as the depth for greater future applications. With the understanding AM may not make significant near-term leaps and changes in the performance of military logistics it is, however, the right time to invest in areas where it's forecasted the technology will make contributions in the future.

The next steps to continue progress and establish a long-term strategy would be to address the constraints that are limiting further implementation, secure Intellectual Property (IP) in the AM field, and familiarize soldiers with the technology. Most constraints are being addressed through technological advancements in the field of AM and concerted efforts to establish raw materials and manufacturing standards. Assuming that private industry and education institutions will continue to overcome the constraints related to current technological shortfalls. Therefore, a focus on establishing standards and certifications for quality assurance of AM repair parts will posture DoD to take full advantage of the technology as it matures.

Simultaneously, an effort to secure raw materials and potentially establish IP within the domain of materials required to manufacture repair parts using AM will position DoD to implement the technology to serve best national security.[59] Establishing IP of raw materials would allow DoD to maintain the full benefits of the technology, improve quality assurance, and better mitigate risk.

Additionally, DoD must consider the benefits of placing basic AM capabilities at the tactical level to allow soldiers, sailors, marines, and airmen to experiment with the technology. This approach would be similar to a Navy program allowing sailors to become comfortable and proficient with the technology posturing the Navy to take advantage of the inevitable future applications of the technology.[60] Allowing an opportunity of controlled experimentation with the technology will likely identify applications and requirements not yet considered and provide a basic familiarity before greater employment of the technology. Employing AM technology at the lowest echelons will have the dual benefit of improved familiarity and meeting the goals outlined by the Chief of Staff of the Army General Milley: maintain the readiness of our current force while simultaneously looking to emerging technologies for the deeper future 2025 to 2050.[61]

The military services rapidly adopted and embraced drone and robotic technologies during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) to overcome enemy threats and more quickly respond to intelligence and threat identification demands. Today, there is a need to implement this same level of enthusiasm and commitment to overcome one of the Army's current enemy – budget constraints. Additive manufacturing provides the opportunity to make systematic changes to logistics operations and could also contribute to other aspects of operations like medical, security and more. Systematic changes will provide the revolutionary changes needed to adapt better to current fiscal constraints.[62] By changing the Army's traditional culture that demands stockpiles of repair parts to one that embraces AM technology, the Army can better control budgetary limitations and improve management of resources.

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